Canadian Wind Energy Association
Association Canadienne de l'Énergie Éolienne

January 16, 2006

Dear Reader,

During 2005 it became apparent that Canadian provinces were operating largely in isolation along their own timeframes to develop interconnection requirements for wind turbines and wind farms.

Particularly at the transmission level, 69kV and above, this was recognised as likely to lead to different sets or requirements with different rules and stringencies in each province whereas a clear benefit could be seen for the all stakeholders in a process of consultation leading to a unified and common set of interconnection requirements across Canada.

CanWEA commissioned Garrad Hassan to examine these issues and propose a set of basic common interconnection requirements (a Base Code) and a path for CanWEA to take them forward with stakeholders, notably the provincial utilities and transmission system operators. This work was partially funded by the Government of Canada's Climate Change Action Plan 2003, through the Technology and Innovation Program (under the Distributed Energy Production activities).

The Base Code proposed by GH incorporates the existing codes developed in Alberta, Ontario, Québec, and through the American Wind Energy Association. It adopts a structure allowing variability in requirements to accommodate both provincial differences and site specific differences. The Base Code contains ten items, some of which are mandatory requirements, some variable, and some of which are not enabled but are recommended for further development ahead of potential future implementation.

Going forward, CanWEA will be taking the Base Code implementation through a process of consultation with the Canadian utilities and transmission system operators within Canada, and in parallel through a similar process with AWEA and the North American Electricity Reliability Council (NERC).

The Executive Summary and proposed Grid Code (in both English and French) are provided below, in addition to the full report (in English only).

Thank you for your interest,

Yours sincerely,

R. Hornung

Robert Hornung
President

220 Laurier Avenue, Suite 320, Ottawa, Ontario, K1P 5Z9
Phone: 1-800-922-6932 or (613) 234-8716
Fax: 613-234-5642 www.canwea.ca info@canwea.ca

Executive Summary

This report provides a brief on work undertaken by Garrad Hassan (GH) on behalf of the Canadian Wind Energy Association (CanWEA). During 2005 it became apparent that Canadian provinces were operating largely in isolation along their own timeframes to develop interconnection requirements for wind turbines and wind farms. Particularly at the transmission level, 69kV and above, this was recognised as likely to lead to different sets or requirements with different rules and stringencies in each province whereas a clear benefit could be seen for the all stakeholders in a process of consultation leading to a unified and common set of interconnection requirements across Canada. GH was commissioned by CanWEA to examine these issues and propose a set of basic common interconnection requirements (a Base Code) and a path for CanWEA to take them forward with stakeholders, notably the provincial utilities and transmission system operators.

GH undertook a complete review of interconnection and grid integration issues in North America together with a more detailed examination of each Canadian province, its issues and progress towards a set of interconnection requirements for wind at transmission level. Following on from this GH were able to draw recommendations on a Base Code for CanWEA to adopt and how best to take it forward.

The Base Code proposed by GH incorporates the existing codes developed in Alberta, Ontario, Québec, and through the American Wind Energy Association, and adopts a structure allowing variability in requirements to accommodate both provincial differences and site specific differences. The Base Code contains ten items, some of which are mandatory requirements, some variable, and some of which are not enabled but are recommended for further development ahead of potential future implementation. The proposed Base Code is as follows,

1.	Frequency tolerance	mandatory
2.	Voltage tolerance	mandatory
3.	Power control	not a current requirement
4.	Reactive power capability/control	variable
5.	Voltage control	variable
6.	Frequency response	not a current requirement
7.	Low Voltage Ride Through (LVRT)	mandatory but variable
8.	Power system stabilisers	not a current requirement
9.	Data Provision	mandatory
10.	Operational monitoring	mandatory

GH concluded that the CanWEA should take the Base Code implementation forward through a process of consultation with the Canadian utlities and transmission system operators within Canada, and in parallel through a similar process with AWEA and the North American Electricity Reliability Council (NERC). Time has been identified as of the essence due to ongoing developments throughout North America.

The complete proposed Grid Code is provided below.

Sommaire

Le présent rapport fait état des travaux réalisés par Garrad Hassan (GH) pour le compte de l'Association canadienne de l'énergie éolienne (ACÉÉ). En 2005, on a constaté que les provinces canadiennes travaillaient en grande partie de manière isolée, en suivant chacune son propre calendrier, pour la définition d'exigences d'interconnexion des éoliennes et des parcs d'éoliennes. En ce qui a trait notamment au transport, sous 69 kV et plus, on a reconnu que la présente situation pourrait probablement mener à l'adoption de conditions ou d'exigences différentes, de règles et d'obligations variables d'une province à l'autre, alors qu'il y aurait nettement avantage à ce que tous les intéressés participent à un processus de consultation en vue d'établir un ensemble d'exigences d'interconnexion unifiées et communes à l'échelle du Canada. GH a été chargé par l'ACÉÉ d'examiner la question et de proposer un ensemble d'exigences de base communes en matière d'interconnexion (un Code de base) ainsi qu'un processus permettant à l'ACÉÉ de communiquer ces exigences aux intéressés, notamment aux services publics et aux exploitants de systèmes de transport d'électricité provinciaux.

GH a effectué un examen général des enjeux de l'interconnexion et de l'intégration des réseaux en Amérique du Nord ainsi qu'un examen plus détaillé de la situation particulière de chacune des provinces canadiennes et de leurs progrès en ce qui concerne l'établissement d'exigences d'interconnexion pour les éoliennes au niveau du transport. Dans la foulée de ces travaux, GH a pu formuler des recommandations pour l'adoption et la mise en oeuvre optimale d'un Code de base par l'ACÉÉ.

Le Code de base proposé par GH intègre les codes existants élaborés en Alberta, en Ontario, au Québec, et par l'intermédiaire de l'American Wind Energy Association (AWEA). Ce code adopte une structure qui permet aux exigences de varier en fonction des différences provinciales et des particularités des différents emplacements. Le Code regroupe dix points, comprenant des exigences obligatoires, des exigences variables ainsi que des dispositions non actives qui sont seulement recommandées en prévision de la mise en oeuvre possible de futures installations. Ces points sont les suivants :

1.	Tolérance de fréquence	obligatoire
2.	Tolérance de tension	obligatoire
3.	Commande de puissance	pas exigé à l'heure actuelle
4.	Capacité/commande de puissance réactive	variable
5.	Commande de tension	variable
6.	Réponse en fréquence	pas exigée à l'heure actuelle
7.	Maintien d'alimentation en creux de tension (Low Voltage Ride Through - LVRT)	obligatoire mais variable
8.	Stabilisateurs de systèmes d'alimentation	pas exigés à l'heure actuelle
9.	Fourniture de données	obligatoire
10.	Contrôle d'exploitation	obligatoire

GH a conclu que l'ACÉÉ devrait procéder à la mise en oeuvre du Code dans le cadre d'un processus de consultation avec les services publics et exploitants de systèmes de transport d'électricité à l'échelle du Canada, et en parallèle avec les travaux de consultation effectués en ce sens par l'AWEA et le North

American Electricity Reliability Council (NERC). On a jugé qu'il fallait agir sans tarder, étant donné l'évolution de la situation dans toute l'Amérique du Nord.

Note : En complément à ce sommaire, le Code de base est également fournie en français.

APPENDIX C: CANWEA BASE CODE REQUIREMENTS

The following requirements are those proposed for inclusion within the CanWEA Base Code. They consist of the following:

1. Frequency tolerance
2. Voltage tolerance
3. Power control
4. Reactive power capability/control
5. Voltage control
6. Frequency response
7. Low Voltage Ride Through (LVRT)
8. Power system stabilisers
9. Data Provision
10. Operational monitoring

The requirements also have the following characteristics:

- *Mandatory* indicates the requirement must be implemented.
- *Automatic access standard* indicates that, if met, the requirement will allow interconnection regardless of a) province, and b) site.
- *Reduced access standard* indicates a level less than automatic is allowable according to a) province, and b) site, subject to agreement with the relevant system operator.
- *Noted but not a requirement* implies a requirement is not enabled at present but may be in the future.

The following provides text format for the requirements in plain form, i.e. the detail and recommendations to CanWEA are not included.

C.1 FREQUENCY TOLERANCE

Frequency tolerance is a mandatory requirement. The requirement is for:

1. Continuous normal operation between 59.4Hz and 60.6Hz.
2. Under-frequency time based capability.
3. Over frequency time based capability.

C.2 VOLTAGE TOLERANCE

Voltage tolerance is a mandatory requirement. The requirement is for:

1. Continuous normal operation between +10% and -10% of nominal voltage at the interconnection point (high voltage side of transformer). Note that in Northern Ontario this range may be exceeded.
2. Over-voltage time based capability.
3. Under-voltage time based capability.

C.3 POWER CONTROL

Power control, including the capability to limit maximum power output and control ramp rates, is useful and desirable but not a requirement. It is likely to become a requirement for new projects further in the future as wind penetration starts to become high.

C.4 REACTIVE POWER CONTROL/CAPABILITY

Reactive capability is a requirement but is allowed to vary by a) province, and b) site. The requirement is as follows:

1. Reactive capability at full output.
   A capability providing 0.90 lagging to 0.95 leading at full MW output, and meeting the further requirements of reactive capability as set out below will allow automatic interconnection regardless of a) province or b) site specific conditions.

   If a reduced capability is sought then this is to be determined by the following:

   a) In accordance with provincial rules.

   b) In accordance with the findings of System Impact Studies developed for the specific site and which show the actual maximum capability that is required.

   The intention of this clause is to allow the actual reactive capability to be varied according to actual requirements. Variation according to a) or b) should be agreed with the system operator.

2. Reactive capability at reduced output.
   A capability providing reactive power up to the power factors 0.90 lagging to 0.95 leading throughout the power output range, and meeting the further requirements of reactive capability as set out herein will allow automatic interconnection regardless of a) province or b) site specifics. In addition to this the wind farm should offer a capability beyond this to the system operator if reasonably available through the turbines.

   If a reduced capability is sought then this is to be determined by the following:

   a) In accordance with provincial rules.

   b) In accordance with the findings of System Impact Studies developed for the specific site and which show the actual maximum capability that is required.

   The intention of this clause is to allow the reactive capability at reduced MW loading to be varied according to actual requirements. Variation according to a) or b) should be agreed with the system operator.

   It should be noted that Québec currently requires the MVAr defined by 0.95 lead to 0.95 lag power factor at full MW load to be available throughout the MW output range.

3. Dynamic reactive capability.
   Subject to the findings of 1a) and 1b), at least a portion of the reactive capability should be dynamic. The control system for the reactive capability should provide that the dynamic capability is always available such that the provided capability at the point of interconnection appears to the system operator as similar to either a synchronous machine or a dynamic reactive device and hence is capable of meeting any dynamic reactive requirements most notably in regards to voltage control.

4. Balance of reactive sources.
   It is wholly satisfactory to provide all or part of the reactive power capability from the turbines or separate reactive devices located within the wind farm provided the other requirements pertaining to reactive capability are met. In some cases this may extend to reactive compensation devices on the system operator's network where this has been identified as a solution and agreed with the system operator.

5. All reactive capabilities are defined at the point of interconnection. This is normally the high voltage side of the main grid transformer. It is noted that Alberta currently defines the requirements on the lower voltage side of the main grid transformer.

C.5 VOLTAGE CONTROL

Voltage control is a requirement but is allowed to vary according to a) province, and b) site. The requirement is as follows:

1. Voltage Control at the point of interconnection (or otherwise agreed) is a requirement. If the control is fully capable of utilising the agreed reactive capability of the project defined elsewhere then interconnection is automatic regardless of a) province, and b) site specifics.

   A reduced requirement for voltage control may be sought in accordance with the following:

   a) Provincial rules.

   b) The findings of System Impact Studies developed for the specific site and which show the actual maximum capability that is required.

   It should be noted that either a) or b) may define a reduced requirement which may in some circumstances become no requirement at all.

   The intention of this clause is to allow the actual required voltage control capability to be varied according to requirements. This voltage control requirement must be related back to reactive capability requirements. Variation according to a) or b) should be agreed with the system operator.

C.6 FREQUENCY RESPONSE

Frequency response is not a requirement. It may become a requirement for new projects further in the future as wind penetration starts to become high.

C.7 LOW VOLTAGE RIDE THROUGH

LVRT is a mandatory requirement but is allowed to vary according to a) province, and b) site. The requirement is as follows:

1. A LVRT capability defined at the point of interconnection (normally defined as the high voltage side of the grid connection transformer) and meeting or exceeding that shown – that is to remain connected for voltages reduced to 0% for up to 0.15s, thereafter followed by a linear recovery to 85% voltage after 3s – shall be allowed automatic interconnection regardless of a) province or b) site. The capability is shown in the following figure.

   A reduced requirement for LVRT may be sought in accordance with the following:

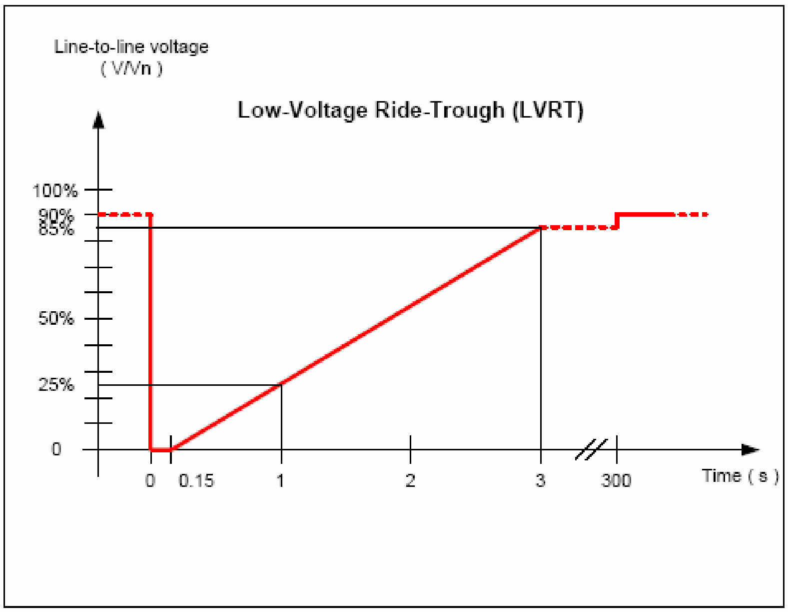
   a) Provincial rules.

   b) The findings of System Impact Studies developed for the specific site and which show the actual maximum capability that is required.

It should be noted that either a) or b) may define a reduced requirement which may in some circumstances become no requirement at all.

The intention of this clause is to allow the actual required LVRT capability to be varied according to requirements. Variation according to a) or b) should be agreed with the system operator.

2. It is noted that LVRT may require tolerance to significant negative phase sequence for short periods and the plant should be capable of this. Item 1 applies primarily to voltage depressions under balanced phase conditions.



Note: Positive sequence voltage at the fundamental frequency

C.8 POWER SYSTEM STABILISERS

The inclusion of a Power System Stabiliser is not a requirement. It may become a requirement for new projects further in the future as wind penetration starts to become high.

C.9 INFORMATION PROVISION

The following data provision clauses are mandatory requirements as applicable.

1. Planning and anticipated operational data. Technical data will be provided to the system operator, generally in advance of connection and during application for interconnection. The required data will encompass the technical and anticipated operational characteristics

of the plant in detail suitable for System Impact Studies. The System Operator will provide the information pro forma upon request.

2. Wind Turbine model. As part of item 1, the project will need to submit a detailed simulation model of the wind turbine(s) to be used in either PSS/E or PSLF format. The model shall be one that is approved by the "*AWEA/CanWEA/System Operator modelling group*".

3. Submission of an application for interconnection with preliminary data only, but with initial fees to secure registration and queue placement, is allowable. In such a case the project developer is allowed access to system data to self study the interconnection and advise the system operator appropriately to gain an interconnection schedule of works and date for interconnection. Subsequent to completion of the wind farm design and turbine selection, the project will submit the full requirements of item 1 and 2 to the system operator for assessment, and will be liable for any inaccuracies through the self study process.

   This clause is intended to ease the issues of timing with data provision and connection. This clause is enabled only by consent of the system operator once the above process is approved.

4. The completed wind farm, once interconnected, will be subject to compliance testing to physically demonstrate the wind farm performance meets that of the Code. Agreement on testing is being sought and this clause is not currently enabled.

C.10 OPERATIONAL MONITORING

The provision of operational monitoring is mandatory.

1. Projects should liaise with the relevant system operator and expect to provide at least some of the following data through real time communications:

   - MW import and export
   - MVAr import and export
   - Voltage
   - Wind speed and direction
   - Site temperature
   - Status of circuit breakers and/or switches
   - Number of turbines available/unavailable

   Other data transmission may be required to be agreed on a) a provincial basis, and b) a site specific basis.

2. In addition to the above data the wind farm should expect to provide at least one automatic channel whereby control commands issued by the system operator can be

received and acted upon. The requirements of the control channels and interface are to be agreed on a) a provincial basis, and b) a site specific basis.

ANNEXE C : EXIGENCES DU CODE DE BASE DE LA CANWEA

Les exigences qu'il est proposé d'inclure dans le Code de base de la CanWEA sont les suivantes :

11. Tolérance de fréquence
12. Tolérance de tension
13. Commande de puissance
14. Capacité/commande de puissance réactive
15. Commande de tension
16. Réponse en fréquence
17. Maintien d'alimentation en creux de tension (Low Voltage Ride Through - LVRT)
18. Stabilisateurs de systèmes d'alimentations
19. Fourniture de données
20. Contrôle d'exploitation

Ces exigences s'accompagnent des caractéristiques suivantes :

- *Obligatoire [Mandatory]* indique l'obligation de mise en oeuvre.
- *Norme d'accès automatique [Automatic access standard]* indique que le respect de l'exigence permet l'interconnexion quels que soit a) la province et b) l'emplacement.
- *Norme d'accès réduit [Reduced access standard]* indique qu'un niveau d'accès inférieur aux exigences d'accès automatique est admissible selon a) la province et b) l'emplacement, sous réserve d'entente avec l'exploitant de système intéressé.
- *Noté mais non exigé [Noted but not a requirement]* indique une disposition qui n'est pas en vigueur, mais pourrait l'être ultérieurement.

Les paragraphes suivants présentent les exigences précitées sans inclure les détails et les recommandations faites à la CanWEA.

C.1 TOLÉRANCE DE FRÉQUENCE

La tolérance de fréquence est une exigence obligatoire visant :

4. l'exploitation normale continue entre 59,4 Hz et 60,6 Hz;
5. le temps de fonctionnement sous la fréquence minimale;
6. le temps de fonctionnement au-delà de la fréquence maximale.

C.2 TOLÉRANCE DE TENSION

La tolérance de tension est une exigence obligatoire visant :

4. l'exploitation normale continue entre +10 % et –10 % de la tension nominale au point d'interconnexion (côté haute tension du transformateur). À noter que dans le Nord de l'Ontario, les valeurs peuvent dépasser cette plage.
5. le temps de fonctionnement au-delà de la tension maximale;
6. le temps de fonctionnement sous la tension minimale.

C.3 COMMANDE DE PUISSANCE

La commande de puissance, y compris la capacité de limiter la puissance de sortie maximale et de contrôler les vitesses de montée, est utile et souhaitable mais non exigée. Elle pourrait être exigée pour des projets futurs lorsque l'énergie éolienne commencera à être largement exploitée.

C.4 COMMANDE/CAPACITÉ DE PUISSANCE RÉACTIVE

La capacité de puissance réactive est exigée, mais des variations sont permises selon a) la province et b) l'emplacement, conformément aux dispositions suivantes :

6. Capacité de puissance réactive à pleine puissance de sortie.
   Une capacité allant d'un facteur de puissance de 0,90 (inductif) et à 0,95 (capacitif) à pleine puissance de sortie (MW), et respectant les exigences de capacité réactive supplémentaires ci-dessous, permettra l'interconnexion automatique quelles que soient a) la province ou b) les conditions particulières de l'emplacement.

   Toute demande visant une capacité réduite sera assujettie :

   a) aux règles provinciales.

   b) aux conclusions d'études sur l'impact du système réalisées pour l'emplacement visé et indiquant la capacité réelle maximale qui est exigée.

Cette disposition vise à permettre la variation de la capacité de puissance réactive réelle en fonction des exigences réelles. Toute variation en fonction de a) ou de b) devrait faire l'objet d'une entente avec l'exploitant du système.

7. Capacité de puissance réactive à puissance de sortie réduite.
   Une capacité allant d'un facteur de puissance de 0,90 (inductif) à 0,95 (capacitif) sur toute la gamme des puissances de sortie, et respectant les présentes exigences de capacité réactive supplémentaires ci-dessous, permettra l'interconnexion automatique quelles que soient a) la province ou b) les conditions particulières de l'emplacement. En outre, le parc d'éoliennes devrait offrir à l'exploitant du système une capacité supérieure lorsque celle-ci peut raisonnablement être obtenue au moyen des éoliennes.

   Toute demande visant une capacité réduite sera assujettie :

   a) aux règles provinciales.

   b) aux conclusions d'études sur l'impact du système réalisées pour l'emplacement visé et indiquant la capacité réelle maximale qui est exigée.

   Cette disposition vise à permettre la variation de la capacité de puissance réactive réelle en fonction des exigences réelles. Toute variation en fonction de la province (a) ou des conditions particulières de l'emplacement (b) devrait faire l'objet d'une entente avec l'exploitant du système.

   À noter que le Québec exige actuellement que la puissance réactive en Mvar définie par un facteur de puissance allant 0,95 (capacitif) à 0,95 (inductif) à pleine charge (MW) soit disponible sur toute la plage des puissances de sortie (MW).

8. Capacité de puissance réactive dynamique.
   Sous réserve des conclusions de 1a) et de 1b), au moins une partie de la capacité de puissance réactive devrait être dynamique. Le système de commande de la capacité de puissance réactive devrait assurer la disponibilité permanente de la capacité de puissance dynamique de manière que la capacité fournie au point d'interconnexion soit pour l'exploitant du système semblable à celle d'une machine synchrone ou d'un dispositif réactif dynamique, et qu'elle puisse ainsi satisfaire à toutes les exigences de puissance réactive dynamique, tout particulièrement en ce qui concerne la commande de tension.

9. Équilibre des sources de puissance réactive.
   Il est entièrement satisfaisant que la puissance réactive soit fournie en tout ou en partie à partir des éoliennes ou de dispositifs réactifs séparés situés à l'intérieur du parc d'éoliennes pourvu que les autres exigences applicables à la capacité de puissance réactives soit respectées. Dans certains cas, des dispositifs de compensation de puissance réactive du réseau de l'exploitant du système pourront également être inclus lorsque l'utilisation de ces dispositifs aura été identifié comme une solution et fait l'objet d'une entente avec l'exploitant du système.

10. Toutes les capacités de puissance réactive sont définies au point d'interconnexion, qui correspond normalement au côté haute tension du transformateur du secteur. Il est noté

que l’Alberta définit actuellement les exigences en prenant pour référence le côté basse tension du transformateur du secteur.

C.5 COMMANDE DE TENSION

La commande de tension est une exigence, mais cette exigence peut varier selon a) la province et b) l’emplacement, conformément aux dispositions suivantes :

2. La commande de tension au point d’interconnexion (ou au point convenu) est une exigence. Si la commande est entièrement capable d’utiliser la capacité de puissance réactive convenue du projet définie ailleurs, l’interconnexion est automatique quelles que soient a) la province et b) les conditions particulières de l’emplacement.

   Toute demande visant à réduire les exigences de commande de tension sera assujettie :

   a) aux règles provinciales.

   b) aux conclusions d’études sur l’impact du système réalisées pour l’emplacement visé et indiquant la capacité réelle maximale qui est exigée.

   À noter que a) ou b) peuvent définir une exigence réduite et que cette exigence peut dans certains cas ne plus être applicable.

   Ces dispositions visent à permettre la variation de la capacité de commande de tension réelle requise en fonction des exigences. Cette exigence relative à la commande de tension doit être reliée aux exigences de capacité de puissance réactive. Toute variation en fonction de a) ou b) devrait faire l’objet d’une entente avec l’exploitant du système.

C.6 RÉPONSE EN FRÉQUENCE

La réponse en fréquence ne constitue pas une exigence. Elle pourra cependant le devenir dans le cas de nouveaux projets lorsque l’énergie éolienne commencera à être largement exploitée.

C.7 MAINTIEN D’ALIMENTATION EN CREUX DE TENSION (Low Voltage Ride Through - LVRT)

Le maintien d’alimentation en creux de tension (LVRT) est une exigence obligatoire, mais cette exigence peut varier selon a) la province et b) l’emplacement, conformément aux dispositions suivantes :

3. Une capacité LVRT définie au point d’interconnexion (qui correspond normalement au côté haute tension du transformateur du secteur), et respectant ou dépassant la capacité indiquée – qui doit demeurer raccordé pour des tensions réduites à 0 % pendant jusqu’à

0,15 s, la tension étant ensuite ramenée par récupération linéaire à 85% en 3 s – devra permettre l'interconnexion automatique quels que soient a) la province ou b) l'emplacement. La capacité est indiquée sur la figure ci-après.

Toute demande visant une capacité LVRT réduite sera assujettie :

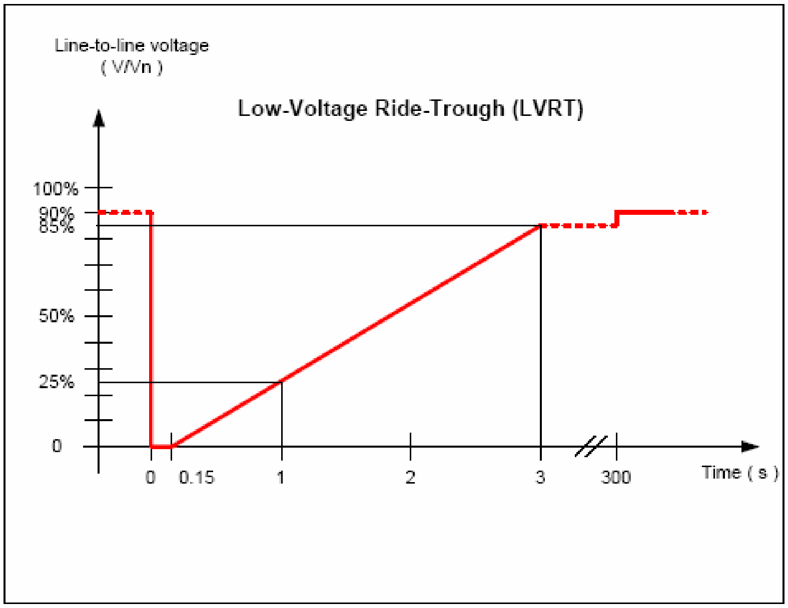
a) aux règles provinciales.

b) aux conclusions d'études sur l'impact du système réalisées pour l'emplacement visé et indiquant la capacité réelle maximale qui est exigée.

À noter que a) ou b) peuvent définir une exigence réduite et que cette exigence peut dans certains cas ne plus être applicable.

Ces dispositions visent à permettre la variation de la capacité LVRT réelle requise en fonction des exigences. Toute variation en fonction de a) ou b) devrait faire l'objet d'une entente avec l'exploitant du système.

4. Il est noté que la capacité LVRT peut exiger la tolérance à une inversion de l'ordre des phases pendant de courtes périodes et que les installations devraient avoir les capacités nécessaires dans ce cas. Le point 1 vise principalement les baisses de tension dans des conditions de phase équilibrées.



Note: Positive sequence voltage at the fundamental frequency

Note: « Positive sequence voltage at the fundamental frequency » = Tension en séquence positive à la fréquence fondamentale
« Line-to-line voltage » = Tension entre phases
« Low-Voltage Ride-Through (LVRT) » = Maintien d'alimentation en creux de tension (LVRT)

Time (s) = Temps (s)

C.8 STABILISATEURS DE SYSTÈMES D'ALIMENTATION

L'inclusion d'un stabilisateur de système d'alimentation ne constitue pas une exigence. Elle peut le devenir dans le cas de nouveaux projets lorsque l'énergie éolienne commencera à être largement exploitée.

C.9 FOURNITURE DE DONNÉES

Les dispositions suivantes visant la fourniture de données constituent des exigences obligatoires dans les cas applicables.

5. Données de planification et d'exploitation prévue. Des données techniques seront communiquées à l'exploitant du système, en général avant la connexion et au moment de la présentation de la demande d'interconnexion. Les données requises comprendront les caractéristiques techniques et les caractéristiques de l'exploitation prévue des installations, comprenant les détails nécessaires aux fins des études sur l'impact du système. L'exploitant du système fournira l'information pro forma sur demande.

6. Modèle d'éolienne. Aux fins du point 1, les responsables du projet devront présenter un modèle de simulation détaillé de l'éolienne ou des éoliennes à utiliser en format PSS/E ou PSLF. Le modèle devra être un modèle approuvé par l'*AWEA/CanWEA/System Operator modelling group*.

7. La présentation d'une demande d'interconnexion accompagnée uniquement de données préliminaires, mais incluant les frais initiaux pour garantir l'inscription et la mise en file d'attente, est admissible. Dans un tel cas, le promoteur du projet est autorisé à avoir accès aux données du système afin d'étudier l'interconnexion et de conseiller efficacement l'exploitant du système en vue de l'établissement d'un calendrier des travaux d'interconnexion et de la date cible pour l'interconnexion. Après avoir terminé la conception du parc d'éoliennes et sélectionné les éoliennes, les responsables du projet présenteront l'ensemble des exigences des points 1 et 2 à l'exploitant du système pour évaluation, et seront responsables de toute inexactitude associée à leur étude de l'interconnexion.

   Cette disposition vise à atténuer les problèmes d'échéancier liés à la fourniture de données et à l'interconnexion. Elle n'est validée qu'avec l'accord de l'exploitant du système après approbation du processus précité.

8. Le parc d'éoliennes, une fois terminé et interconnecté, fera l'objet d'essais de conformité afin de démontrer matériellement que les performances du parc d'éoliennes répondent aux exigences du Code. Une entente relative aux essais est en voie de négociation et la présente disposition n'est pas en vigueur pour le moment.

C.10 CONTRÔLE D'EXPLOITATION

Le contrôle d’exploitation est une exigence obligatoire.

3. Les responsables des projets devraient se tenir en liaison avec l’exploitant du système et communiquer au moins certaines des données suivantes en temps réel :

   - Importation et exportation de MW
   - Importation et exportation de Mvar
   - Tension
   - Vitesse et direction du vent
   - Température à l’emplacement
   - État des disjoncteurs et/ou commutateurs
   - Nombre d’éoliennes disponibles/non disponibles

   D’autres communications de données pourront devoir faire l’objet d’ententes a) provinciales et b) propres à un emplacement.

4. Outre les données précitées, les responsables d’un parc d’éoliennes devraient fournir au moins un canal automatique au moyen duquel les commandes données par l’exploitant du système pourront être reçues et exécutées. Les exigences relatives aux canaux de contrôle et à l’interface devront faire l’objet d’ententes a) provinciales et b) propres à un emplacement.

Canadian Grid Code for Wind Development
Review and Recommendations

Client	**Canadian Wind Energy Association**
Contact	Sean Whittaker
Document No	11163/OR/01
Issue	B
Status	Final
Classification	Client's discretion
Date	7 October 2005

Author:

M P LeBlanc, L Evans,
P Gardner, N C Scott

Checked by:

N C Scott, P Gardner

Approved by:

A D Garrad

ACKNOWLEDGEMENTS

This work was commissioned by the Canadian Wind Energy Association. This work was partially funded by the Government of Canada's Climate Change Action Plan 2003, through the Technology and Innovation Program (under the Distributed Energy Production activities).

DISCLAIMER

Acceptance of this document by the client is on the basis that Garrad Hassan Canada Inc. are not in any way to be held responsible for the application or use made of the findings of the results from the analysis and that such responsibility remains with the client.

Key To Document Classification

Strictly Confidential	:	Recipients only
Private and Confidential	:	For disclosure to individuals directly concerned within the recipient's organisation
Commercial in Confidence	:	Not to be disclosed outside the recipient's organisation
GH only	:	Not to be disclosed to non GH staff
Client's Discretion	:	Distribution at the discretion of the client subject to contractual agreement
Published	:	Available to the general public

Revision History

Issue No:	Issue Date:	Summary
A	15 Sep 05	Interim issue for CanWEA comment.
B	7 Oct 05	Final issue incorporating CanWEA’s comments.

Circulation:	Copy No:
CanWEA	1
GH Glasgow	2
GH Bristol	3
GH Ottawa	4

Copy No: ____

CONTENTS

Executive Summary

This report provides a brief on work undertaken by Garrad Hassan (GH) on behalf of the Canadian Wind Energy Association (CanWEA). During 2005 it became apparent that Canadian provinces were operating largely in isolation along their own timeframes to develop interconnection requirements for wind turbines and wind farms. Particularly at the transmission level, 69kV and above, this was recognised as likely to lead to different sets or requirements with different rules and stringencies in each province whereas a clear benefit could be seen for the all stakeholders in a process of consultation leading to a unified and common set of interconnection requirements across Canada. GH was commissioned by CanWEA to examine these issues and propose a set of basic common interconnection requirements (a Base Code) and a path for CanWEA to take them forward with stakeholders, notably the provincial utilities and transmission system operators.

GH undertook a complete review of interconnection and grid integration issues in North America together with a more detailed examination of each Canadian province, its issues and progress towards a set of interconnection requirements for wind at transmission level. Following on from this GH were able to draw recommendations on a Base Code for CanWEA to adopt and how best to take it forward.

The Base Code proposed by GH incorporates the existing codes developed in Alberta, Ontario, Québec, and through the American Wind Energy Association, and adopts a structure allowing variability in requirements to accommodate both provincial differences and site specific differences. The Base Code contains ten items, some of which are mandatory requirements, some variable, and some of which are not enabled but are recommended for further development ahead of potential future implementation. The proposed Base Code is as follows,

1.	Frequency tolerance	mandatory
2.	Voltage tolerance	mandatory
3.	Power control	not a current requirement
4.	Reactive power capability/control	variable
5.	Voltage control	variable
6.	Frequency response	not a current requirement
7.	Low Voltage Ride Through (LVRT)	mandatory but variable
8.	Power system stabilisers	not a current requirement
9.	Data Provision	mandatory
10.	Operational monitoring	mandatory

GH concluded that the CanWEA should take the Base Code implementation forward through a process of consultation with the Canadian utlities and transmission system operators within Canada, and in parallel through a similar process with AWEA and the North American Electricity Reliability Council (NERC). Time has been identified as of the essence due to ongoing developments throughout North America.

1. INTRODUCTION

1.1 Background

Electrical grid interconnection issues are one of the most significant challenges facing the Canadian wind energy industry. At present, different provinces in Canada have different requirements for utility-scale wind farm interconnection, a situation that greatly increases the uncertainty (and associated costs) of new wind power projects.

At a recent AWEA/CanWEA wind integration and interconnection workshop in Toronto, participants discussed the new Canadian interconnection standards and an AWEA Grid Code, and noted the need for development of consistent guidelines across North America. In Canada, this presents a unique challenge as each province is at a different stage of development with respect to wind interconnection requirements, and each may require a modified guideline to take into account the technical characteristics of their systems. Note that in this case “guidelines” should be thought of in a wider context to include both standards and requirements.

Garrad Hassan (GH) has been working in the wind industry for 20 years and is established worldwide as one of the leading consultants. GH has been active in the US since 1984, and active in Canada since 1997 with a permanent office since 2004. GH has assisted many of the existing Canadian wind projects to fruition in one role or another. In recent times, it has been clear that grid integration issues are a key issue for continued wind energy development in Canada. This has already resulted in the introduction of a wind orientated Grid Code in Alberta, Québec, and Ontario, considerations in other provinces to introduce similar rules, and in the US the introduction of an American Wind Energy Association (AWEA) Grid Code adopted by the Federal Energy Regulatory Commission (FERC). The AWEA Grid Code is currently the subject of an ongoing consultation process but has recently, at time of writing, been adopted by the North American Electricity Reliability Council (NERC) with some amendment.

The Canadian Wind Energy Association (CanWEA), through this work, appears to be making a timely move to introduce and harmonise as far as possible a Grid Code for Canada before such issues become a barrier to further wind energy development. This is a positive and proactive step.

1.2 Objectives of this Study

This study has two main objectives:

1. To provide an overview of key issues in interconnection, and the status of utility-scale wind interconnection guidelines across Canada.

2. To provide recommendations on how CanWEA can facilitate development of “wind-friendly” grid interconnection standards across Canadian provinces. These recommendations consist of both *technical recommendations* (e.g. a Base Grid Code) and *process recommendations* (e.g. who CanWEA should engage in each province, and how they should be engaged to implement the Base Code).

This study only addresses transmission interconnected wind farms at 69 kV or higher voltages. It does not address distributed generation applications that are currently within the mandate of MicroPower Connect. The current and most likely future trend in Canada is to develop larger projects, e.g. 50MW+, which are transmission connected or connected very close in to the transmission system. This is a little different to other parts of the world such as Europe where wind energy has historically developed through smaller distribution connected projects.

A Steering Committee has been formed to oversee this work. The committee consists of members of CanWEA's Standards and Technical committee, plus representatives of Natural Resources Canada (NRCan), the American Wind Energy Association (AWEA) and the Utility Wind Interest Group (UWIG).

It is of course possible to achieve these objectives with a generic Grid Code, i.e. which covers all generating technologies with only a minimum of technology-specific requirements. GH has proceeded on the basis of a wind-specific document to act as a supplement to existing documents. The scope of this work, as agreed with CanWEA, is detailed in Appendix A of this report.

1.3 Exclusions

As this report primarily concerns technical interconnection standards for wind at the transmission level and in particular those commonly known as Grid Codes or Grid Code requirements, the following issues are considered as outside the scope of this work unless clearly relevant in any particular instance:

- Connection policies, charging practices, and Use of System practice and charging.
- Reinforcement and constraint issues, practice and management.
- Commercial issues.
- Market and regulatory issues except those impacting on the technical requirements.
- Forecasting.
- Capacity and capacity factor issues.
- Distribution system issues.

1.4 Canadian wind energy development

Canada has seen a tremendous growth in installed wind energy capacity with an average annual growth of 35% between 2000 and 2004. As of July 2005, there are 570 MW of installed capacity across Canada with approximately 2000 MW which are under construction or have secured power purchase agreements (PPAs) [1.1]. With this growth and estimated wind resource potential across the country, the outlook for future Canadian wind energy developments is very positive.

The majority of the large operational wind energy developments are found in Alberta (275 MW) and Québec (212 MW). The remaining 83 MW are installed in Saskatchewan, Ontario, Nova Scotia, Prince Edward Island, and Yukon, see Figure 1.1.

National government is committed to wind and many provinces have set provincial targets for wind energy the sum of which will likely see several thousand MW of wind energy being developed and grid connected over the coming years.

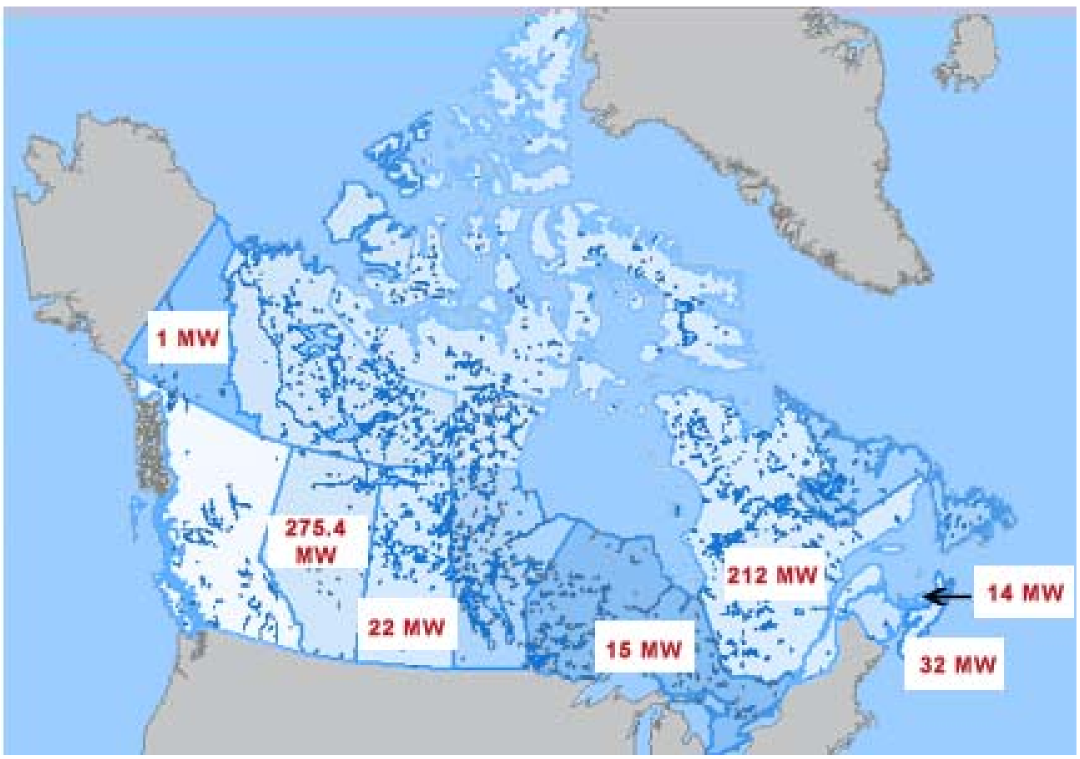


Figure 1.1: Current installed Canadian wind energy capacity by province [1.1]

2. NORTH AMERICAN INTERCONNECTION ISSUES

2.1 Introduction

This section of the report reviews the study work that has already been undertaken, or where possible “is in progress”, to assess the broad range of issues relevant to Canada and its individual provinces and the existing experiences with interconnection of larger wind farms. The review is focused on larger transmission connected (69kV plus) projects and in some cases those other projects which affect the transmission system. The issues identified are chiefly technical in nature and related to the ongoing satisfactory operation of the transmission system and related areas as the penetration of wind in the system increases to the point where it is no longer a minor player. In the case of many Canadian provinces and regions this point is likely to be reached quickly and thus the issues become very important very quickly and require urgent measures to mitigate them (e.g. a defined Grid Code for wind).

This section cannot provide an exhaustive review but instead aims to review the most up to date and relevant information in the public domain. The review focuses very strongly on the US and Canada with only limited comment brought to bear from Europe and other parts of the world.

GH has contacted the provincial system operators to assess their views although at time of writing feedback was still awaited from two provinces.

2.2 Reviewed studies

GH has reviewed the following studies and work stream presentations. This list was defined by CanWEA with input from GH, and is considered to be representative and appropriate if not exhaustive.

- Papers by Dr. Geza Joos of McGill University; the first presented at the 2004 CanWEA conference [2.1], and the second following the Toronto interconnection workshop [2.2].
- Paper entitled: "Comparison of International Regulations for Connection of Wind Turbines to the Network", prepared by Vestas [2.3].
- Studies undertaken on behalf of Alberta Electric System Operator leading to the revised Alberta Grid Code for wind [2.23] [2.24] [2.25].
- Studies undertaken for British Columbia Transmission Corporation. (available at http://www2.bctc.com/system/eng_repts.shtml) [2.26] [2.27].
- UWIG / AWEA Wind Integration and Interconnection Workshop, April 2005 [2.16] [2.17].
- UWIG/AWEA Annual Meeting – Wind Integration: Focus on System Operation, April 2005 [2.14] [2.15].
- AWEA Annual Conference, May 2005 [2.18] [2.19] [2.20] [2.21].
- KTH Fourth and Fifth International Workshops on Large-Scale Integration of Wind Power and Transmission Networks for Offshore Wind Farms (2003, 2005) [2.4] [2.5] [2.6] [2.7] [2.8].
- AWEA Grid Code. This is primarily reviewed as part of Section 4 of this report along with other Grid Codes rather than as part of the review of studies in Section 2.
- Papers presented at March 30/31 2005 CanWEA/AWEA workshop in Toronto on wind interconnection and integration [2.11] [2.12] [2.13].
- Any other relevant papers identified during the course of the work.

2.3 Key issues and experiences

The following issues can be identified from the reference list of studies and work streams.

2.3.1 System thermal limitations – constraint

Transmission system thermal limitations arise in all areas studied and are commonly dealt with by reinforcements. In some cases, a constraint mechanism has been applied whereby wind farms may be requested to constrain back their output or disconnect during periods when the system is in danger of being overloaded.

West Texas is a good example where transmission system thermal transport capacity has been severely limited such that existing wind farms are subject to constraints and complete curtailment currently amounting to some 20-30% of the potential generation export. The constraints are to be removed by system reinforcements [2.7].

Constraint can also be applied to other issues such as voltage control and stability constraints. Constraint can be achieved by a number of means in practice which include, turbine shut downs, complete wind farm shut downs, or regulation of power output to a determined constraint level. The latter is the most smooth allowing a reduced power and revenue loss to the wind farm, and the achievement of power control which can be implemented for other functions such as frequency response.

2.3.2 External interconnections

There is no doubt that transmission systems that are more interconnected to other systems are better able to cope with high wind energy penetrations. The case of Denmark is a particularly acute and well known example where the interconnectors to three other countries have been a vital part of balancing the system by either exporting excess wind energy or importing any deficits. The Danish interconnectors are used for other ancillary services such as reactive power balancing and provision of fault current, and as an aid to stability.

Many Canadian Provinces are poorly interconnected to each other with relatively little capacity for import and export of balancing power and other services. It is therefore vital that the capability to internalise such functions is retained through generation within the province including wind.

2.3.3 Internal interconnections and locational aspects

Interconnections within regions are also vitally important, particularly where there is a locational mismatch between the wind energy resource and the demand. This is somewhat unfortunately rather common with wind projects as many of the windiest areas are by their very nature less populated and contain poor grid infrastructure. This is notable in Texas, Alberta, British Columbia, California, and to a lesser extent Québec, among many other examples.

In the case of Texas, most of the wind resource is in the west or north with most of the demand in the east. Wind farms located in the west have been curtailed, losing as much as 20-30% of potential production until system reinforcements can be completed. The power flow issue and required reinforcement works have been identified by strategic studies and are now progressing.

In Alberta, much wind is located in the south west and proposed projects exceed the current system capability to transmit power from that region. Alberta is progressing a system reinforcement to uprate the system in this area and, at least temporarily, remove this constraint.

While there are no existing wind projects in British Columbia, recent work by GH has shown that a significant resource exists in the north-eastern or Peace region of the Province, whereas the major demand is in the south and west [2.35]. There are also several hydroelectric stations totalling to over 2.5 GW in the Peace region which could acts as localized storage for any installed wind energy capacity.

In California, the large wind resource in the Tehachapi area could not be exploited further due to a requirement for transmission capacity that was more expensive than any one project could afford. The system operator wishes to reinforce the system in the area to allow additional wind generation, but there is currently a regulatory difficulty about how this should be paid for.

2.3.4 Power regulation

Power control of wind farms can be an important capability. However, its necessity is perhaps surprisingly limited. Power control is probably most widely used at present to assist with system operation during contingencies where system capacity is reduced and the system would otherwise become overloaded. As many system operators design to cope with single or double contingency cases such occurrences tend to be very specific. Despite this, constraint is still common in some regions, notably the US. Other reasons for power control capability might include frequency regulation but this is not in widespread use with wind farms, and not at all in North America at present, and hence the need to control the power output is only exercised rarely.

Control of output power can provide significant benefits however, particularly when penetration of wind energy is high. The Danish requirements [2.8] are comprehensive:

- cap, i.e. an adjustable limit which the wind farm shall not exceed;
- delta control, i.e. the wind generation shall produce at a level which is an adjustable amount below that which it could produce if unconstrained;
- ramp rate control, both up and down;
- control of shutdown of multiple turbines.
- Automatic frequency control also has to be available while some of these limits are in place.

In most regions in the U.S. the technical requirement for wind generation to back down generation when an order is issued from the system operator is incorporated in the interconnection agreement on a case by case basis. The general trend is to only require backdowns for abnormal or emergency operating conditions and short term measures are often put in place until permanent upgrades to the transmission system can be made to mitigate the limitation. Another trend that GH has seen developing regarding this issue is the requirement to incrementally back down all the generators for an instructed backdown as opposed to the more traditional shutting down of turbines to limit generation. This is typically seen where relatively smaller projects (less than 50 MW) are interconnected at relatively electrically weak interconnection points to the grid.

In summary then, it is logical to require power control since modern turbines are capable of this, but its use is generally limited to contingent situations where available system capacity is limited and curtailment is necessary. In many ways this is more a connection policy issue rather than an ongoing technical issue, although most realise that much more wind can often be connected provided some generally infrequent constraint is permissible.

2.3.5 Reactive power regulation

Reactive power is usually associated with transmission system voltage control and servicing reactive demands of loads, and hence the capability to provide reactive power is important. Reactive power capabilities are usually framed either in terms of a power factor, or absolute MVAr, both in terms of leading and lagging senses and most generators on a transmission system will tend to export reactive power.

Virtually all system operators identify reactive power capability of generation as important, but in regards to wind farms this is usually tied closely to voltage regulation rather than servicing reactive demands of loads.

In keeping with traditional synchronous generators system operators will generally specify a normal operating power factor somewhere within a range but also require the capability to adjust on command. In some cases this is extended to a “dynamic” capability usually to assist with system voltage regulation.

Voltage regulation is covered in the following section with further discussion on the provision of reactive power.

2.3.6 Voltage regulation

The issue of voltage changes is very common on distribution system connected projects and is often addressed by capping the connectable wind capacity or utilising a fixed power factor to nullify the effects of the real power injected into the system. These are local issues common throughout the world. On transmission systems, the issues of reactive power flows and voltages are perhaps more critical. Many systems experience issues with the control of voltage and reactive power and voltage regulation is identified as a key issue and concern just about everywhere including the Canadian provinces. Some examples are discussed below.

Denmark has traditionally provided reactive power for voltage control and demands on the distribution networks from the transmission system. In recent times, the potential fluctuating requirements due to wind, as well as becoming difficult to meet, have resulted in reduced capacity on the transmission system for real power flows. To alleviate this problem, the western Danish transmission system operator has set up a new control regime whereby distribution networks take responsibility for the control of reactive power themselves with the transmission system only providing a limited service under normal conditions. The control is to be achieved through distribution connected generators (including wind).

In Texas, transmission of large amounts of wind generated power over long distances from west to east has resulted in serious issues with voltage control. To correct these issues a range of reactive devices such as capacitor banks is to be fitted around the system as identified as part of strategic studies. In addition, Grid Code requirements are being set which require wind farms to be able to operate at a range of power factors, both leading and lagging, and assist in direct control of network voltage. There are wind farm projects which actively monitor transmission system voltage and adjust the import or export of reactive power to control that voltage.

Initial studies for a large transmission-connected offshore wind farm at Cape Cod showed that voltage control would be an issue, and therefore wind turbines and wind farm controllers which could adjust reactive power output to control voltage at some remote point on the system were necessary [2.4].

In Alberta [2.25], it was found necessary for wind generation to have the ability to control voltage at the Point of Connection, both in the steady-state and during transient events. This results in a general requirement for wind generation to be able to operate with a power factor controllable within the range 0.9 lagging (i.e. exporting reactive power) to 0.95 leading (i.e. importing reactive power). This is not an onerous requirement in principle, if taken into account early in the project design stage. The study favoured a flexible approach, i.e. the reactive power requirement should be determined specifically for each project, rather than a fixed mandatory requirement. Therefore the range suggested above is indicative only.

The Alberta study also found that reactive power control devices at major network nodes would also result in satisfactory performance, but due to the uncertainty in the timing and location of wind generation developments, recommended that this function is provided at each wind farm. There may still be a justification for reactive power facilities operated by the system operator for steady-state control only. In [2.24], the possibility is raised of unwanted interactions between voltage control functions of the wind farm and of other network elements. This issue is not new and should be addressed during detailed consideration of each project.

2.3.7 Steady state stability

Transient stability is the response to faults, and is covered in the next section.

The term ‘steady state stability’ is sometimes also raised in connection with wind generation. GH understands that this can mean two separate issues: voltage regulation, which is covered in the previous section, and dynamic stability. Dynamic stability is associated with spinning inertias and is covered in Section 2.3.10 below.

2.3.8 System security during and after faults – transient stability

Security of the transmission system has been identified as an issue of key concern in many studies and by many system operators (See also Sections 3 and 4 of this report). This level of concern is generally supported throughout the world and reflected in the imposition of requirements for Low Voltage Ride Through (LVRT), also known as fault ride through, on transmission connected wind farms. Wind farms have traditionally disconnected from the system during abnormal or fault conditions, largely to avoid issues with islanding and resynchronisation. This practice has been applied worldwide as well as in North America and is still a common practice for distribution connected wind farms.

With increasingly high levels of wind energy connected to the system this is no longer a suitable strategy and wind farms are now being asked to ride through system abnormalities and assist in controlling the system by providing fault current during the fault and continuing to generate as normally as possible after the fault is cleared. This requirement is being instigated through (transmission system) Grid Codes where it is already in place. In some countries, e.g. Great Britain, this is also being applied to distribution system connected wind farms above a certain capacity as much of the wind capacity is distribution connected.

Stability issues are present in Texas during post contingency conditions, and in Spain a curtailment requirement is in place during high winds and low demand to ensure system stability. It is worth noting that Spain has not made LVRT through capability on wind farms mandatory and this will be an optional service for future wind farms, with financial benefits for those projects which implement it. There is therefore a significant risk of system instability, which cannot be quantified since the number of wind farms choosing to opt for LVRT in the future cannot be anticipated. This seems to indicate that LVRT should be considered a mandatory requirement fundamental to system security, at least once a certain wind penetration has been achieved.

In Alberta, studies found that with 1000MW of wind, the system was at risk if a transmission disturbance caused the wind generation to shut down [2.23] to [2.24]. The simplest way to avoid this is to specify that the wind generation must have LVRT capability. The Alberta studies also found that, for faults at lower levels of the transmission system (138kV), the duration of the low-voltage event may be prolonged. Although these faults will affect less of the total wind generation, the studies recommended that this issue is best dealt with by improving the protection on specific parts of the 138 kV system, rather than by increasing the LVRT requirements for wind generation.

LVRT is also an important issue for Québec where the extensive transmission system is susceptible to dynamic and transient effects [2.22].

As system security ("keeping the lights on") is identified as a fundamental issue and requirement then it follows that LVRT is also a fundamental requirement for generators. In cases where wind penetration is significant then LVRT must also be applied to wind. Wind generation that can ride through a low voltage event (or a fault), generate fault current and return quickly to as normal as possible generation after a fault offers the system several key services:

- Assistance with fault clearance by the provision of fault current.
- Assistance in maintaining system voltage by the provision of reactive and real power during the fault.
- Assistance in system recovery post fault by provision of real and reactive power.
- Assistance in returning the system to normal conditions via the provision of control services (voltage control and/or frequency response).
- Assistance in a stable recovery without undue oscillation provided the turbine response remains stable and is appropriately damped.

There is and continues to be much debate around LVRT but the key issues are to define the required turbine capability and response in terms of the above list, and to define the fault characteristics, chiefly:

- Event or Fault type, e.g. phase, ground.
- Event or Fault duration.
- Depth of voltage dip. In North America voltage dips are either defined as retaining 15% voltage (ref. AWEA, AESO) or 0% (ref HQ, NERC proposals). These two values are also commonly used throughout the world.
- Production of real power in the immediate post-fault period.

Unbalanced faults may present particular difficulties, both in definition of the true requirements, and in meeting them [2.5]. It is therefore to consider the requirements for balanced and unbalanced faults separately.

It is not necessary to define the dip per se and in some cases, e.g. Ontario, and Great Britain, an alternative approach is taken whereby the wind farm must calculate the dip based on system studies – this approach yields case by case requirements and although these may often show less onerous requirements, can result in a disparate capability across the system. GH cautions against such an approach as it can result in wide variations in requirements, may prevent manufacturers of turbines from standardising LVRT capabilities, and does not set a baseline which may be relevant and effective at all future times.

Note that the NYSERDA study [2.10] found that the addition of wind generation (with good LVRT capability) would ***improve*** the post-fault response of the NYISO system, compared to conventional generation. Joós [2.2] also makes the same point.

2.3.9 Negative phase sequence withstand

Negative phase sequence withstand is a requirement on all power systems since no phase system will operate as perfectly balanced. Continuous negative phase sequence levels are usually below 2-3% and within capabilities of modern wind turbines. This generally falls under “power quality” issues.

Negative phase sequence currents also arise during unbalanced faults and can be much more severe than imbalance during normal continuous system operation, albeit for short durations according to fault clearance times. The ability to be able to withstand such currents is an important part of LVRT capability ensuring system security. This has been discussed above in Section 2.3.8 but is sometimes glossed over in existing requirements and often in need of better recognition and definition.

2.3.10 Low frequency oscillations and power system stabilisers

Many odd effects can occur on large power systems. Those with long lines can experience standing wave effects, and wide areas oscillations are sometimes witnessed. These oscillations are usually of a low frequency, around a Hertz or so, and have been noted in work conducted within North America, e.g. [3.1].

Québec also can experience oscillations around 0.5Hz [2.22]. These are a result of long 735kV transmission lines connecting generation in the north to the demand in the south. To mitigate these effects Québec requires Power System Stabilisers (PSS) on traditional plant although not on wind farms at least for the time being.

In Europe, German studies have indicated wide area oscillations can arise with sudden disconnection of large amounts of wind energy, and resonance modes can also occur or be aggravated by wind [2.28]. It is possible that Germany will introduce more stringent connection conditions beyond LVRT to deal with these issues. Oscillations between England and Scotland have also been an issue in the past leading to specific requirements for PSS on larger generators to damp them out, and a proposal to also require PSS on wind farms [2.29] although this has been withdrawn at least for the time being.

New and more stringent connection condition requirements will address many of the stability concerns on transmission systems, but other measures may need to be considered such as the installation of Power System Stabilisers on wind farms or the capability of wind farms to provide appropriate damping. GH is not aware of any requirements in North America or any other countries for Power System Stabilisers on wind farms at present, but is aware that this is under consideration and may be introduced in the future. Both Alberta and Québec makes notes in this respect in their current sets of interconnection requirements, discussed further in Section 4.

2.3.11 Frequency response / control

Frequency response (or control) requires generators to be able to adjust their output power over short timescales in response to frequency changes on the system. This is effectively balancing load with generation but in very short timescales to tightly control the frequency within a narrow band. System frequency is the manifestation of the kinetic spinning inertia in generation plant which increases if there is too much supply of energy (over-generation = over-frequency) in the system or decreases if there is too little supply of energy (under-generation = under-frequency). Balancing system generation and load over longer timescales is discussed in Sections 2.3.19, 2.3.20, 2.3.22, and 2.3.24 in regards to various aspects.

Frequency response requires generators to be able control their real power output. Not all plant is suitable for frequency response and the capability to respond varies.

The capability of wind to provide frequency response is clearly dependent on the wind conditions, since no wind means there is no power output that can be adjusted. It is also dependent on the type of wind turbine. Traditional, and now relatively uncommon in new projects, stall regulated cage rotor induction generator wind turbines are unable to control their power output and thus can not provide this function whereas modern variable speed power converter connected and pitch regulated turbines can.

A key issue for those turbines that can provide frequency response is that they must partly de-load in order to be able to increase output when required on falling frequency. This is important because energy is lost and wind farms normally generate as much as possible when the wind resource is available (since the resource availability is not controllable). This implies lost and non-recoverable revenue unlike other plant where the fuel source can be stored. In general terms then wind would prefer not to participate in frequency response except when absolutely necessary.

The capability to provide frequency response is a not uncommon requirement for wind farms and has been implemented at Horns Rev Offshore Wind Farm in Denmark [2.30], and in the UK.

Frequency response is only likely to be necessary from wind farms in cases where penetration is particularly high (well above 10%), or in exceptional circumstances such as islanding. In Canadian provinces where hydro reserves are abundant, the fast response times of hydro plant are likely to be sufficient to cover this function. This is supported by experience from hydro rich nations, and studies performed in Canada's hydro rich provinces, e.g. [3.2].

2.3.12 System inertia and generator response

System inertia is important in that it has a large effect on system stability and frequency. Systems with low inertia (low rotating mass in the generators) tend to be more sensitive to load/generation imbalances, more "twitchy", and less stable in response to faults. This has not been seen to be a big issue in North America where systems are interconnected and therefore tend to be large and more robust. Canada's islanded provinces, e.g. NWT, Nanavut, Yukon and Newfoundland will however need to consider inertia more seriously.

Wind turbines generally have similar inertia in their rotating parts as conventional generators, per MW of capacity. However the important difference is that conventional generators are directly and synchronously connected to the electricity system, and therefore a drop in system frequency automatically extracts energy from the plant inertia as it slows down. However most modern wind turbines are variable-speed, and so a drop in system frequency does not automatically result in energy being extracted from the inertia. Their contribution to total system inertia is therefore effectively zero and as conventional generation is displaced, total system inertia decreases.

In the Republic of Ireland concerns over the lack of inertia wind turbines bring to the system have been raised although no action taken, and in Great Britain at one time a moratorium was placed on further connection of gas turbines with one of the main concerns the reduced inertia they were bringing to the system.

Modern power electronic converter turbines do offer, in principle, the option of providing ghost inertia – that is by programming the controllers such that the turbines behave and look to the system as if they have more inertia than they really have. This is essentially a power control function related to frequency response. This 'ghost inertia' function has been demonstrated by simulation [2.31] but to GH's knowledge has not been demonstrated on an operating wind turbine.

Inertia has been noted as a potential issue in Canada but generally only for cases where there are small island systems, or where small parts of the wider system can become islanded. A good example is Vancouver Island in BC which must ride through potential islanding and already has a load shedding scheme to assist in retaining and controlling frequency [2.27]. Reducing system inertia may leave the island in a very difficult position in controlling islanding and may be reason enough to require inertia from all new connecting generation.

2.3.13 Fault contributions

The general principle in conventional generation is that it is beneficial for generators to provide large currents in the event of short-circuits or other faults on the electricity system. These large fault currents ensure that the fault is detected correctly and protection operates quickly to isolate the faulty area.

Simple induction generators provide fault current in most circumstances, but it decays to zero very quickly. For small wind farms of induction generators connected to distribution systems, this was only rarely a problem: in most cases, the fault current from the network source was much greater, and sufficient to allow correct operation of protection.

Variable-speed wind turbine generators may not generate any significant fault current, depending on design [2.4], see also Appendix B. For distribution-connected wind farms, this is not a problem, as noted above. For transmission-connected wind farms, it may in some circumstances cause difficulty [2.2], particularly if the wind generation results in the displacement of conventional generation in the same area. GH is not aware that this has yet become an issue, but it is possible that in future wind farms in some locations will be asked to provide a certain minimum fault current for a specified duration. This should be feasible with only software modifications, until the limits of power-electronic devices are reached. Fault current in excess of device limits will require larger devices to be provided, which will have a significant effect on wind turbine capital cost.

Therefore, it may be appropriate for fault currents to be considered in the development of a Canadian Grid Code, particularly in respect of the detail of LVRT capability. However, GH does not consider the issue of fault contribution should be considered outside of this within the development of the CanWEA Base Code.

2.3.14 Protection

Protection is always an issue but rarely a problem in regards to wide scale integration of wind energy. All system operators have specific protection requirements which in general terms follow “best industry practice” and established standards. Protection is therefore a normal part of project design and should not be considered as a special requirement requiring consideration within the Base Code.

2.3.15 Earthing

Earthing issues and requirements are generally specific to the system operator. GH believes that earthing requirements for generation connections are already well understood and specified. Also, compliance is generally a matter for design of the wind farm electrical system rather than the individual wind turbines. Therefore GH believes there is no justification for developing earthing requirements specifically for wind turbines.

2.3.16 Power quality

Power quality is generally taken to regard three key issues:

- Voltage flicker
- Voltage step changes
- Harmonics

Each of these is addressed in North America by appropriate IEEE standards which should be applied to wind farms. IEC standards tend to be more prescriptive and definitive but are not in widespread use in North America. IEC 61400-21 is one of a series of wind turbine specific standards and deals specifically with power quality.

GH's experience spans more than 20 years of grid connected wind turbines throughout the world and despite many concerns from system operators in regards to flicker GH can recall only one or two cases where flicker has been an issue. In general terms, if system voltage regulation and thermal limitations are satisfactory then flicker usually is too. This is perhaps fortunate because until recently wind turbine flicker was almost impossible to calculate. IEC 61400-21 provides guidance on calculating flicker from grid connected wind turbines based on measured and documented characteristics and simple engineering calculations and is invaluable in this respect. The calculation results should then be related to the limits set out in the applicable local standards such as IEEE to determine whether the results are acceptable or not.

Voltage step changes occur from various events, including turbine start-ups, shut downs, trips, and other events. Voltage step changes are also produced by wind farm electrical systems from events such as transformer energisations, wind farm trips, and other switching events. IEC 61400-21 provides guidance for the calculation of voltage step changes from turbine switching events such as start-ups and shut-downs, the results of which can then be related to the allowable limits set out in local standards such as IEEE.

Experience has shown that voltage steps arising form the wind farm electrical system are often worse and more problematical than those from the turbines. Modern turbines are all "soft started" in some way and thus inrush currents and voltage step changes are moderated. Plant such as turbine transformers does not benefit from such control and in some cases can lead to issues. For wind farms that are transmission connected this is less likely to be an issue as system fault levels will be higher. Sectionalised or even individual energisations can be undertaken operationally to limit effects on the system.

Harmonics are less simple to assess and are becoming more of an issue to system operators around the world as the uptake of electronic goods and other harmonic producing plant increases. Given the trend to power electronic converter connected wind turbines, harmonics are likely to become a more important issue for wind farms in the future.

IEC 61400-21 provides limited guidance on harmonic calculations but does provide a methodology whereby turbine harmonics are measured and detailed in testing. These harmonic currents can then be applied to the local standards to determine acceptability.

Harmonics may be produced by normal continuous operation or by specific events within turbines or wind farm electrical systems such as capacitor switching. GH has experience of wind farm harmonic emissions being problematical in the following cases:

- Individual harmonic orders emitted by turbines may exceed system planning limits.
- The contribution to and resultant increase in system Total Harmonic Distortion may exceed system planning limits.
- The connection of the wind farm may result in a resonance condition leading to unacceptable harmonic conditions.

Harmonics should be dealt with using IEC61400-21 and appropriate simulation modelling to assess compliance or otherwise with local standards.

A final consideration is system imbalance (sometimes called unbalance). This has been discussed in Section 2.3.9 in regards to steady state continuous operation which is the relevant consideration here. Consideration of imbalance during abnormal system conditions is most relevant to LVRT capability and has also been discussed in Section 2.3.8 and 2.3.9.

In summary then, power quality is often raised as a major concern but its technical analysis and consideration goes no further than the existing standards applied universally to transmission systems and it does not therefore require special consideration as part of a CanWEA Base Code. It is noteworthy however that IEC 61400-21 does provide an important, and relatively new, source of quantification of the effects of wind turbines on the system in regards to power quality.

2.3.17 High wind shut downs

Most wind plant shuts down when wind speeds exceed 25m/s to avoid structural damage. GH has been involved in commercial projects where (near) simultaneous shut down of turbines at a wind farm could result in system instabilities leading to voltage collapse. In addition, sudden loss of generating power can be regarded as a system contingency although as most farms are relatively small this is hardly comparable to the loss of a major thermal plant. However, rapid increases in wind speeds can result in shut downs at wind farms across wide areas in relatively short timescales (hours) as seen in February of 2005 in Denmark [2.32]. This can become a genuine system contingency. This is a rare but potentially serious event.

Some modern wind turbines are being offered to the market with capabilities to operate beyond normal shut down wind speeds of 25m/s, e.g. Enercon’s “storm control”, and most manufacturers can offer a degree of control under most high wind conditions. Issues arising from high wind shut downs are thus largely a project specific case, usually relating to power quality voltage steps.

In the case of wide area shut downs there is little that can be done technically. In such rare cases it is important that the system operator has visibility of the event in advance and thus operational monitoring and forecasting become valuable. This is even more valuable if the system operator has the power to reduce wind farm output in advance of the event (see constraints in Section 2.3.4 above). In this case, the problem should be readily manageable.

An alternative is to require wind farm operators to limit the maximum negative ramp rate due to high wind conditions, with penalties for failure. This puts the onus for forecasting and early output reduction on to the wind farm operators. This may be administratively simpler, but requires policing. GH is not aware that this has been done anywhere.

Problems with wide area shut downs will only start to occur at higher penetrations so at least initially this need not be a major consideration except in specific cases where a windy area is served by a weak interconnection and voltage regulation and stability problems might arise, e.g. West Texas.

Another potential solution to voltage issues during high wind shut downs is to shut down the turbine power generation but continue to use any reactive capability for voltage control assistance.

2.3.18 Ramp rates

Maximum ramp rates are often specified in Grid Codes to ensure "smooth" system operation. A ramp rate is the rate at which a generator increases or decreases its power output. For large thermal and hydro stations which can be several thousand MW this is important and system operators like to see sets brought up and down over time so as not to cause sudden changes on the system. For wind farms, which are generally much smaller, this is less of an issue. Most Grid Code ramp rates are specified at MW per second/minute/hour rates that are much larger than most wind farms.

Ramping down of a wind farm will usually be a relatively smooth process involving turbines gradually coming off through low wind speed cut-out. At high wind speeds, there is some possibility of high wind shut-downs occurring across a project in short timescales and this is more important as this will represent sudden loss of rated power (or in some cases near rated). This has been discussed in Section 2.3.17 above.

Ramp rates are also an issue during normal operation of a wind farm due to fluctuations in wind. In principle, all pitch-regulated wind turbines can limit the upward ramp rate.

Ramp rates have been examined in BC [2.26] [2.27] and found not to be an issue as the large hydro sets already operate at much larger ramp rates, e.g. 100 MW/minute plus. Similarly the New York study found no need for system-wide ramp rate limits on wind farms [2.10] [2.12].

Studies conducted on the CAISO, PJM and WAPA Rocky Mountain Control Area concluded that significant excess ramping already appears to exist on each of these systems [2.19]. This tends to disprove the often voiced concerns of system operators that wind generation will require significant additions of conventional generation capacity in order to accommodate the addition of new intermittent wind generation.

It is not clear if limits on ramp rate will be necessary in some provinces in Canada in the future. Therefore the need for a requirement in the base Grid Code is a matter for discussion.

2.3.19 Generation scheduling

In the U.S. markets the scheduling of an intermittent resource like wind is handled in various ways depending on the region. In general, most regions recognize that an intermittent resource like wind will have unintended deviations from schedules due to the nature of the technology and are attempting to incorporate rules for intermittent generators that minimize or exclude wind generation from unintended generation schedule deviations. The FERC has also recognized this unique feature of wind generation and has adopted a philosophical viewpoint that wind forecasting is a better basis for policy than assuming generator imbalances can be deterred with high penalties as with conventional generation technology [2.17].

The California System Operator (CAISO) has instituted a program called Participating Intermittent Resource Program (PIRP) [2.18] which nets the individual metering period scheduling deviations over one month period with a self-correcting bias that will drive the scheduling deviation toward zero. Since maintaining a realistic hourly schedule for the intermittent schedule from CAISO perspective can sometimes be in conflict with the bias feature, a limited amount of bias correction is utilized for any given hourly schedule.

In the Midwest Independent System Operator market (MISO), the intermittent resource is scheduled as any other generation except the intermittent resource is not subject to any Uninstructed Deviation Penalties. [2.14]

For wind generation operating within or under an entity that has traditional dispatchable generating resources, the intermittence of the wind can be included as a network resource within the control area and dispatched in conjunction with the traditional resource to provide a more stable schedule. For wind generation outside of an entity's control area a dynamic schedule can be utilized which virtually moves the remote intermittent generation schedule from the local region to remote region where the load is being served. The reserve requirement and ancillary services are also virtually transferred to the remote control area [2.15].

A significant issue yet to be fully resolved is the "seams" issues for different rules in adjacent / or even over lapping geographic areas.

Scheduling and balancing is also a concern for Canadian provinces (Section 2.3.22). Despite this, scheduling and balancing in the context discussed is largely a commercial issue and not entirely relevant to the development of CanWEA's Base Code. It will not be considered further here.

2.3.20 Power fluctuations and variability

The power fluctuations of wind plant output caused by the variability of the wind speed have caused concern for system reliability. Numerous studies have been conducted to attempt to quantify the impact on system operating parameters such as spinning reserve margins and additional regulating capability.

A statistical analysis performed for the New York State Power System (NYISO) [2.16] found that there was minimal impact on system load-following performance and system regulation performance for wind penetration levels of up to 10%.

Another study [2.20] looking at a local region in the US Midwest concluded that wind generation imposes additional load following requirements in the hourly time scale and underscores the need for the system operator to use a Unit Commitment Program to ensure sufficient ramping capability and fast moving generation is available to meet system requirements.

In Canada, wind variability has been examined as part of studies undertaken in BC [2.26] and [2.27] but found not to be overly significant due to the abundance of responsive hydro units. Study [2.27] discusses variability at some length with reference to various works in the US.

In Alberta studies on wind variability [2.36] have just been concluded and the impact on system operation is currently being considered. Implications are likely to be commercial rather than technical but may require the implementation of wind energy forecasting.

2.3.21 Operational monitoring

It is quite normal for larger transmission connected generators to provide real time data to the system operator and market operator. This is used for system monitoring and control purposes by the system operator and commercial purposes by the market operator.

The system operator uses operational monitoring to build a picture of the system operation which is vital for control purposes. In the case of wind many system operators are concerned over its variability and consider operational monitoring as essential. This is probably not justified on variability concerns alone, as studies have shown wind variability not to be a serious issue and relatively small on short timescales such as hour by hour.

Operational monitoring also allows system operators to build a historical database which can be used to improve system control, anticipate conditions and contingencies, and for forecasting on longer timescales.

Studies undertaken in various Canadian provinces have recommended operational monitoring is undertaken. This includes Alberta [2.25] and BC [2.27], and Québec, Alberta and Ontario also currently require operational monitoring.

The burden to a wind farm of providing operational monitoring is relatively small and thus it is justifiable for this to be undertaken, particularly since it can be used to provide useful information and it allows a route to implement certain functions, such as forecasting, retrospectively. GH considers that it will be desirable to implement operational monitoring through a CanWEA Base Code.

2.3.22 System balancing and reserves

In Alberta [2.25], an approximate analysis concluded that in 2007 (assuming 1200 MW total wind generation capacity), there would be a need for a significant increase in regulating reserve (i.e. spinning reserve responsive to Automatic Generation Control), and also in contingency reserve (i.e. reserve to cope with the single worst contingency).

The study [2.25] concludes that the costs of this increase in reserve requirement can be reduced through real-time provision of data from the wind generation to the system operator, the ability to constrain wind generation (particularly ramp rate), and by forecasting.

The study also suggests two possible modifications to market rules for intermittent and non-dispatchable generation, both of which have been used elsewhere:

- day-ahead market, with penalties for mismatch on a monthly basis;
- hourly market, mismatches penalised by having to buy or sell power on the spot market.

Alberta is currently undertaking a market restructure which at time of writing seems to be in favour of a roughly hourly market but not a day ahead market. The AESO is also undertaking “wind variability studies” to examine the effects of the variable output of wind on the system and reserves for balancing. AESO expect to input the results of this study into the market restructuring and be able to define wind forecasting requirements as a result of the studies.

Other studies on other systems have shown relatively wide disagreement about the additional cost for load-following and regulation caused by wind generation [2.6] [2.9]. GH believes that this wide range of results is partly due to different methodologies in the studies (in particular, conservative assumptions where uncertainty exists), and is partly due to differences between systems. However it is clear that the additional costs are not prohibitive, even at relatively high wind penetration levels.

As with related issues discussed in Sections 2.3.19 and 2.3.22 this is largely a commercial issue for the market and does not merit consideration within CanWEA’s Base Code.

2.3.23 Forecasting

Forecasting is not a necessary requirement for connection of wind plant. A system can be operated at any penetration of wind without a need for forecasts of wind generation output. However, as penetration of wind increases operation of the system becomes more difficult and more expensive and forecasting can be used as an aid to improve control and reduce costs. Forecasting is thus about information provision and providing tools to make system operation easier and more cost-effective.

General worldwide experience suggests that in most cases a wind penetration of 10% to 20% by energy can be accommodated with relatively modest costs (e.g. approximately US$4.5/MWh [2.10] [2.12], or UK£3/MWh [2.33]). It appears that the major elements of these costs come from events in the unit commitment timescale, i.e. 10-30 hours ahead. It is likely that forecasting could reduce these costs.

It is probably more important to at least provide the functionality for forecasting at some future point should it be deemed necessary. This is largely about provision of operational monitoring. Some of the studies undertaken in Canada have recommended forecasting of wind plant be undertaken, e.g. for BC [2.27] and Alberta [2.25].

Despite the above comments, forecasting can be more important under other circumstances, e.g. when the system is an island or particularly small. Experience of the AESO in Alberta in sometimes finding difficulty in predicting the need for balancing services and then scheduling those services has been partly responsible for market restructuring but also driven a review of the effects of wind variability on the uncertainty levels and thus whether forecasting should be implemented even at low penetrations. AESO also comments that forecasting will give better visibility of system constraints and operational issues ahead of real-time. Some conclusions from AESO’s initial studies on this issue are contained in [2.34] but the final outcomes are not yet known as of time of writing.

One of the main debates is whether forecasting is best done by the system operator or the individual wind farms. There are pros and cons of each. If market conditions provide strong incentives for wind farm operators to produce forecasts, it makes sense to aggregate these forecasts. Otherwise, it may be cheaper overall for system operators to produce forecasts for their area, which may not identify specific wind farms.

2.3.24 Capacity Credit and peaking power and generation adequacy

Capacity credit of wind generation has been, and continues to be, a source of much debate throughout the world. The capacity credit of any generation is generally accepted to be a quantification as to how "firm" generation can be regarded, and to what extent it can be relied upon to meet system peak demands. Capacity credit of wind is much lower than traditional fossil fuel, nuclear and hydro plant by the nature of its lower capacity factor.

Estimates of the capacity credit of wind vary, depending on the system, location, and methodology. A summary of results of some US studies is given in [2.11].

Generation adequacy is a term applied to determine whether the total system generation is adequate to meet the total system demand. It is expected that a number of Canadian provinces will start to experience low generation adequacy as soon as 2007, e.g. Ontario, Alberta. The capability of wind to contribute to generation adequacy is therefore important, and this is likely to be an area of intense study. Capacity credit is not in itself a technical interconnection issue. This report will not discuss this issue further.

2.3.25 Information provision

Provision of real-time data, operational monitoring, has already been discussed. The provision of other data at various stages of a project is also important. Most important in respect of grid interconnection is the data defining the plant technical characteristics that is used to determine the effects of the plant on the system through simulation modelling and calculation. Most of this data is required ahead of connection, and generally ahead of provision of an offer to connect, and is used in System Impact Studies. System Impact Studies are required of all projects connected to the transmission system and to some extent determine the requirements on the project from the grid, and the works such as reinforcement that the grid operator needs to undertake.

The technical characteristics of wind plant are different from those of traditional plant and most existing grid codes do not contain provisions for the type of data required since they generally concern large thermal synchronous generators. There is therefore a need to define the exact data requirements from wind turbines needed to model them within the common power system simulation tools. In North America the most common simulation tools are the Siemens owned PTI PSS/E software, and General Electric's PSLF. As turbines are different, it is often necessary for a suitable simulation model to be developed and this is currently an ongoing task with all turbine manufacturers, and one which is meeting with varying degrees of success and confidence from grid operators.

There is also a need to decide how to model wind farms. If every generator in the wind farm is modelled, the simulation task and duration becomes very large. This will be particularly true in future when the effect of a new wind farm on several existing wind farms becomes important.

Therefore it may be necessary to agree how to produce aggregated models of a wind farm, i.e. represent a wind farm by a small number of large aggregated wind turbines. There is simulation evidence [2.4] that this can be satisfactory. Disaggregated models will still be necessary for design of the electrical system within the wind farm. There is a related issue of validation of models.

Although data provision is not a technical issue as such it is always a part of Grid Codes and given the current issues with turbine models and validation GH considers that it merits consideration within CanWEA's Base Code. This assertion is strongly supported by AWEA who in their Grid Code recognise these issues and propose enduring processes to deal with them. Further comment on this is given in Section 4 where the Base Code is developed.

2.3.26 Voltage and frequency operational ranges

As noted in earlier sections, the traditional approach for wind generation was that, in the event of difficulties with the electricity system, the wind generation should disconnect. This is not acceptable when wind generation reaches high penetrations [2.2].

One feature of grid codes published so far is that the wind generation is now required to be able to continue to operate over a wide range of both voltage and frequency. In addition to a range for which continuous operation is required, there may be more extreme limits for which operation over a defined time is required, or for which reduced output is permitted. These are important considerations for securing the system with increasing penetrations of wind energy.

A CanWEA Grid Code should therefore include specified ranges of voltage and frequency. Different ranges for different systems may be appropriate. This is the case in Europe, where the relatively small GB and Irish system require operation over a wider frequency range than the larger continental European system.

The specified voltage and frequency ranges in the US are generally set by the individual reliability council and based on complying with NERC Operating Guides. The frequency range that the generators are required to operate through has tended to increase over the last few years as the reliability councils have implemented operating procedures to try to improve the reliability of the high voltage transmission system.

It should be noted that the required voltage range is best specified at the Point of Interconnection of the wind farm. The voltage range which each turbine may experience may well be larger than that, due to the voltage drop/rise across components of the wind farm electrical system. In particular, if the wind farm is required to be able to produce and consume large amounts of reactive power, the additional voltage drop/rise within the wind farm may become large [2.4].

2.4 Summary

2.4.1 General discussion

As noted frequently within the preceding sections, those provinces which are hydro dominated have a significant advantage integrating wind into their systems. Hydro is typically very responsive and controllable and can be used to "soak" up a lot of the variability in the wind, taking a lead role in performing operations such as load following and frequency response. This is the case for BC, Manitoba, Québec, Labrador, and to a much lesser extent Ontario. In addition, the costs of using hydro for this function are generally understood to be less than for thermal plant.

Many provinces are interconnected with the US and each other. Interconnections are generally regarded as useful in strengthening power systems and assisting in making them less susceptible to the effects of contingencies. Interconnections also allow some flexibility of operation in importing or exporting real and reactive power and to some extent the services associated with them, e.g. balancing power, peaking power. This improves the position of those provinces which are interconnected to deal with significant wind. Provinces which are not interconnected or regions which are subject to islanding from time to time are much more sensitive and will need to consider the issues carefully.

Many of the key issues in Canada, the US, and indeed other parts of the world stem from the fact areas of high wind resource are often located far from the main demand centres. This often leads to issues of inadequate system thermal capacity, constraint, and ensuing system reinforcements. In parallel with these issues problems with voltage control and stability may occur.

The type of technical integration issues this work is concerned with are primarily concerned with the basic requirements of Grid Codes – that is ensuring system security and an ongoing satisfactory operation of the system, i.e. maintaining the system within prescribed operational limits, primarily regarding thermal, voltage, frequency, and stability criteria.

Issues of inadequate grid thermal capacity are thus not entirely relevant as these are matters for the grid operator, although turbine capability to control output power can be used for curtailment in such circumstances. Other issues which sometimes occur in these circumstances such as voltage control and stability are relevant. These respectively require a reactive power control capability and a degree of fault tolerance (low voltage ride through capability, as well as tolerance to voltage and frequency variations).

Another issue which is fundamental to satisfactory grid operation is frequency control. This places a requirement on the turbines to be able to control power output.

This section of the report has also identified other issues which are important and these include: Negative phase sequence withstand, power system stabilisation, and provision of inertia.

Operational monitoring is generally regarded as useful in providing the system operator with real time data which can be used to understand the system state and assist with operation. Operational monitoring also provides historical statistics on the wind plants' operation and can be useful in forecasting and system studies. The availability of monitoring also allows for forecasting and other functions to be implemented as seen necessary. Related to this is the provision of modelling data, particularly models which adequately describe the turbines for simulation work.

2.4.2 Key interconnection requirements

The basic set of interconnection requirements that can be identified from the review at thisstage are therefore:

1. Power control (caps, ramp rates)
2. Ability to assist with system frequency control
3. Reactive power control
4. Ability to assist with system voltage control
5. Fault ride through capability
6. Frequency tolerance
7. Voltage tolerance
8. Negative phase sequence withstand
9. Information provision – plant data and operational monitoring
10. Power system stabilisation
11. Provision of inertia

GH is currently not aware of anywhere in North America or the rest of the world where the last two items (10 and 11) are currently required of wind plant, but as noted in the preceding sections these have been and continue to be considerations, and may become requirements in some areas in the future. GH therefore recommends that these are noted but not taken forward at present in Canada unless a clear and specific need for them is found.

Further to the above list, each requirement will be subdivided into more detailed and prescriptive requirements. GH anticipates that these detailed requirements will largely be discussed and implemented through the procedural recommendations in Section 5 of this report. GH does however provide some commentary for guidance on these details within Section 4. As an example the following items can be derived from Requirement 2 – Reactive Power Control, most of which regard minimum requirements:

- Reactive capability (leading and lagging) at full MW output.
- Reactive capability at reduced MW output to zero.
- Reactive capability according to voltage at the connection point.
- Reactive capability across system frequency range.
- Speed of response in providing/adjusting reactive power.
- Minimum allowable granularity in reactive capability (i.e. the extent to which it can be stepped or should be continuous).

There will also be requirements on reactive power control which are derived from the other requirements, notably voltage control and to a lesser extent fault ride through.

These key requirements will be taken forward with the findings of the next Section in developing a Base Grid Code for Canada in Section 4.

The following section discusses the current state of development of interconnection requirements for wind plant in Canada and relevant parts of the US.

3. NORTH AMERICAN GRID CODE DEVELOPMENTS

3.1 Introduction

Historically wind has enjoyed a position where it has been able to generate freely when the resource has been available with very little liability to the ongoing operation of the grid it has been connected to. This has been the case since wind penetrations have been small, connections have been to the distribution networks, and the effects on the wider transmission system largely irrelevant. As penetration of wind in various networks has grown concern over its effects has also grown. In 1999 both Eltra (the transmission system operator for Western Denmark) and E.ON Netz (a major German transmission system operator) both introduced specific interconnection requirements for wind derived directly from their respective Grid Codes for larger transmission connected traditional plant (thermal, hydro and nuclear). Since that time other transmission system operators have also started to introduce such requirements as wind penetration has either become significant or has been seen as likely to become so. The rapid changes in this area are illustrated by the fact that Eltra has developed its views significantly since the first requirements were issued: the latest version of its requirements for wind generation were issued in November and December 2004 [2.8].

The purpose of this section of the report is to reveal the current state of development of the various ongoing workstreams throughout Canada in respect of Grid Codes for wind. This is clearly important, as to bring the various workstreams together this report must appreciate the differing stages each province is at, the likely timescales being worked to, and the nuances of each province. This section therefore provides a province by province brief on the following:

- An outline of the electricity industry structure.
- A description of the generation mix.
- Interconnections and their use.
- Market issues.
- Reliability organisation affiliation and issues.
- The current uptake of wind and future proposals.
- The extent to which the system operator has studied wind integration and developed Grid Code requirements.
- Specific system technical issues.
- Main participants in developing wind integration requirements and the willingness of each system operator to become involved with CanWEA’s proposals for a Canada-wide Grid Code.

In addition to the Canadian provinces, this section will also comment on requirements developed by US organisations AWEA, FERC, and NERC.

3.2 Canadian overview

Canadian electricity industries have developed along provincial lines. There is limited progress to deregulation and restructured "open" markets with Ontario and Alberta furthest ahead in this respect (unbundling vertically integrated utilities). Those utilities with large hydro reserves have typically tended to use this to earn export revenue (passed through to consumers as these are mostly "Crown Corporations").

In Canada, hydroelectric production is concentrated in British Columbia, Manitoba, Québec, Newfoundland and Labrador. Generation in Alberta, Saskatchewan, Ontario, the Maritime Provinces, and the Territories is largely thermal-based. There is a significant component of nuclear generation in Ontario and New Brunswick, while natural gas-fired generation, as stand-alone facilities or part of a cogeneration process, is becoming more common in most regions. An overview of the Canadian generation mix by province is presented in Figure 3.1. Some key points are:

- Generation supply is adequate till 2006 but will start to become an issue in many provinces from 2007.
- Renewables will become an important contributor to supply adequacy and environmental objectives in the future. Growth in alternative and renewable resources, particularly wind, is accelerating. The drivers include the establishment of regional renewable portfolio standards, incentives such as the federal Wind Power Production Incentive (WPPI), the coming into force of the Kyoto Protocol and the general desire for clean air.
- There is an upward pressure on electricity prices in all provinces.
- Uncertainty due to market restructuring and other variables is present in most provinces.
- Uncertainty with hydro reserves is probably increasing as there is evidence rainfall may be decreasing or is becoming less certain.
- North-south electricity trade with the US is important (Canada is a net exporter) but there is a growing awareness of the benefits that inter-province connections and trade can bring.
- There is evidence of some degree of inter-province interchanges taking advantage of hydro to provide to provinces dominated by more traditional thermal plant, and vice versa during drought years. Interchanges between provinces, and between provinces and the US is shown in Figure 3.2.

A good overview of Canadian electricity markets is presented in [3.14].

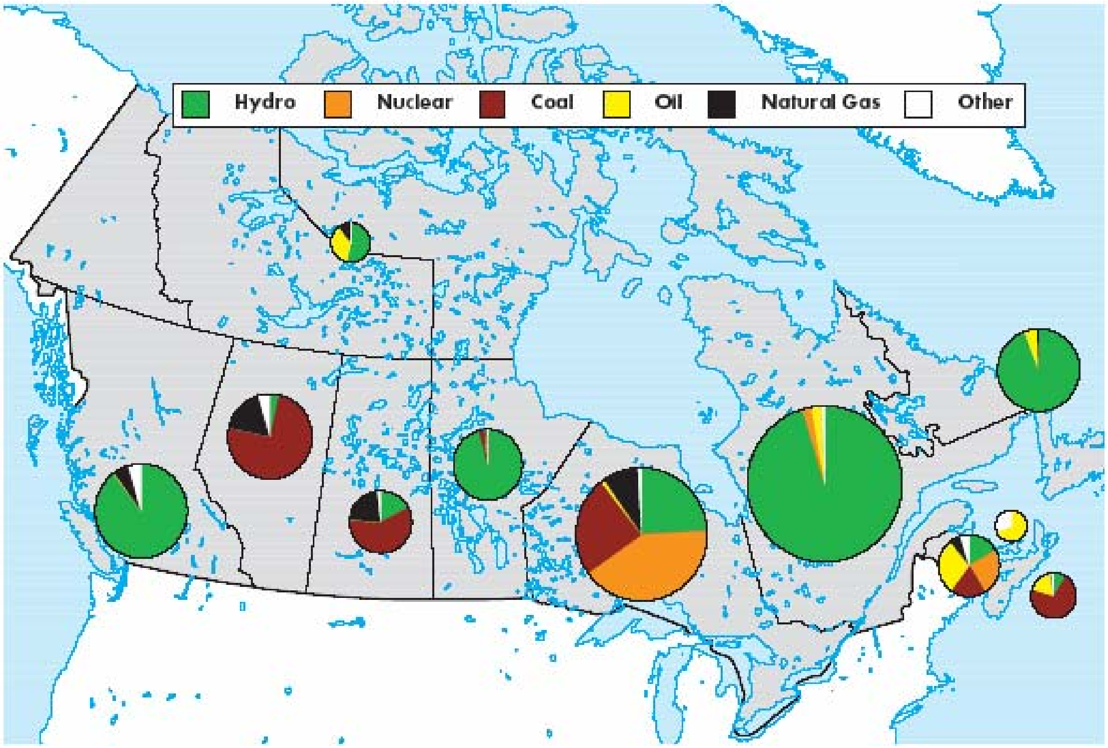


Figure 3.1: Canadian generation mix by province [3.14]

Figure 3.2: Canadian energy exchanges [GWh] [3.14]

Transmission constraints are becoming more prevalent. Furthermore, in the wake of the 14 August 2003 blackout, reliability of the interconnected North American bulk power system has become a priority concern. The Final Report of the Canada-U.S. Task Force [3.10] outlined 46 recommendations to improve overall reliability and called for the establishment of mandatory reliability standards. A number of recommendations have been implemented. The proposed creation of an Electric Reliability Organization (ERO) to administer mandatory reliability standards is still awaiting legislation in the U.S. to be passed and implemented. The ERO will replace the current North American Electric Reliability Council (NERC) which administers the current system of voluntary standards to which a number of Canadian provinces subscribe. NERC oversees a number of smaller regional reliability organizations relevant to individual provinces. The other large US electrical reliability organization relevant to Canada is FERC. A useful overview of reliability and associated issues for Canada is presented in [3.15]

3.3 Developments in Canadian Provinces

3.3.1 British Columbia

British Columbia is a hydro dominated province (84% by capacity) with a vertically integrated utility (BC Hydro) with BC Transmission Corporation as the system operator. BC Utilities Commission has a regulatory role. The wholesale market is open to independent power producers to participate. BC is interconnected to Alberta in the east and to the Pacific North West (US) in the south, and trades largely with the US including California as part of the Pacific North West system. BC also trades with Alberta using its Hydro to provide peaking power, but also importing cheaper "baseload" power from Alberta.

Plans to further interconnect both mainland BC and Vancouver Island to the US via subsea cables, the "San Juan" interconnector cables are being progressed and this would strengthen the BC grid system and allow increased trade with the US [3.16].

BCTC is a member of the Western Electricity Co-ordinating Council (WECC) and NERC, by virtue of its interconnections to the US, and WECC standards are applied. BCTC is also a member of the Northwest Power Pool which coordinates regional contingency reserve sharing.

Concerns exist over generation adequacy in the near future although it is anticipated that any shortfalls can be accommodated through imports on BC's interconnections.

BC has set a target for 50% of new generation to come from clean energy sources but to date has only accepted a single 50MW wind farm proposal, which subsequently fell through. GH understands that there may be a call for renewables capacity later this year.

There is a very large wind resource. In particular the Peace River region has existing transmission infrastructure, a good wind resource, and existing hydro generation. BC Hydro has issued a policy "white paper" [3.18] regarding its targets.

BCTC has already commissioned studies on wind power integration [3.1] [3.2] although as yet has not developed a separate set of requirements for the interconnection of wind farms. BCTC, as with other provinces, does have an existing Grid Code [3.3].

In discussions with GH, BCTC identified the issues in the ABB reports and also highlighted concerns over wind turbine simulation models in regards to their accuracy and the ease with which manufacturers can change control systems making models outdated.

BCTC considered a forum to discuss the issues of interconnection would be useful but noted that they would wish to avoid various groups working on the same area, i.e. that there is a need for a primary focus group. BCTC also noted that requirements tend to be led by the individual provinces.

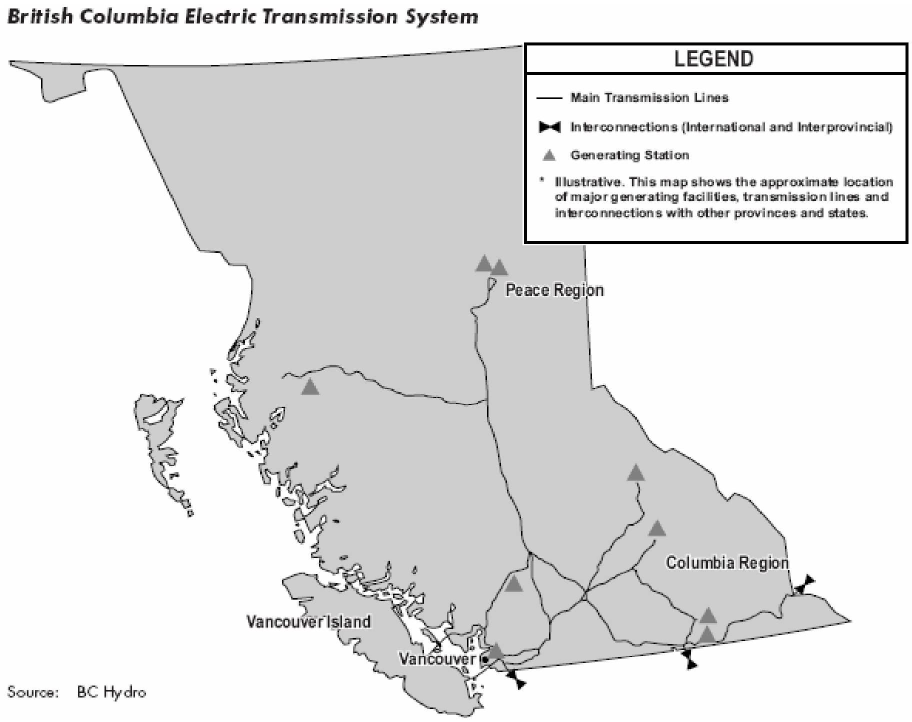


Figure 3.3: British Columbia Transmission System Schematic [3.14]

3.3.2 Alberta

Alberta, along with Ontario, is the province with the most deregulated electricity market in Canada. Transmission and distribution are regulated monopolies with Alberta Electric System Operator (AESO) responsible for the system. The province runs a competitive market dominated by coal and gas. Alberta Energy and Utilities Board (EUB) perform a degree of regulation. The market is currently being restructured by Department of Energy who hope to address a number of issues including the increased uptake of wind and concerns over generation adequacy which may start to become an issue as of 2007.

Alberta is aiming for 3.5% of total electricity supply from new renewable sources by 2008, most of which will be wind. Alberta currently has 272MW of operational wind with plans for over 500MW in progress which would have a significant impact on the system. The first merchant wind plant is now under way.

The market restructuring may bring a forecasting requirement (likely to be 1-2 hours ahead) and market imbalance penalties to wind generators and this will necessitate operational monitoring at wind farms. AESO is currently assessing the impact of “wind variability” to form a view on balancing issues with increasing wind and forecasting requirements and this will affect the market restructuring.

Alberta is interconnected with BC in the west and Saskatchewan to the east. Alberta plans to upgrade the interconnection with BC to further take advantage of respective peak hydro supply from BC and offloading surplus cheap thermal generation during off-peak periods. An interconnection to the US will also soon be in place. Alberta currently also trades with the US Pacific North West via BC and would like to further develop this trading.

Alberta is a member of WECC/NERC by virtue of its interconnection to BC and trade with the US. The AESO’s current planning criteria align with WECC’s standards for guidance while considering provincial needs.

Due to ageing transmission assets, continued load growth and concerns over generation adequacy and system capabilities AESO has issued a “10 Year Transmission Plan” [3.4] outlining a widespread set of reinforcements and additions to the Alberta transmission system.

Alberta has developed additional supply that includes wind, biomass and small hydro. A number of factors encourage the development of wind generation in the southern part of the province. These include alleviating transmission constraints in south west Alberta as outlined in the plan and recently approved by the regulatory EUB, the quadrupling of the federally-funded Wind Power Production Incentive (WPPI), retail products that provide green energy at a premium, and the value of renewables in response to climate change initiatives.

AESO has conducted studies on wind integration [3.5] [3.6] [3.7] and subsequently introduced a wind Grid Code [3.8]. As noted above, AESO is currently conducting a “wind variability” study [2.34] to form a view on whether and how forecasting requirements will be implemented. Alberta’s Grid Code notes that requirements may be added or changed as required by NERC or WECC. As noted above, AESO is currently conducting a “wind variability” study to form a view on whether and how forecasting or other requirements will be implemented and whether the Grid Code needs adjustment. At time of writing, the initial variability studies had been completed but the impact on the system and subsequent requirements had not. The Alberta Grid Code is discussed along with other provincial interconnection requirements in Section 4.

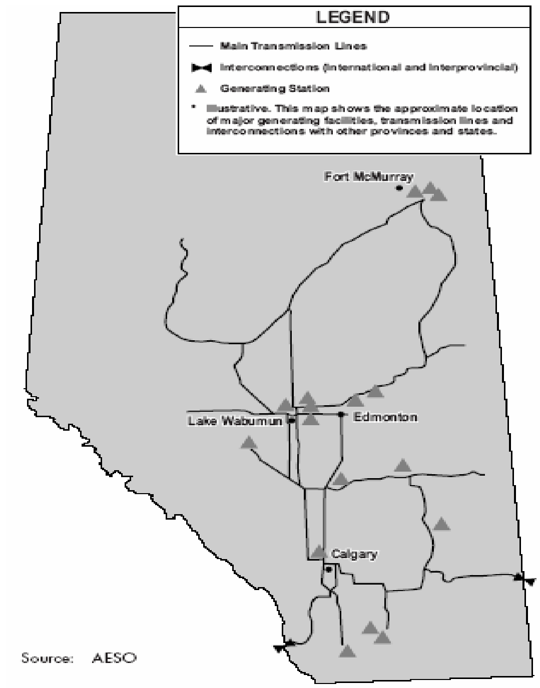


Figure 3.4: Alberta transmission system [3.14]

3.3.3 Saskatchewan

Saskatchewan is a coal dominated market (50%) with most of the other generation from gas (25%) and hydro (25%) all by capacity. The province is interconnected with Alberta in the west, Manitoba in the east and the US to the south. Saskpower (and subsidiary Northpoint Energy Solutions) is the dominant vertically integrated utility, retains control of transmission system operation, and has strong environmental targets.

The province currently has a target for 5% of electricity to come from wind energy which amounts to about 200MW. Support for renewables is present via a “Green Power Portfolio” of “Environmentally Preferred Power”. Qualifying projects must sell all energy to Saskpower.

Saskatchewan currently has 22MW of operational wind plus the Centennial Wind Farm, a 150MW project, the biggest in Canada, under development in the south west of the Province. SaskPower currently has a call for 45 MW of renewables.

Saskpower has commissioned wind integration studies but these are not yet in the public domain and there are no actions resulting from them as yet.

Saskpower is a member of NERC and the Midwest Reliability Organization (MRO). SaskPower has decided to formally adopt NERC standards, and to maintain its ability to trade in the U.S., SaskPower has complied with FERC requirements for open access.

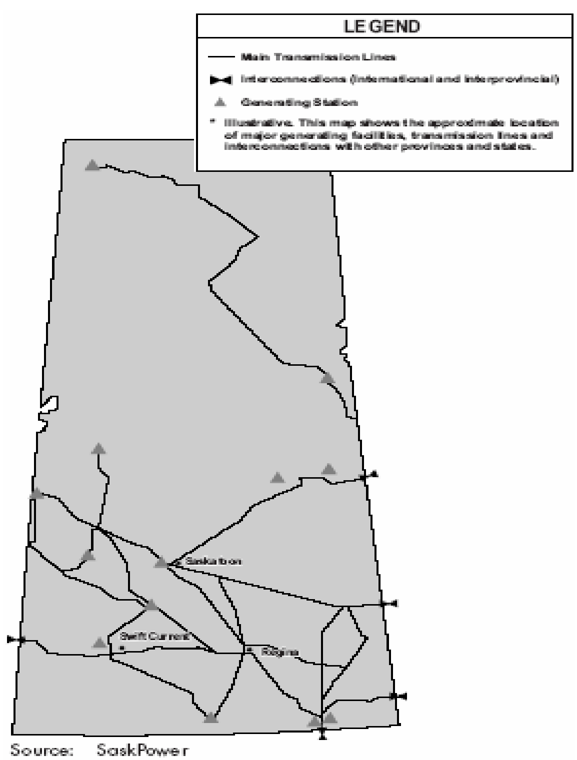


Figure 3.5: Saskatchewan transmission system [3.14]

3.3.4 Manitoba

Manitoba is a hydro dominated province (over 90% by capacity) with plans to construct further new hydro plant. Significant hydro generation is located in the north away from the main load centres meaning large bulk power transports from north to south. Manitoba Hydro is entirely dominant and is a vertically integrated utility also operating the transmission system.

Manitoba is connected to Saskatchewan to the west, Ontario in the east, and the US to the south. Manitoba is usually a net exporter (30% of generation) and has a strong position as a supplier of green power. Most export is currently to the US, although there are plans for a significant increase of green power export to Ontario which may involve at some point new hydro capacity specifically to serve Ontario. Like most other hydro dominated provinces, and despite the current “over-capacity”, Manitoba has needed to import in recent times during abnormally dry years.

Manitoba Hydro retains control of its system but due to US trades must coordinate with the Midwest Independent System Operator in US which is “merging” with PJM to form a single market. This requires participation in day ahead and real time US markets. Manitoba Hydro is also a member of NERC and the Midwest Reliability Organization and therefore complies with NERC planning and operating standards.

Despite plenty of green hydro capacity the Department of Energy has a mandate to develop the province’s natural resources including wind. Manitoba recognizes wind hydro integration benefits (flexibility of hydro) and a privately developed and owned project, the St-Leon Wind Farm at around 100MW capacity is being progressed in the south west with the output to be sold to Manitoba Hydro. Provincial targets are for 1000MW of wind in the period 2009-2014. Manitoba Hydro currently has 2300MW of wind in its generator connection queue which is greater than 50% if the peak load.

Manitoba Hydro has concerns over wind hydro integration and has made studies although these are aimed at specific projects rather than a general assessment of integration. During discussions between Manitoba Hydro and GH, Manitoba Hydro raised the following issues:

- Large dynamic over-voltages occur on the system requiring an over-voltage tolerance, noted as beyond 120%. It is worth noting that Hydro Québec already sets out over-voltage requirements beyond the common +/10%.
- Low temperature operation. Manitoba Hydro is concerned that wind turbines cannot continue to operate in the low temperatures seen even with “cold weather additions”. This was noted as typically an issue below -30^{0}C, and likely to be coincident with system peak (winter) loads. Other Canadian system operators have noted this issue although GH does not view this as relevant to the CanWEA Base Code.
- Frequency tolerance was noted as being necessary.
- Frequency response at timescales under 30s is considered an issue for high wind penetration in Manitoba and hence is anticipated to become a requirement at some point. The ability to operate in situations where the province is islanded was also noted.
- Power control was noted as an issue primarily to avoid congestion, although it was noted that inter-tripping also offers a solution without the need for power control.
- Manitoba Hydro also identified LVRT and voltage control as general issues, along with load following, and forecasting.

Manitoba's market places no additional requirements on wind beyond the technical set defined by Manitoba Hydro.

Manitoba Hydro declined an interest to work with CanWEA in taking the work forward considering a Canada-wide Grid Code for wind as unnecessary, but identified a number of existing forums including:

- Existing Canadian Grid Codes.
- NERC.
- AWEA and UWIG.
- Various IEEE and CIGRE groups.

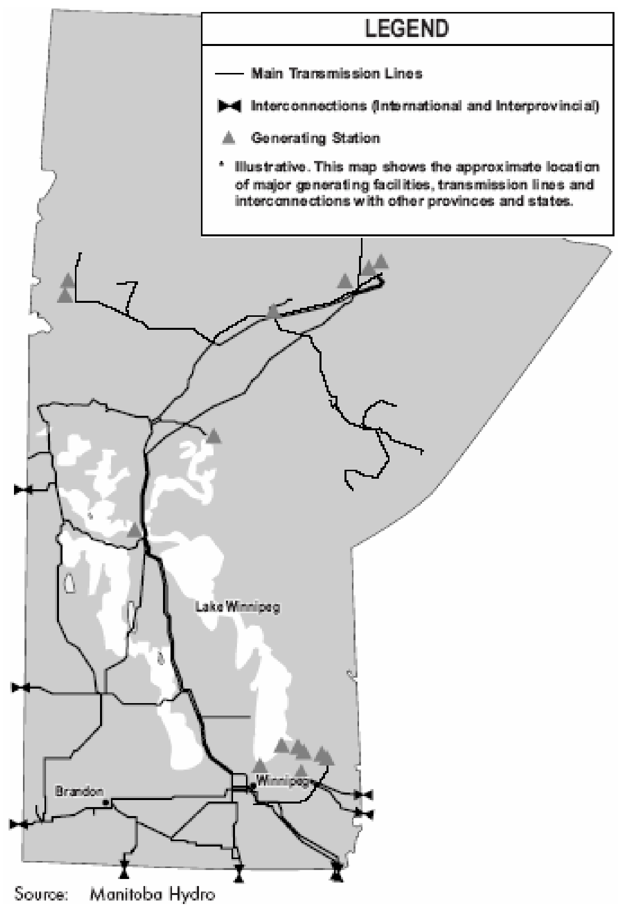


Figure 3.6: Manitoba transmission system [3.14]

3.3.5 Ontario

Ontario's generation is a mix with nuclear providing 41% of electrical energy followed by coal and hydro supplying most of the rest, but coal is to be phased out by 2007 for environmental and health reasons. A recent series of Requests For Proposals (RFPs) has been progressed to contract new generation to ensure supply adequacy – this includes a 350 MW wind RFP in 2004 followed by release of a further RFP for 1000 MW of wind in spring 2005. Ontario currently has a 10% renewable capacity target for 2010. Ontario currently has 15 MW of operational wind plus over another 250 MW under development.

Interconnections with neighbouring provinces and US states allow Ontario to engage in trade, optimize the utilization of generation, and enhance the reliability of the Ontario power system. The largest transfer capabilities are with Michigan, New York and Québec, followed by Manitoba and Minnesota.

Most of Ontario's electricity trade is with Michigan (mainly imports) and New York (mainly exports) where Ontario takes advantage of US price differentials. Sales to Québec have risen in recent years despite the fact that Hydro-Québec energy is less expensive than Ontario's. The increased sales reflect purchases of off-peak energy from Ontario, allowing Québec, and to a lesser extent Manitoba, to save water behind their dams and sell in U.S. markets when prices are high.

Ontario is a member of the Northeast Power Coordinating Council (NPCC)/NERC. The IESO is responsible for ensuring compliance with NPCC standards and although the standards are voluntary, they are mandatory in Ontario and a condition of market participation.

There is some supply uncertainty beyond 2007 and new imports from new hydro in Manitoba or imports from Newfoundland and Labrador may assist, else Ontario may need to import more from the US. An ongoing RFP and refurbishment process will also assist. The drive for (low cost) green power is also one of the drivers resulting in plans to boost imports from Manitoba, possibly with new hydro capacity specifically built in Manitoba to supply Ontario.

Along with Alberta, Ontario has progressed the furthest to a deregulated electricity market with separated electricity industry functions. The Ontario market is the most complicated Canadian market with tiered and capped price structures operating in a "hybrid" deregulated market in generation and supply. The market can be explained as follows:

To increase the competitive aspect of Ontario's electricity market following the initial restructuring, the incumbent vertically integrated utility Ontario Hydro was unbundled into a number of separate entities:

- Ontario Power Generation (OPG) owns and operates all fossil-fuelled and most of the hydro generating stations that were formerly owned by Ontario Hydro, as well as the Pickering A, Pickering B and Darlington nuclear plants, for a total of 75 percent of the installed generating capacity in the province. Bruce Power Limited Partnership is the licensed operator of the Bruce A and Bruce B nuclear generating stations.

- Hydro One owns and operates 97 percent of the provincial transmission lines, and most rural distribution lines. Since restructuring, Hydro One has acquired 88 of the

180 smaller municipal utilities in Ontario, making it the largest electric distribution company in the province. Toronto Hydro, which serves about 20 percent of the province, is the next largest distributor.

- The Independent Electricity System Operator (IESO), formerly the Independent Market Operator, directs the operation of Ontario's bulk power system, ensuring that the system is operated reliably, runs the wholesale electricity market and is responsible for shorter term electricity supply forecasting.

- The recently formed Ontario Power Authority (OPA) is responsible for ensuring adequate long-term electricity supply and contracting for new generation (including wind) through an RFP process.

The Ontario Energy Board (OEB) has regulatory oversight of the IESO and other market participants, including generators, distributors, retailers, transmission companies and wholesale power consumers.

A recent study of wind integration for Ontario [3.11] showed that at least 2,000 MW of wind generation should be readily manageable on the Ontario system (maximum demand around 20,000 MW), despite poor correlation between diurnal wind and demand curves.

IESO has a set of requirements for wind generation connecting to the transmission system [3.9] and these are reviewed in more detail in Section 4 of this report. GH is aware that wind projects connecting to the IESO grid in Ontario must undertake detailed system impact studies, the results of which set out requirements for connection and include all common aspects of Grid Code compliance such as Low Voltage Ride Through, reactive power and voltage control, and other items.

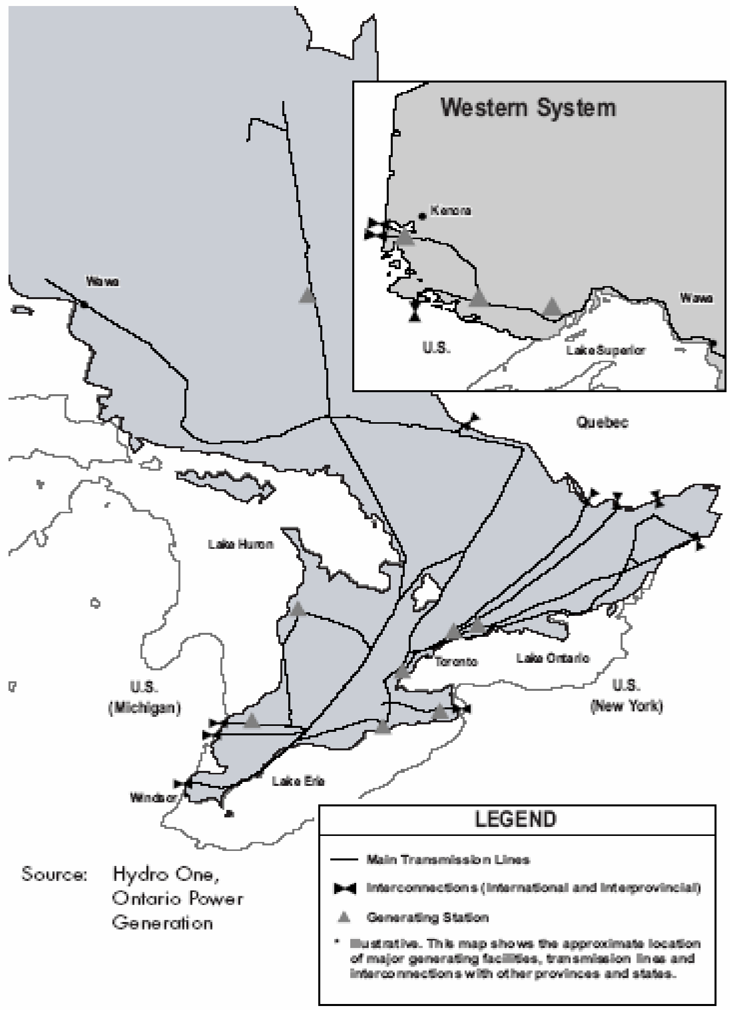


Figure 3.7: Ontario transmission system [3.14]

3.3.6 Québec

Québec constitutes Canada’s largest electricity market and largest power exporter although exports have declined with recent drier years and increasing home demand. Hydro generation is dominant (93% by capacity) and still being built with significant hydro generation in the far north remote from the load centers in the south meaning large bulk power transfers from north to south over distances in the order of 1000km. This has led to the development of a 735kV transmission system.

Québec is interconnected to Ontario, Labrador, New Brunswick, and the north eastern US although not synchronized with these systems.

The market is not greatly deregulated and Hydro-Québec is the dominant utility but consists of unbundled divisions, with HQ TransÉnergie operating and administering the transmission grid.

HQ TransÉnergie is a full member of NERC and NPCC and participates in standards setting. According to a recent audit by NERC, HQ TransÉnergie sets standards in line with NPCC/NERC requirements and in some cases more stringent. This is reflected in the interconnection requirements set out for wind which are discussed in detail in the next section of this report.

The market is fixed so that distribution (and supply) must purchase from Hydro-Québec’s generation up to a certain cap which currently constitutes the complete market. In 2005 it is expected that this cap will be exceeded and distribution will be required to purchase power from other suppliers.

HQ Distribution contracted 990MW of wind in 2003 which will be built over the coming years. A second RFP for 2000MW has already been issued. Québec currently has 212MW of wind in place. The low cost hydro means wind costs are relatively expensive at just over double hydro costs. Provincial government has instructed Hydro Québec to achieve 2000MW of wind by 2013.

Hydro-Québec has studied the integration of wind and developed a set of detailed technical requirements. Along with Alberta and Ontario, HQ is the only system operator in Canada to have progressed this far in developing interconnection requirements for wind.

The government of Québec recently funded a study to consider the capacity of the HQ system to integrate new wind developments [3.12]. The study did not include detailed load-flow or dynamic analysis of the HQ system, but instead looked in detail at the existing system, by geographical area, to identify issues which could limit integration of wind energy.

The main findings were:

- New generation outside the metropolitan areas in the extreme south is limited to around 2,000 MW. Beyond that, reinforcement of the major north-south transmission lines (735 kV) becomes necessary.
- A new 735 kV transmission line in parallel with parts of the existing system would release approximately a further 3,000 MW of new wind capacity.
- The total capacity of new generation anywhere in the system is limited to approximately 3,600 MW (i.e. around 10% of maximum demand) by the conditions during low-demand periods. This is particularly limiting in the Québec case due to the relatively large

amount of generation which is classed as 'must run', either because it is needed for the stability of the extensive transmission system, or because it is run-of-river hydro. New generation above this total is feasible but must expect to be constrained during low-demand periods.

Hydro Québec TransEnergie has put interconnection requirements for wind projects in place since 2003, and these were recently updated and extended in December 2004. The requirements also extend to projects that are distribution connected. The interconnection requirements are reviewed in more detail in Section 4.

GH has contacted Hydro Québec TransEnergie to discuss the CanWEA Base Code work and Hydro Québec TransEnergie are prepared to be involved in further progression of this work.

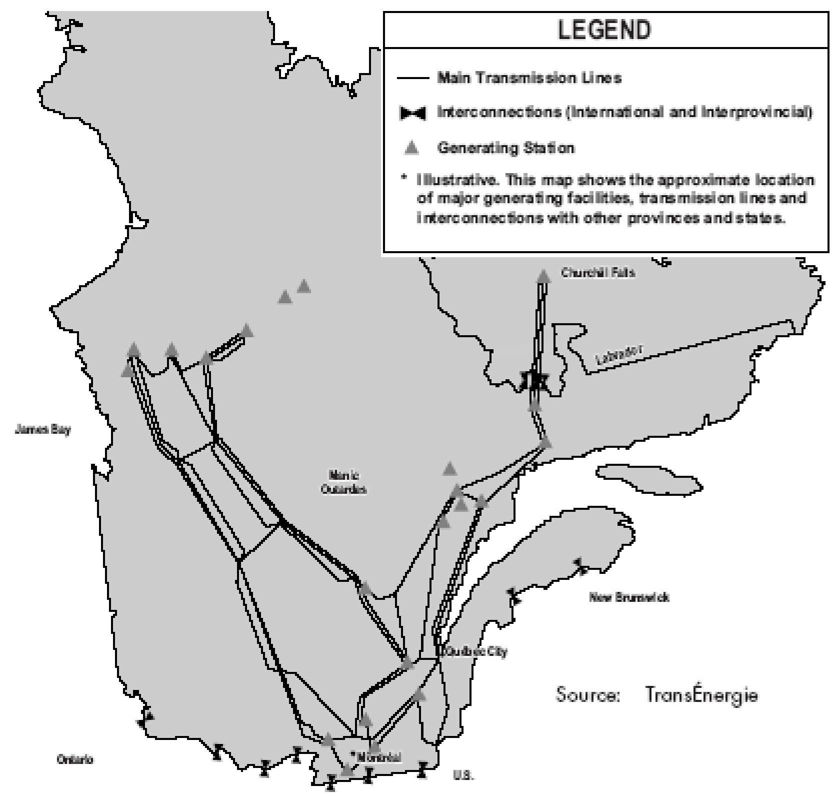


Figure 3.8: Québec's transmission system [3.14]

3.3.7 New Brunswick

Generation in New Brunswick is mixed with roughly 40% oil, 20% hydro, 15% nuclear with the rest mainly coal and gas by capacity. The electricity industry is partly separated and regulated with New Brunswick System Operator controlling the transmission grid. There is a possibility that a "Maritimes" market may be created in the future and this may well result in NBSO become the Independent System Operator. The New Brunswick market has been opened to competition and operates on bilateral contracts.

The nuclear energy is supplied by one station (25% of the energy supplied) and this may close. This is an important issue for New Brunswick as this would represent a very severe depletion in generation capacity.

Two HVDC interconnections link the province with Québec, while the province is also connected to Prince Edward Island, Nova Scotia, New England and Maine through AC interconnections. A new 345kV interconnection to New England is targeted for 2007.

NB Power is a voting member of the NPCC/NERC, and participates in its standard setting process and adheres to NPCC reliability standards. NBSO is currently undergoing certification by NERC to become the reliability coordinator for the Maritimes region. This implies that any reliability standards adopted by NERC will be passed through to the Maritimes provinces (New Brunswick, Nova Scotia, Prince Edward Island, and Northern Maine of the US) and thus it is likely that these provinces will need to adopt the AWEA interconnection requirements as a minimum standard for interconnections at 69kV and above in the near future. NBSO is also a member of NPCC but NBSO does not anticipate that this will affect wind beyond the requirements of NERC.

There is no wind connected at present but there is interest in contracting wind through an RFP process. Recently an RFP for 40 MW per year for 10 years was issued. A 20 MW wind project on Grand Manan Island has recently gained a power purchase agreement. NBSO comments that the 345kV ring around the province, see Figure 3.9 gives the transmission system a high degree of reliability and allows new generation such as wind good flexibility in terms of location. Most of New Brunswick's best wind resource is located along the coastal areas where access to the grid is more likely to be via 69kV radial systems and hence NBSO foresees voltage regulation as a likely key issue requiring assistance from wind farms. NBSO also raises concerns over regulation and load following (and the additional costs therein) should the penetration of wind become "significant".

NBSO is currently working on a study of wind integration in the Maritimes region. The study is concerned with the potential capacity contribution of wind and the impact of increasing levels of wind on load variability (load following and balancing). The study is expected to become available during late summer 2005, but may not be in the public domain. NBSO does not at present have plans for further studies.

NBSO does not at present have any specific wind interconnection requirements, but rather identifies any requirements through the System Impact Study as is common in other provinces.

NBSO intends to support the AWEA/FERC interconnection guidelines but has not, at present, adopted them. NBSO is supportive of the development of a Canada wide set of interconnection requirements and intends to take part in CanWEA's initiative.

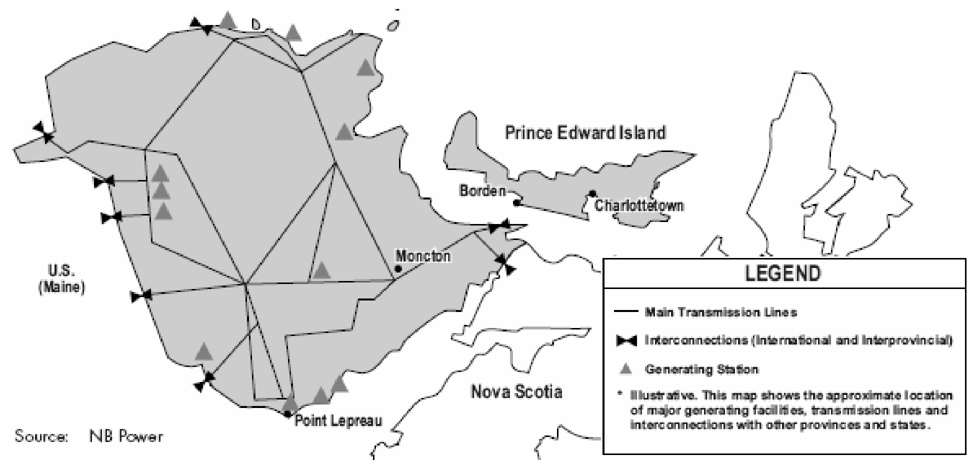


Figure 3.9: New Brunswick transmission system [3.14]

3.3.8 Prince Edward Island

Prince Edward Island lies off the New Brunswick coast and relies on New Brunswick to supply electricity via two 138kV submarine cables with 200MW total capacity. There are concerns over the future adequacy of this link, particularly in the case of a single cable failure. To ensure future demands can be met Maritime Electric has just installed a 50MW gas plant which should cover energy needs on the island for the next 10 years. The Maritime Electric Company Ltd is the main utility and is regulated. The rest of the "on-island" generation is oil fired although it is only used in emergency situations as it is expensive.

Prince Edward Island has 14MW of wind power in operation and a proactive policy to develop wind to diversify supply. Targets are 15% renewable supply for 2010 by 40MW wind, and it is examining options for 100% renewable supply by 2015 although this would likely need to involve both on-island wind generation and imports of green power from New Brunswick.

Maritime Electric is currently undertaking some study work on the integration of wind and these are largely steady state loadflow studies. Nothing is in the public domain however. Any requirements on wind projects are currently determined from the System Impact Studies but are at present limited to relatively simple items. Maritime Electric has a number of concerns with wind integration:

- Voltage regulation is the main concern. This is a particular concern since most of the good wind resource is on the extremities of the system and the connection of wind generation leads to high system voltages. Maritime Electric is therefore at present asking wind to consume reactive power to assist in maintaining voltages within limits.
- Variability. Maritime Electric presently provides schedules to New Brunswick regarding its import requirements. Deviations in these are charged and hence wind variability is a concern. Maritime Electric currently receives forecasts from wind generators and passes some penalty through to them for "imbalance".
- Low voltage ride through is also a concern although at present the on-island wind is required to disconnect during system disturbances. Maritime Electric is concerned that with higher penetrations of wind sudden disconnections will result in instability so low voltage ride through may be implemented on future projects.

The market place requires forecasts are provided by wind generators and Maritime Electric make use of the energy metering for allocating imbalance penalties.

The province is not a member of NERC although Maritime Electric does provide information and is represented within NERC by New Brunswick. Hence any NERC requirements are passed through via New Brunswick.

Maritime Electric Company Ltd is supportive of CanWEA's work and considers some form of industry group a suitable way to take the work forward across Canada.

3.3.9 Nova Scotia

Nova Scotia is another smaller Maritimes market. Coal is dominant at about 43% capacity with oil and gas (25%) and hydro (17%).

Nova Scotia is interconnected to New Brunswick. The province is part of the NPCC control area, and therefore NERC rules are applied. NSP points out that recent moves in the US to make reliability requirements mandatory present a legal problem for Canadian provinces, as there is no equivalent mechanism for imposing mandatory requirements. It is possible that the association of public utility regulators may reach agreement with NERC on this issue.

Nova Scotia Power Inc (NSP) is the dominant vertically integrated utility and is regulated by the Nova Scotia Public Utility and Review Board. There are no firm plans to appoint an ISO. Currently generators can sell only to NSP, but an Open Access tariff is due to be introduced late in 2005, which will allow generators to use the transmission system to sell to others, including municipal utilities.

A mandatory Renewable Portfolio Standard is to be established to foster renewable development. 31 MW of wind was contracted in 2004 and built in 2005 with contracts in progress for about double this. A target of 5% renewable supply by 2010 has been set which will require approximately 100 MW of wind.

The regulator is most likely to issue RFP for further new generation as and if seen necessary.

The major issues foreseen by NSP relate to the limited interconnection capacity to other systems. Under some circumstances this can be limited to 1000 MW. The situation during low demand periods is also a concern. It is likely that this will restrict wind generation, i.e. some form of curtailment may be necessary in these circumstances.

The existing thermal generation on the system has limited load-following capability, and some units require 12 hours notice to start.

LVRT is also important, as the system is vulnerable to disturbances due to faults.

Voltage control was also raised. At present NSP are not sure if fast voltage control is needed, or if mechanically switched capacitor banks are adequate. It is possible that fast control could be justified in the east of the Province, but not elsewhere.

Voltage flicker is also a concern, as much of the interest in wind project development is in areas with relatively weak radial 69 kV lines. Flicker has been an issue for the first wind farm in the Province.

The issues of concern for Nova Scotia which are relevant to this work are therefore:

- the ability to curtail wind generation in certain circumstances
- LVRT
- voltage control
- flicker.

Currently NSP's technical requirements are set out in generic documents, depending on project size and voltage level.

No detailed wind integration studies have yet been carried out. NSP has followed the work of the Alberta studies closely. NSP mentioned a study that has been carried out by NBSO for the energy ministers of the Atlantic Provinces. This appears to be the same study referred to for New Brunswick above. It is not yet published, but is understood to consider the following issues:

- hourly variations and load-following;
- generation adequacy studies.

NSP are keen to be involved in development of a Canadian grid code for wind generation.

NSP suggested that the Canadian Electricity Association (CEA) may be an appropriate forum for carrying forward the work of developing a grid code for wind.

NSP also stated that it would be useful to develop a 'checklist' or similar for distribution-connected wind generation, in order to spread experience and avoid problems. In particular they pointed out that European turbine technology sometimes created problems for connection to North American systems. This is not strictly relevant for the scope of the current work, but may be worth consideration by CanWEA.

3.3.10 Newfoundland and Labrador

Newfoundland (Island) and Labrador operate two separate electric systems. Labrador is hydro dominated whilst Newfoundland is a mix of hydro and oil. Newfoundland and Labrador Hydro owns and operates most of the generation and transmission, but is regulated. Newfoundland Power buys most of the Hydro power and generates a further 10% itself for supply.

Labrador is interconnected to Québec, through which the 5,400MW Churchill Falls hydro in Labrador is a major exporter to Québec via a long term contract due to expire in 2041. There are some plans to expand the capability of Churchill Falls and the interconnection to provide more power to Québec. The transmission route from Churchill Falls to Québec's main load centres forms around 1000km of 735kV transmission system and is one of Québec's most important.

Newfoundland is an island system with no interconnections.

Labrador currently has a considerable generation surplus, although Newfoundland as an island is not in this position and a generation deficit is forecast for around 2010.

An RFP process is normal for contracting new generation. A small demonstration wind project exists on an island off Newfoundland. As Newfoundland is an island there are concerns over wind integration, notably regarding stability.

Neither utility is a member of NERC, nor are they subject to compliance with NERC standards.

3.3.11 Yukon, Nunavut and NW Territories

These are large sparsely populated Northern provinces with fragmented and islanded grids. The Yukon is hydro dominated (89% by capacity); NW Territories is split between hydro and diesel, whereas Nunavut is entirely local diesel supplied.

Yukon Energy Corporation and Yukon Electric Company Ltd are the relevant (vertically integrated) utilities and system operators. North West Power Corporation is the dominant (vertically integrated) utility in NW Territories, Nunavut Power Corporation in Nunavut. No market restructuring is likely as the markets are so small.

As the provinces are not interconnected to the US they are not members of NERC.

Wind in Yukon is less than 1 MW with no substantial installed capacity in the Northwest Territories or Nunavut. There is however strong interest throughout the territories, driven by high electricity costs.

These provinces are less relevant to CanWEA's Base Code as they are relatively small systems with special considerations.

3.4 US Developments and relation to Canada

Of particular relevance to Canada are FERC, the US Federal Energy Regulatory Commission, and NERC, the North American Electricity Reliability Council. Both impose requirements on Canadian provinces by virtue of their interconnection and trade with the US. FERC, in conjunction with AWEA, has recently developed and issued a set of requirements for interconnection of wind farms which has recently been accepted by NERC. The requirements are still in a consultative process with the current adoption timeframe likely to be early 2006.

3.4.1 NERC

NERC was formed in 1968 and has ten regional councils, comprising about 140 control areas in Canada and the U.S under its control. Figure 3.10 shows NERC's jurisdiction and the extent to which this includes Canadian provinces. NERC's stated mission "is to ensure that the bulk electric system in North America is reliable, adequate and secure." Toward that end, the organization develops planning standards and operating policies, which are the main methods it employs to achieve reliability. However, the standards and policies are currently voluntary, and are enforced by peer pressure. There are moves in the US to make these mandatory. NERC sets overall standards as a minimum, and its regional councils customize these to their unique circumstances, including local regulatory requirements.

Most Canadian provinces have utilized NERC standards, either through the utilities under provincial regulation or in provincial legislation. Ontario, for example, has legislation making these requirements mandatory and empowers the IESO, with regulatory oversight by the Ontario Energy Board (OEB), to levy financial penalties for non-compliance with standards. If the requirements become mandatory in the US, it is likely that a mechanism will have to be developed to make them also mandatory in Canadian systems synchronously connected to the US.

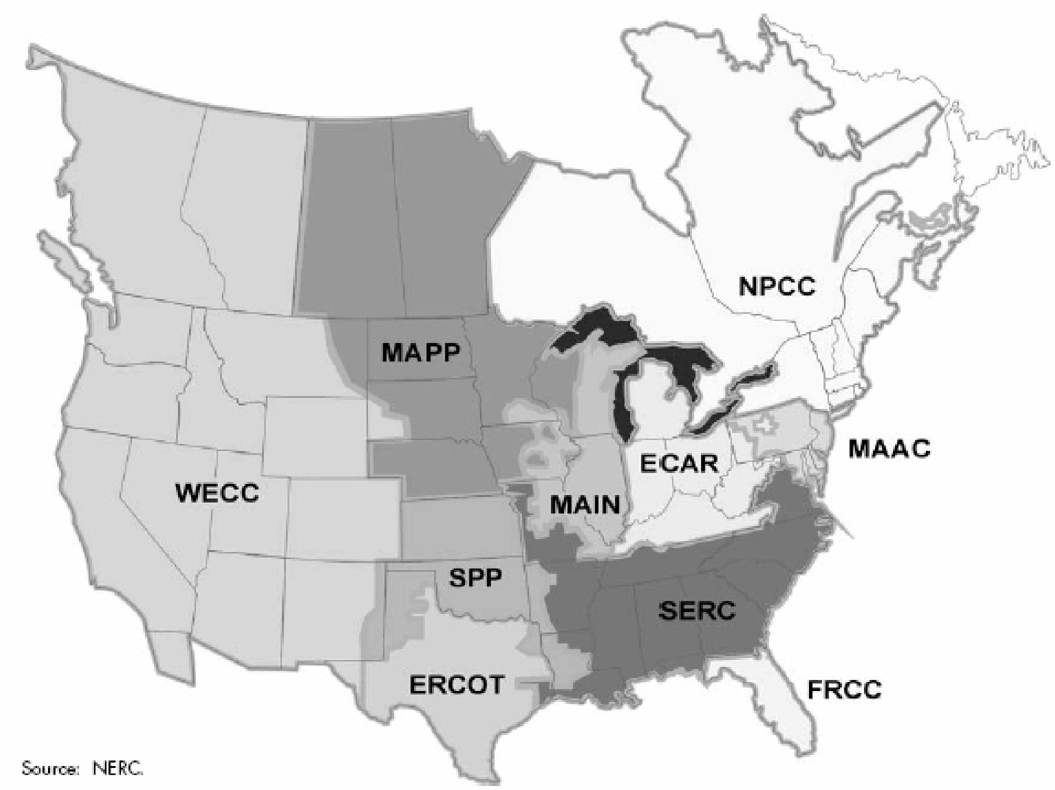


Figure 3.10: Regional reliability councils administered by NERC [3.15]

3.4.2 FERC

The Federal Energy Regulatory Commission [3.13] is the regulatory entity in the US that has jurisdiction over wholesale electricity transactions and interstate transmission (transfers of electric energy across state lines). The FERC answers to US Congress and receives its power to regulate and enforce through statutes enabled through legislation. The FERC is the ultimate authority in the US in determining the rules to implement the energy policy enacted through the legislative process.

The FERC is comprised of five commissioners who head up the agency and a staff to provide technical, legal and administrative support. The FERC regulates / operates by opening dockets where testimony is solicited and used to provide rulings based on factual evidence. The submittal of testimony by the parties is called a regulatory filing or just filing.

FERC’s responsibilities with respect to energy regulation differ from individual states’ powers. In general the states each have the power to regulate retail rates for electricity, intrastate transmission (transfers of energy within the states borders), setting and enforcement of service standards, and approval of planning of transmission and generation facilities.

3.4.3 AWEA Grid Code

AWEA proposed an interconnection standard and set of procedures for wind facilities of 20 MW and larger with FERC on May 20, 2004 [3.17], to be used by regulated transmission owners/operators for future requests for interconnection of wind farms. The Commission is using the Grid Code Filing to start a docket (RM02-1-005) to determine standard wind farm interconnection requirements for Open Access Transmission Tariffs (OATT) regulated by FERC. NERC has recently accepted the filing with some amendment and it is in process for full and final implementation around early 2006.

The key technical issues addressed in the AWEA Grid Code are:

- Low voltage ride through.
- Telecommunication capabilities.
- Power factor (0.95 lead to 0.95 lag).
- Turbine and system models for design studies.

If adopted as proposed by AWEA, the Grid Code Filing provides developers with an improved process for interconnection, and a uniform set of requirements known to all equipment vendors.

One important aspect is the proposed change in the interconnection study process which allows the option for the developer to study the initial feasibility of interconnection designs. The wind generator will be permitted to self-study the feasibility of interconnection and present the Transmission Provider with an electrical design and wind turbine/plant models that will be used for subsequent interconnection studies. The process described here will be a requirement for FERC-regulated transmission providers to adopt.

The other important aspects are that manufacturers of turbines will have a consistent set of requirements to design to, which are broadly in line with Europe, and that AWEA's proposals recognize that turbine models must go through a continual update and improvement process which the transmission system operators should take part in.

It should be noted however that the AWEA Grid Code defines a limited base set of requirements and it is GH's view that transmission system operators will invariably go beyond this base set in establishing their requirements. The current Alberta, Ontario and Québec Codes show that this is likely to be the case in Canada at least.

3.4.4 New York State recommendations

The New York State Energy Research and Development Authority (NYSERDA) and the NYISO commissioned work on the effect of possible new wind generation on the NYISO system [2.10]. The results included a recommendation that NYISO should require all new wind farms (except perhaps those below some defined size) to have the following features:

- voltage regulation at the Point of Interconnection;
- controllable power factor range (0.95 leading to 0.95 lagging power factor found to be satisfactory);
- Low Voltage Ride-Through;

- monitoring, metering and event recording;
- power curtailment capability.

These requirements are broadly the same as the AWEA Grid Code. The following were also recommended to be required as they become available;

- control of ramp rates;
- governor functions (i.e. frequency control);
- reserve functions (i.e. the ability to provide increased output in response to sudden loss of other generation);
- voltage regulation even when not generating.

3.5 Summary

Discussions with Canadian provincial utilities and system operators has revealed that most provinces have an interest in wind energy and its integration with the transmission system:

- In three provinces (Alberta, Ontario, and Québec) this has led to separate interconnection requirements for wind.
- Several other provinces have progressed studies on wind integration but not yet issued any specific interconnection guidelines for wind. These provinces are British Columbia, Saskwatchewan, Manitoba, and New Brunswick. Current interconnection requirements are defined through System Impact Studies and existing Grid Codes which probably need some interpretation for wind.
- Of the remaining provinces, Nova Scotia and Prince Edward Island have both expressed concerns with wind and a keen interest in CanWEA's Base Code.

Due to budget constraints and the nature of the transmission system GH has not spoken directly with North West Territories, Yukon, or Nanavut. Table 3.1 presents a summary of the position in each province with regards to wind interconnection requirements at transmission level. Given the ongoing developments, it is clear that time is of the essence.

Also apparent from Table 3.1 is the importance of the US and NERC. Virtually all provinces are a party to NERC and therefore must adopt NERC standards although this is currently voluntary. It will therefore be important for CanWEA to engage NERC in the process of developing and implementing its Base Code. As NERC has recently accepted AWEA's Grid Code (with some amendments) CanWEA's Base Code will need to encompass this.

Unlike NERC, no suitable existing Canadian forum has been identified for implementing the Base Code. CanWEA will therefore have to consider convening its own forum in Canada, possibly in parallel with NERC.

From a technical perspective, the issues identified in the provinces largely follow those identified in Section 2 of this report and listed in section 2.4. The review conducted in this Section is thus supportive of that of Section 2 and the same issues will be carried forward to form a CanWEA Base Code.

Province	ISO or relevant utility	Wind integration Studies	Specific wind interconnection requirements	Relevant affiliations
British Columbia	BCTC	Completed	None	NERC WECC
Alberta	AESO	Completed, variability impact studies in progress	In place November 2004	NERC WECC
Saskewatchan	SaskPower	Have been commissioned	None	NERC MRO MAPP
Manitoba	Hydro Manitoba	TBC	None	NERC MRO MAPP
Ontario	IESO	Some studies completed.	In place July 2005	NERC NPCC
Québec	Hydro Québec	Some studies completed.	In place since 2003, updated December 2004.	NERC NPCC
New Brunswick	NBSO	Completed by September 2005	None	NERC, NPCC
Prince Edward Isle	PE	None	None	(NERC) NPCC
Nova Scotia	NS Power	None	None	NERC NPCC
Newfoundland and Labrador	N&L Hydro	None	None	None
NW Territories	NW Power Corp	Not known	Not known	N/A
Yukon	Yukon Electric	Not known	Not known	N/A
Nanavut	Nanavut Power Corp	Not known	Not known	N/A

Table 3.1: Summary of provincial progress to a Wind Grid Code

4. BASELINE GRID CODE

4.1 Introduction

This section discusses the various basic Grid Code requirements for wind projects that have been identified in Sections 2 and develops them into a proposed set of requirements for CanWEA to take forward for Canada with reference to the provincial characteristics identified in Section 3 through discussions with the various system operators.

This section of the report therefore establishes the fundamental aims of a Grid Code and its necessary considerations before examining the four relevant codes (AWEA, Alberta, Ontario, and Québec) in detail. Conclusions are drawn from the various current codes on how to frame the CanWEA Base Code requirements whilst allowing appropriate room for variation and future development without being unnecessarily stringent.

4.2 Introduction to Grid Codes - aims and structure

The general nature and aim of a Grid Code has in part been discussed in previous sections. Grid Codes are generally aimed at all stakeholders involved in the ongoing development and operation of a transmission system and from a technical standpoint this specifically implies satisfactory development and operation of the system according to certain criteria. For generators this means a minimum set of technical requirements must be met to ensure they do not adversely affect the transmission system. These criteria can broadly be divided into three types of system technical issues along with a fourth category of “information provision” as follows:

1. System security, e.g. fault ride through.
2. Local system control and operational issues, e.g. voltage control.
3. Global system control and operational issues, e.g. frequency control.
4. Information provision and exchange, e.g. fixed data regarding the plant characteristics, and ongoing data such as real time output through operational monitoring.

The most fundamental of the above is system security as this is aimed at “keeping the lights on” through contingencies. Loss of generation becomes unacceptable when that generation becomes a significant part of the system and fault ride through capability and associated requirements such as voltage and frequency tolerance are therefore cornerstone requirements.

It is useful to separate security issues that are local and global. Fault ride through capability is important in securing the system locally but is also important globally such that local events do not become catastrophic. Voltage tolerance is largely a local issue, whereas frequency tolerance is a global issue.

Issues such as voltage control are largely specific to certain locations or parts of the system and are generally acted upon by generation or other devices in that area. This can thus be largely regarded as a local issue and the extent to which it is required or expected to be required will in general be site specific.

Frequency control is a good example of a global system issue. Such issues can be dealt with by generators at any point on the system subject to any local constraints. It is not therefore necessary to implement these requirements on all generation, only to ensure that sufficient generation has the appropriate capability and is available to provide it. This is important as generation which is not best suited to provide such capabilities, such as wind, may be excused from this type of requirement with a number of provisos.

Information provision is essential since it would not be acceptable for any generation to be connected without its characteristics and resultant system impact known. However it may be appropriate for certain generators to provide only limited data, due to their location, size or technology.

In connecting small amounts of wind to the system it is the local effects and issues that are most important, often being assessed through a System Impact Study. As wind penetration increases, its effects on the whole system start to become important and global issues also need to be addressed. These considerations lend weight to the case for developing a CanWEA Base Code focused initially on the more pressing requirements of security and local control and operation with less development or more variability available in regards to the global issues.

The development of a baseline Grid Code must take a number of other objectives into account, some of which may be conflicting. Important generic considerations include:

- A common requirement enshrined in most codes or system operator licenses to treat all generation fairly and equally. It is not therefore acceptable to allow wind turbines concessions other than those that are a necessity of the technology. This also implies that basic code requirements must be met regardless of location and turbine type. By the same token it is equally important to ensure that wind turbines are not asked to meet requirements that other generators are not because of a lack of understanding of the technology and its capabilities.

- The purpose of the technical requirements in a code is to provide the capability through the generators to operate and maintain the system satisfactorily. It is important to realise that in many ways the technical requirements of a code are about ensuring the technical capability to achieve this aim is present through the generation. This does not imply the requirements will necessarily be called upon or indeed are wholly relevant to the individual connected project. Efficiency and economy are therefore important considerations as neither are met by requiring capabilities that will not be needed.

4.3 Turbine technology and capabilities

The significant increase, both installed and proposed, in the level of penetration of wind power generation into the national grids of Europe and North America has resulted in turbine manufacturers and wind farm designers modifying their existing designs or introducing new equipment in order to provide continuous control of real and reactive power, ride through significant faults occurring on the main transmission system, assist in system control issues, be tolerant to frequency and voltage variations, and other capabilities.

In general terms the most suitable turbine types are those which are power converter connected and pitch regulated. These type include doubly-fed induction turbines, fully power converter connected turbines and to a lesser extent fixed speed induction machine wind turbines with pitch control. A more detailed discussion of the various turbine types, their capabilities, and the additional plant that can be used is contained within Appendix B.

It is important to note that Grid Code requirements are best applied to wind farms rather than wind turbines. It is the wind farm that is connected to the system, and it is feasible (and may be economically optimum) for equipment to be provided with the wind farm to allow Grid Code requirements to be met. For example, Static Var Compensators (SVCs) could be used to meet the reactive power and LVRT requirements, even with fairly simple fixed-speed induction generators.

4.4 CanWEA Base Code outline proposals

This section sets out the qualitative form proposed for the CanWEA Base Code, with the following Section 4.5 examining the individual quantitative requirements with detailed reference to the existing codes. The final Section provides a summary of the proposed CanWEA Base Code.

4.4.1 General discussion on existing wind Grid Codes

There are currently four relevant codes specifically aimed at wind. They are the AWEA Grid Code, and those of Alberta, Ontario, and Québec. The following paragraphs discuss these codes ahead of the detailed analysis of individual requirements in Section 4.5 and aims at developing qualitative proposals for the CanWEA Base Code in terms of structure, format and content with the existing codes in mind. Table 4.1 below provides a summary of the relevant requirements identified through the review work of Section 2 and Section 3 and the appearance of these requirements in the existing codes.

The Québec requirements set out by Hydro Québec TransEnergie are primarily aimed at system security. Their requirements contain relatively stringent LVRT capability, and frequency and voltage tolerance. Their primary concern in protection is also given as ensuring the plant remains connected for as long as possible through system disturbances. These requirements also include reactive power capability and voltage control capability although these are much less prescriptive.

The Alberta requirements of AESO cover a broad range of categories and have probably been set out to provide cover for a broad spectrum of issues both current and prospective. AESO covers the fundamental security requirements and is prescriptive about reactive power and voltage control over which it has identified concerns. The AESO code appears to be aimed at allowing good penetrations of wind provided other generation can pick up the wider system issues involving reserves and frequency control.

The AWEA Grid Code is the simplest and most liberal of the current codes. In recognition of the diversity of requirements seen across the US AWEA has implemented a simple code based on the key problem issues seen. This code is useful as a benchmark and is forcing the issue of a standard code on the US (and Canada). The code in itself is not suitable for a long term position but provides a starting point on what appear to be fundamental requirements – LVRT, and reactive power provision and voltage control. It has forced debate on these issues and made sensible comment on incorporating flexibility into the requirements.

Ontario is similar to the other Canadian codes in that it is geared to security with allowance for local control of voltage. Unlike the other codes IESO's LVRT requirement is determined on a site by site basis, although GH notes in general terms this will lead to a more relaxed requirement.

Issue	**Present in provincial requirements for wind**
Turbine power control	Alberta – indicated via ramp rates restrictions. Québec – noted as possible via ramp rates and frequency control.
Turbine reactive power control	AWEA Alberta Ontario Québec
System frequency control	Alberta - high frequency curtailment only. Québec – noted as possible.
System voltage control	AWEA Alberta Ontario Québec
Fault ride through capability	AWEA Alberta Ontario Québec
Frequency tolerance	Alberta Ontario Québec
Voltage tolerance	Alberta Ontario Québec
Negative phase sequence withstand	Alberta by inference
Information provision – fixed data and operational metering	AWEA Alberta Ontario Québec
Power system stabilisation	Alberta – noted only Québec – noted only
Provision of inertia	None

Table 4.1: Relevant issues identified in existing Grid Codes

Figure 4.1 shows a qualitative assessment of the various Grid Codes currently in place. GH has chosen to break the codes into three broad categories which can be stacked in terms of importance according to wind penetration (along the y-axis). If ensuring system security is taken as a fundamental requirement placed upon all generators, then beyond this it becomes necessary to next consider local issues and finally at much higher general penetrations global issues such as load following and frequency control become important.

The detail of a code also reflects to some extent the rigour and complexity of the requirement and this is placed along the x-axis. It can be seen that the AWEA Grid Code is most liberal whereas Québec's and Alberta's are the most onerous in the requirements they set out.

All the codes contain the basic system security requirement of LVRT with the Canadian codes extending security concerns to cover frequency tolerance and voltage tolerance. Of these Québec is the most detailed.

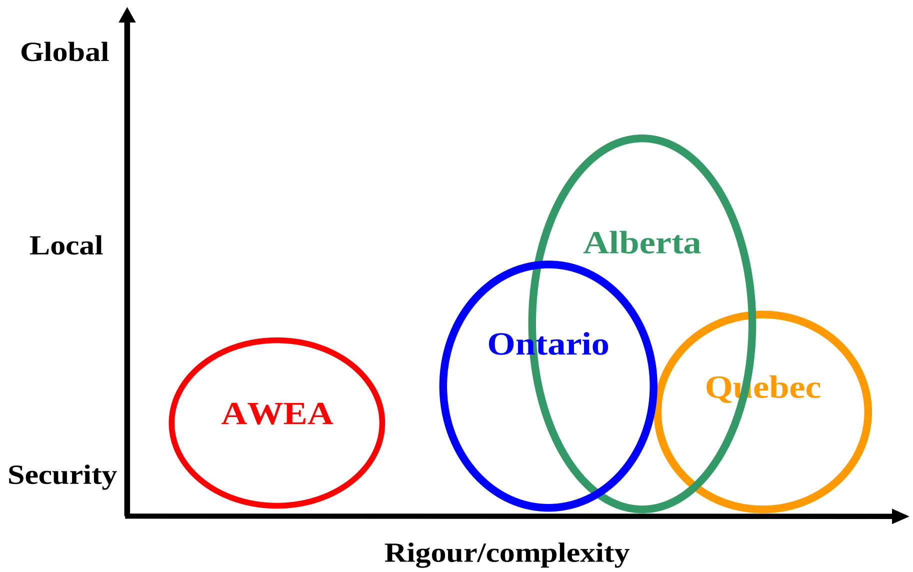


Figure 4.1: Qualitative assessment of current Grid Codes for wind

It is apparent that even with a security requirement, a project may often need to assist with local control issues. For wind farms these issues seem to centre on voltage control issues quite often since projects are located in remote areas where lines are long and distant from load centres and often other large generators. Local control issues might also require power control if system capacity is inadequate for whatever reason (thermal or stability for example). Such requirements can be very site specific however and it will not always be necessary to implement them.

Many of the concerns identified by system operators do concern higher penetration and wider system issues such as wind variability, load following and scheduling reserves although the codes currently contain little in regards to system global control issues. Canada is not yet at the point where such requirements are necessary but they will become more pressing as penetrations increase. Some of the requirements that stem from these issues are frequency control, power system stabilisation, and inertia provision, and some of these are noted in the codes but not enacted as yet.

GH considers that any Base Code must encompass the codes already operating but also allow for a degree of flexibility. In most provinces the introduction of interconnection rules is likely to follow similar patterns to those already in existence, addressing security and local control issues first as these are most pressing, and then addressing wider system issues as penetrations increase.

4.4.2 Variability of requirements

A degree of variability with the Base Code is desirable to prevent continual "over design" of turbines and projects to meet worst-case design criteria. Variability in the context of a Canada wide Grid Code can be viewed at three levels:

i. Site specific to account for local system conditions.
ii. Province specific to allow for provincial variations.
iii. Varied over time, i.e. not required initially but implemented at a later date for new projects once installed capacity reaches a certain level. An example of this may be the frequency control function.

Grid Codes are usually written to define a basic set of required capabilities which must be implemented regardless of their actual need. In many cases, especially in regards to local issues such as voltage control, the site specific requirements can be much less than that required of the code and the imposition of the full code requirements only leads to additional costs. There is therefore a very good case for introducing a full standard which if applied to a project would allow automatic connection regardless of local conditions, but allowing for a site specific variation (i.e. less onerous requirements) on the basis of the System Impact Studies.

A similar case for variability becomes apparent when the provincial differences are considered. In this case a full standard allowing automatic access would need to be the lowest common denominator across the provinces, i.e. the province with the most stringent requirement to meet or in other words the most onerous or costly. Such a full requirement would allow automatic connection in any province, but could still be open to site specific or provincial variation which could define a lesser requirement as acceptable.

4.4.3 Base Code qualitative aims

With the previous discussions in mind, GH proposes to formulate the CanWEA Base Code with the following principle aims:

- Suitable to encompass the existing codes of AWEA, Alberta, Ontario and Québec.
- Flexible to allow wind to connect at lower penetration levels without an over-burden of unnecessary requirements, but also allow additional requirements on further new projects as penetrations increase.
- Flexible enough to allow sensible variation according to provincial requirements.
- Flexible on a site by site basis so that requirements can be tailored to local site specific conditions rather than an unrealistic worst case.

The following Section looks at the individual technical requirements in detail and forms recommendations for the inclusion of the individual requirements within the CanWEA Base Code and for their form.

4.5 Detailed technical requirements

4.5.1 Overview

Each of the requirements identified from Sections 2 and 3 is covered in the following sub-sections with discussion on the application of the requirement through existing Grid Code requirements in each of the Canadian provinces and the AWEA Grid Code [4.1]. It is important to remember that at this stage, both Alberta and Québec have well developed requirements [4.2] [4.3] [4.4], Ontario less so [4.5], and those provinces which are a party to NERC also must consider the US requirements as currently being finalised between NERC, AWEA and FERC, hereafter referred to as the AWEA Grid Code.

In respect of each requirement GH draws conclusions and makes recommendations as to how the requirement should be implemented within CanWEA's Base Code. The final section of this chapter draws this and preceding sections together to form the CanWEA Base Code.

4.5.2 Frequency tolerance

AWEA
The AWEA Grid Code makes no requirements on frequency tolerance.

Alberta
The Alberta AESO requirements for frequency tolerance are set out in Table 4.2. GH considers that they are typical frequency tolerance requirements in terms of range and duration. AESO adds a few clarifications to the requirements, most notably in respect of abnormally low voltages.

Frequency (Hz)	Minimum Time Delay
>61.7 Hz	0 seconds
61.6 Hz to 61.7 Hz	30 seconds
60.6 Hz to <61.6 Hz	3 minutes
>59.4 Hz to <60.6 Hz	Continuous Operation
>58.4 Hz to 59.4 Hz	3 minutes
>57.8 Hz to 58.4 Hz	30 seconds
>57.3 Hz to 57.8 Hz	7.5 seconds
>57.0 Hz to 57.3 Hz	45 cycles
57.0 Hz or Less	0 seconds

Table 4.2: Alberta AESO frequency tolerance requirements [4.2]

Ontario

Projects are required to meet Appendix 4.2 Reference 3 of the Market Rules [4.6]. This requires each generation facility to:

- Operate continuously at full power in the range 59.4 to 60.6Hz.
- Operate at full power for a limited period of time at frequencies as low as 58.8 Hz.
- Not trip for underfrequency excursions that are above a straight line defined on a linear-log plot of time and frequency by the points (300s, 59.0Hz) and (3.3s, 57.0 Hz) unless the *IESO* accepts other trip settings.
- Trip immediately below 57.0 Hz if desired.

These are not untypical requirements although it is notable that over-frequency requirements are not set, leaving wind plant free to disconnect during abnormally high system frequencies.

Québec

The frequency tolerance requirements in Québec are set out in Table 4.3. They are framed similarly to Alberta's requirements but require tolerance to much lower frequencies and for much longer timescales. GH considers that compared to other Canadian provinces and most other countries they are much more stringent. They also apply to projects connected to the transmission system via the distribution system.

Frequency (Hz)	Duration
$F < 55.5$	Instantaneous
$55.5 \le F < 56.5$	0.35 second
$56.5 \le F < 57.0$	2 seconds
$57.0 \le F < 57.5$	10 seconds
$57.5 \le F < 58.5$	1.5 minutes
$58.5 \le F < 59.4$	11 minutes
$59.4 \le F \le 60.6$	**Permanent**
$60.6 < F \le 61.5$	11 minutes
$61.5 < F < 61.7$	1.5 minutes
$F \ge 61.7$	Instantaneous

Table 4.3: Québec frequency tolerance requirements [4.3]

Summary

The three current Canadian sets of interconnection requirements all set out frequency tolerance requirements. This is not surprising as frequency tolerance is a system security issue.

Ontario, unlike Alberta and Québec, does not place requirements on wind farms for over-frequency events. This is not necessarily an issue as disconnection during over-frequency would tend not to be a problem. Conversely, it is important for generation to remain connected and operate during low frequency events as its output power is essential as an aid to bring frequency back up.

GH considers that frequency tolerance can be considered as less important for small and moderate wind penetrations than other requirements, probably to the point of not being necessary for wind plant at low penetrations. However given the importance system operators attach to frequency tolerance and that it is already enshrined in all three of the existing provincial codes, and because it is not a costly requirement to meet, GH considers it should be included within the CanWEA Base Code as a fundamental and mandatory connection requirement.

The question to be answered is at what level should this requirement be pitched. Figure 4.2 shows a comparison of the existing requirements. It can be seen that the Alberta and Ontario requirements are loosely similar whereas Québec's is more stringent requiring tolerance over a much wider range.

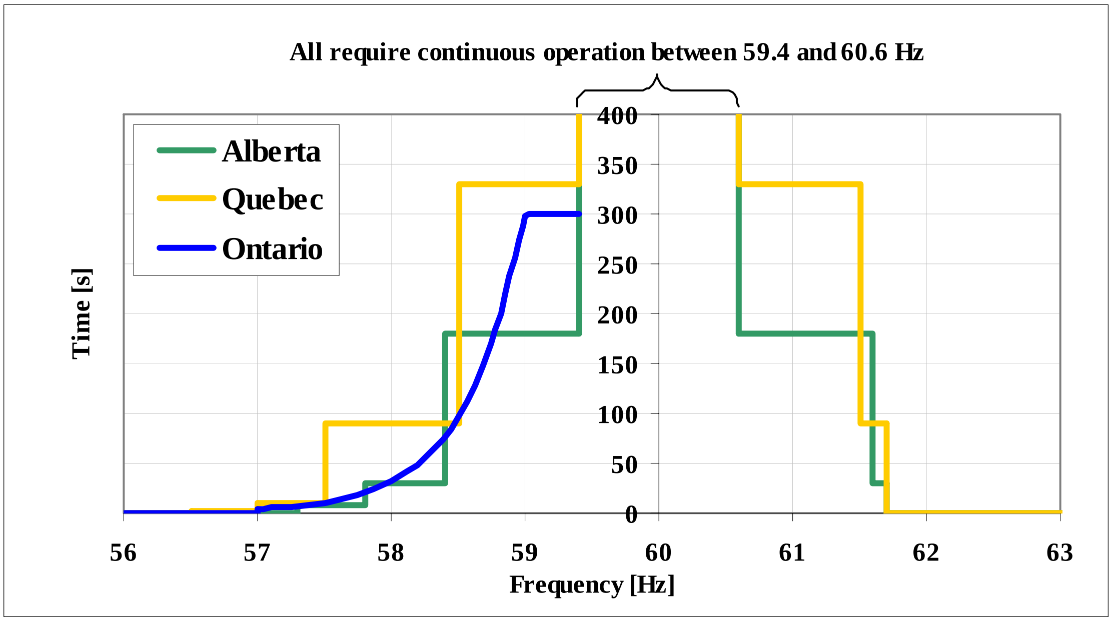


Figure 4.2: Comparison of frequency tolerance requirements from [4.2] [4.3] [4.6]

All three require continuous operation between 59.4Hz and 60.6Hz (i.e. +/-1% of nominal 60Hz) and it can therefore be concluded that this range should be adopted for continuous operation. It is desirable to adopt an under and over frequency time based range that encompasses all three ranges, but this implies working to the widest range (or the collection of widest points) which is most onerous. GH considers that either CanWEA adopts an envelope covering Ontario and Alberta with Québec as a special case, or an envelope that covers all three. Either way, it is likely that all other provinces, excepting those that run islanded systems, would be covered.

Recommendation
Frequency tolerance is adopted in the CanWEA Base Code as a mandatory requirement. The recommended requirement is for:

1. Continuous normal operation between 59.4Hz and 60.6Hz.
2. Under-frequency time based capability.
3. Over frequency time based capability.

   The under and over frequency time based tolerance should be either:
   i. Specified to encompass both Alberta and Ontario with Québec noted as a special case, or,
   ii. Specified to encompass Alberta, Ontario and Québec.

GH also recommends that the detailed characteristics of this requirement be taken forward by a working group or similar. A particular point to note is how the requirement relates to power and reactive output capability and voltage. Designing turbines to withstand high voltage and low frequency requires relatively significant additional effort and this issue should be considered in more detail.

It should be noted that some European grid codes require continuous operation over the range 47.5 to 52 Hz, and so the Québec requirements do not appear so onerous in a worldwide context.

4.5.3 Voltage tolerance

AWEA
The AWEA Grid Code does not specify any requirements for voltage tolerance as such although it does specify an LVRT requirement.

Alberta
The Alberta AESO requirement for continuous voltage tolerance is +/-10% of system nominal voltage. This is a common range for transmission systems worldwide although the full range is rarely utilised. Many systems also specify a requirement for tolerance outside of this range for short durations, and indeed the LVRT requirements are one such example. AESO also retains a clause stating they will decide the required operating voltage range although it is not clear how this relates to the +/-10% range.

Ontario
Ontario's IESO requires continuous operation for wind farms as with other generators on the transmission system according to the Market Rules Appendix 4.1 [4.6]. Normal conditions requiring continuous operation are defined in Table 4.4.

System nominal voltage [kV]	Minimum continuous voltage [kV]	Maximum continuous voltage [kV]
115	113	127*
230	220	250*
500	490	550

Table 4.4: Ontario IESO continuous voltage tolerance requirements [4.6]

*In northern Ontario, the maximum continuous voltage for the 230 and 115 kV systems can be as high as 260 kV and 132 kV respectively.

Plant must also be able to withstand over-voltage conditions for the period of time it takes to return the system to normal. This is defined as 30 minutes before disconnection is allowed but the level of over-voltage is left undefined. This is also framed as a high-voltage ride through requirement, in some ways similar to Québec.

Projects are also required to meet Appendix 4.2 Reference 2 of the Market Rules [4.6]. This requires the capability to operate continuously at full output within +/-5% of the rated terminal voltage, with all auxiliaries able to operate continuously within this range. Generation is not expected to operate outside of this range to satisfy power factor requirements.

Québec

The voltage tolerance requirements for Québec are shown in Table 4.5. As with Alberta there is a continuous requirement for operation with +/-10% of nominal. The requirements also define minimum connection times for under and over-voltages beyond this range.

Regarding under-voltage conditions, the requirements may be regarded as LVRT requirements, discussed further in Section 4.5.8. There is some justification for discussion with Hydro-Québec about the relationship between the LVRT and undervoltage requirements.

With respect to over-voltages the requirements are more stringent. Although it is not uncommon for minimum times to be specified for connection during over-voltages there are both a large number of stages and ultimately an unspecified ceiling of voltage above 140% where a project must remain connected for at least 30ms. Even up to 140% voltage a project is required to remain connected for no less than 100ms. A similar set of requirements exist for distribution connected wind farms in Québec.

Voltage (p.u.) [note]	Duration
V < 0.60	0.10 second
0.60 ≤ V < 0.75	0.25 second
0.75 ≤ V < 0.85	2.0 seconds
0.85 ≤ V < 0.90	300 seconds
0.90 ≤ V ≤ 1.10	**permanent**
1.10 < V ≤ 1.15	300 seconds
1.15 < V ≤ 1.20	30 seconds
1.20 < V ≤ 1.25	2 seconds
1.25 < V ≤ 1.40*	0.10 second
V > 1.40 p.u.*	0.03 second
Note: Positive sequence voltage at fundamental frequency * : Facilities that use power electronics must remain operational throughout the entire voltage range except for voltage levels greater than 1.25 p.u. where temporary blocking is allowed.	

Table 4.5: Québec voltage tolerance requirements for transmission connected wind farms 2003 [4.3]

Summary

All three of the existing Canadian codes set out requirements for voltage tolerance. The requirements in Québec are much more prescriptive and onerous to meet than in Alberta or Ontario. All three specify under-voltage tolerance in the form of LVRT although this is specifically dealt with in Section 4.5.8 of this report.

As voltage tolerance is a locally important connection issue for system security and appears in all three existing codes, it is pertinent to include requirements within the CanWEA Base Code along with a requirement for an LVRT capability (Section 4.5.8).

Figure 4.3 compares the requirements of the three provinces in regards to voltage tolerance. GH has used the widest percentage tolerance specified in Ontario in Table 4.4, i.e. -4% to +10%, but notes +10% is common to all three voltage levels given. Both Québec and Alberta specify a requirement for continuous operation with +/-10%, and it is noteworthy that this encompasses Ontario as well. IESO notes that the range can be extended in Northern Ontario to beyond +10%. GH considers this an area-specific issue that is IESO's concern and might be applied to specific projects as a "one off" type of requirement specifically identified as such in connection documentation. GH does not therefore consider this worthy of inclusion in the CanWEA Base Code except perhaps as a footnote for information purposes.

GH notes that Alberta has not specified over-voltage requirements in their code [4.2] although over-voltage tolerance for short times is a common requirement around the world. Ontario has noted this is a requirement but has not given any limits, perhaps as the exact requirements are to be determined from system studies. Québec has prescriptive and detailed requirements for over-voltage. Québec's requirement for limited time tolerance to +/-15% is not uncommon in a worldwide context.

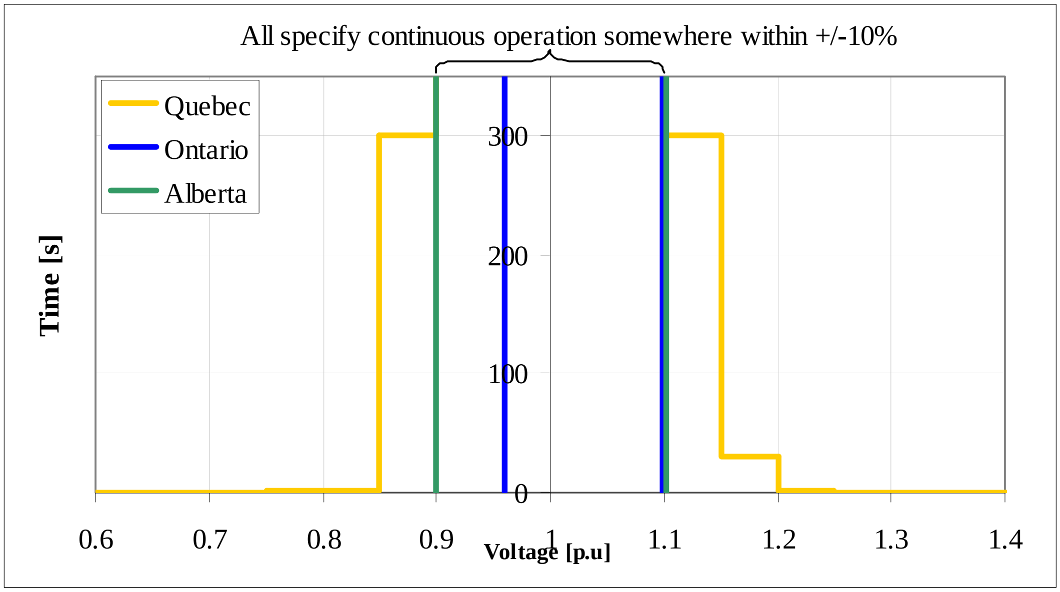


Figure 4.3: Comparison of voltage tolerance requirements of [4.2] [4.3] and [4.6]

GH considers that a +/-10% tolerance to voltage should be made mandatory within the CanWEA Base Code and notes that since transmission connected wind farms will generally do so via a tap changing transformer this will not generally be an onerous requirement.

GH also considers that under and over voltage requirements should be addressed within the Base Code. Regarding over-voltage GH considers that a limited tolerance to +15% as required by Québec is reasonable but that further definitions beyond +15% should be considered. This would imply that either Québec's requirements for over-voltage are adopted or discussions are held as part of the ongoing Base Code process to develop a set of over-voltage requirements for all provinces with Québec as a special case.

In regards to under-voltage, Québec has specific requirements whereas Alberta and Ontario do not but do define LVRT capabilities which can be considered integral to those of voltage tolerance. It is noteworthy that the AWEA Grid Code also defines an LVRT capability (currently identical to Alberta until 2007 when it will likely cede to that of Québec) that can be considered in this respect. As Ontario's LVRT capability is defined on a site by site basis via System Impact Studies it cannot be considered definitively as part of the under-voltage requirements. Inclusion of Alberta's LVRT requirement as an under-voltage requirement yields Figure 4.4. It can be seen that excepting Québec's under-voltage requirement for 300s down to -15% voltage, and requirement for 100ms from -60% to zero the Alberta LVRT characteristic covers the Québec requirements.

Given the uncertainties involved, GH considers that the progression of an under-voltage requirement is probably best dealt with through ongoing discussions between the wind industry and the various system operators. GH can envisage an under-voltage requirement to -15% for a limited time period and thereafter a requirement bounded by the LVRT curve.

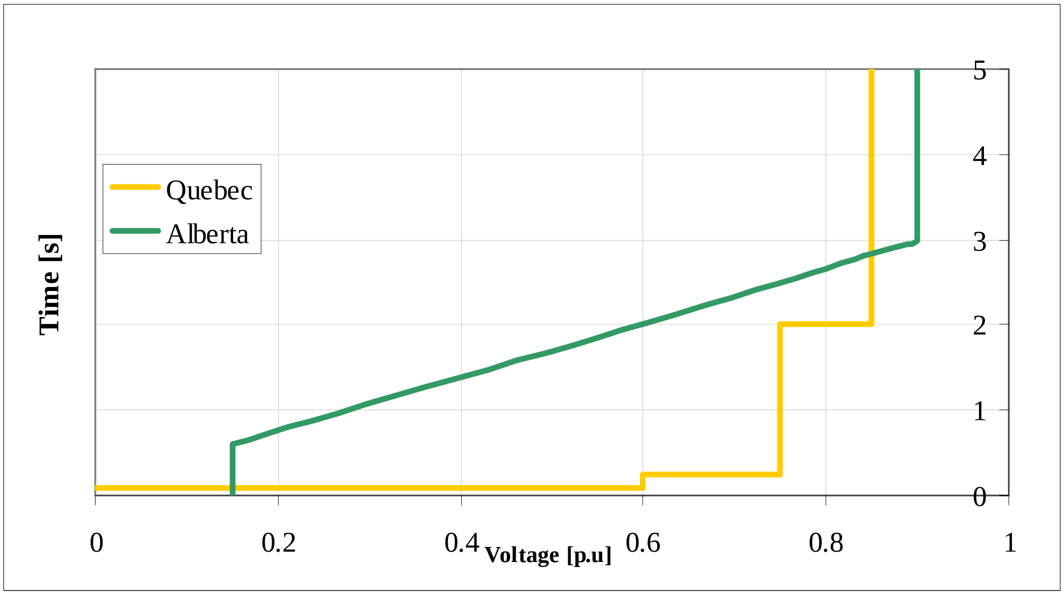


Figure 4.4: Under-voltage tolerance of Québec [4.3] compared to Alberta LVRT [4.2]

Recommendations

Voltage tolerance is adopted in the CanWEA Base Code as a mandatory requirement. The recommended requirement is for:

1. Continuous normal operation between +10% and -10% of nominal voltage at the interconnection point (high voltage side of transformer). A footnote should be added to the CanWEA Base Code text regarding Northern Ontario.

2. Over-voltage time based capability.
   The over voltage time based tolerance should be either:
   i. Specified to encompass other provinces requirements with Québec noted as a special case, or,
   ii. Specified to encompass all provinces including Québec.
   In either case, GH recommends the over-voltage tolerance is only specified once the requirements of other provinces have been considered through ongoing discussions and a best option is more clearly identifiable.

3. Under-voltage time based capability.
   The under-voltage time based tolerance should be progressed through ongoing discussions, particularly the equivalence of LVRT to under-voltage tolerance and the extent to which Québec's requirements can be incorporated as such. As a starting point for discussions, GH recommends the under-voltage requirements are specified by the recommended LVRT requirement as discussed in 4.5.8.

4.5.4 Power control

AWEA
This requirement is not explicitly detailed in the AWEA Grid Code, although it is implied.

Alberta
Requirements for power control are detailed within the Alberta AESO interconnection requirements and the prospect of curtailment is raised in respect to abnormally high system frequencies and other situations. AESO states these requirements might be implemented as a result of their ongoing "variability studies". At time of writing AESO had completed initial variability studies but had not fully assessed the system impact and any ensuing requirements.

AESO state that wind farms capable of controlling MW output to a specified level within 10 minutes may be allowed to remain connected to the system during contingencies – presumably thermal overloads or high frequency events. AESO further states that the maximum power ramp rate shall not exceed 10% of the MW output per minute.

Ontario
Ontario's IESO make no specific requirement on the capability of turbines to control output power.

Québec
Hydro Québec TransEnergie does not set out any explicit requirements for turbine power control although as with other system operators it is clearly desirable, e.g. to achieve curtailment. In their December 2004 update of requirements [4.4], a note is made that ramp rates may be specified if deemed necessary and hence power control can be inferred as required. In addition a further note is made that a suitable control and communication system is required to be installed to allow Hydro Québec TransEnergie to send signals to raise or lower the power output.

Summary
Requirements in the existing codes to control power output are generally either absent, implied or very loosely defined. In contrast to this, wind farms of modern variable speed turbines are capable of power control in a number of ways, including a limiting maximum power output setpoint and the setting of maximum positive ramp rates.

Since at present the need for power control is largely tied to issues of constraint (which can be achieved by shutting down turbines in any case) GH does not see a clear need for power control. As wind penetrations increase, possibly to the point frequency control is required, then the need for power control will become more important. With this in mind GH considers that power control should not be a current requirement of CanWEA's Base Code.

Both Alberta and Québec refer to ramp rate control of MW power output. The case for ramp rate limitation is not clear and in some cases, e.g. BC [2.27], has been shown not to be an issue for wind generation. Indeed, ramp rate control appears to be largely required as a result of unsubstantiated concerns over wind farm output variability despite many studies which appear to show this is not a major issue. It is worth noting that Alberta has, since instigating its requirements in November 2004, undertaken variability studies [2.34] the preliminary results of which appear to cast doubts over the need for ramp rate control. GH therefore recommends that the need for ramp rate control is discussed further within the ongoing development of the CanWEA Base Code.

GH also considers that ramp rates largely relate to voltage power quality issues and thus if a project is shown to meet the applicable power quality standards the ramp rates are largely irrelevant. Changes in power output at various ramp rates appear as voltage variations and as such create voltage flicker and steps – these are power quality issues and are discussed in Section 2.3.16.

As power control is widely available with modern wind turbines, is useful for dealing with system constraints, and is likely to become an important requirement of wind farms as penetrations increase, GH considers that it should be noted as desirable within the Base Code affording benefits to projects where it is available but that it should not be a definitive requirement at present.

Recommendation
Power control, including the capability to limit maximum power output and control ramp rates, is noted within CanWEA's Base Code as useful and desirable but not made a requirement. It should be further noted that it is likely to become a requirement for new projects in the future as wind penetration starts to become high.

As Alberta currently has a ramp rate requirement, it is possible that a province-specific exception may be necessary, but justification should be sought.

4.5.5 Reactive power control/capability

Reactive power control or capability is a common requirement in all the Canadian provinces with interconnection requirements for wind currently, as well as the AWEA Grid Code. In addition, it has been identified as a common issue in just about all provinces largely through concerns over voltage control. A common reactive capability is thus an important requirement to develop.

AWEA
The AWEA Grid Code requires a 0.95 leading to 0.95 lagging power factor capability (presumably at full load) which applies to the wind farm rather than the individual turbines. It is further noted that should System Impact Studies show a capability less than 0.95 lagging is sufficient to meet system reliability requirements then that shall apply, so that flexibility is built into this requirement. The requirements further state that the aim is to provide system voltage control and that the reactive capability can be supplied by a combination of switched or fixed capacitor banks and the turbines' own inherent capabilities. AWEA requirements clearly state that actual applied requirements should reflect the local conditions and in some cases this may mean a power factor requirement is meaningless or can be reduced significantly.

The AWEA Code recognises the fact that power factor and voltage control are largely local issues and thus requirements can be tailored to suit. The important point in tailoring is that the Code defines a base 0.95 lead to lag range to be aimed at and which should allow automatic grid interconnection but the local conditions may allow this to be reduced (but not increased) with benefit for the wind farm and with no reliability issues for the grid.

It is not clear from the AWEA Grid Code what is required in terms of power factor and reactive power at reduced MW output.

Alberta

The Alberta AESO specifies both a required minimum continuous reactive capability and a minimum dynamic reactive capability. The requirements are much more prescriptive than those of the AWEA Grid Code requiring a 0.95 leading to 0.90 lagging power capability (at full load) which applies to the whole wind farm at the lower voltage side of its transmission connection transformer (generally MV). A smaller dynamic range is also specified as 0.985 leading to 0.95 lagging at full load. Both requirements are reduced pro-rata with MW output to zero and are shown in Figure 4.5. Some further detail is provided on AESO's expectations of the reactive capability including the extent to which fixed reactive compensation and dynamic devices can be used to achieve the minimum required capability. AESO's requirements do not allow for site specific variation.

AESO also requires a reactive capability in the shaded areas to be available if the turbine can operate in these areas. GH has clarified this understanding directly with AESO. This is a fairly relaxed requirement and many turbines will be able to operate substantially within the shaded areas at no extra cost or detriment. Insistence on operation throughout the shaded regions would be onerous as many turbines cannot continue to produce significant reactive power right down to zero MW output.

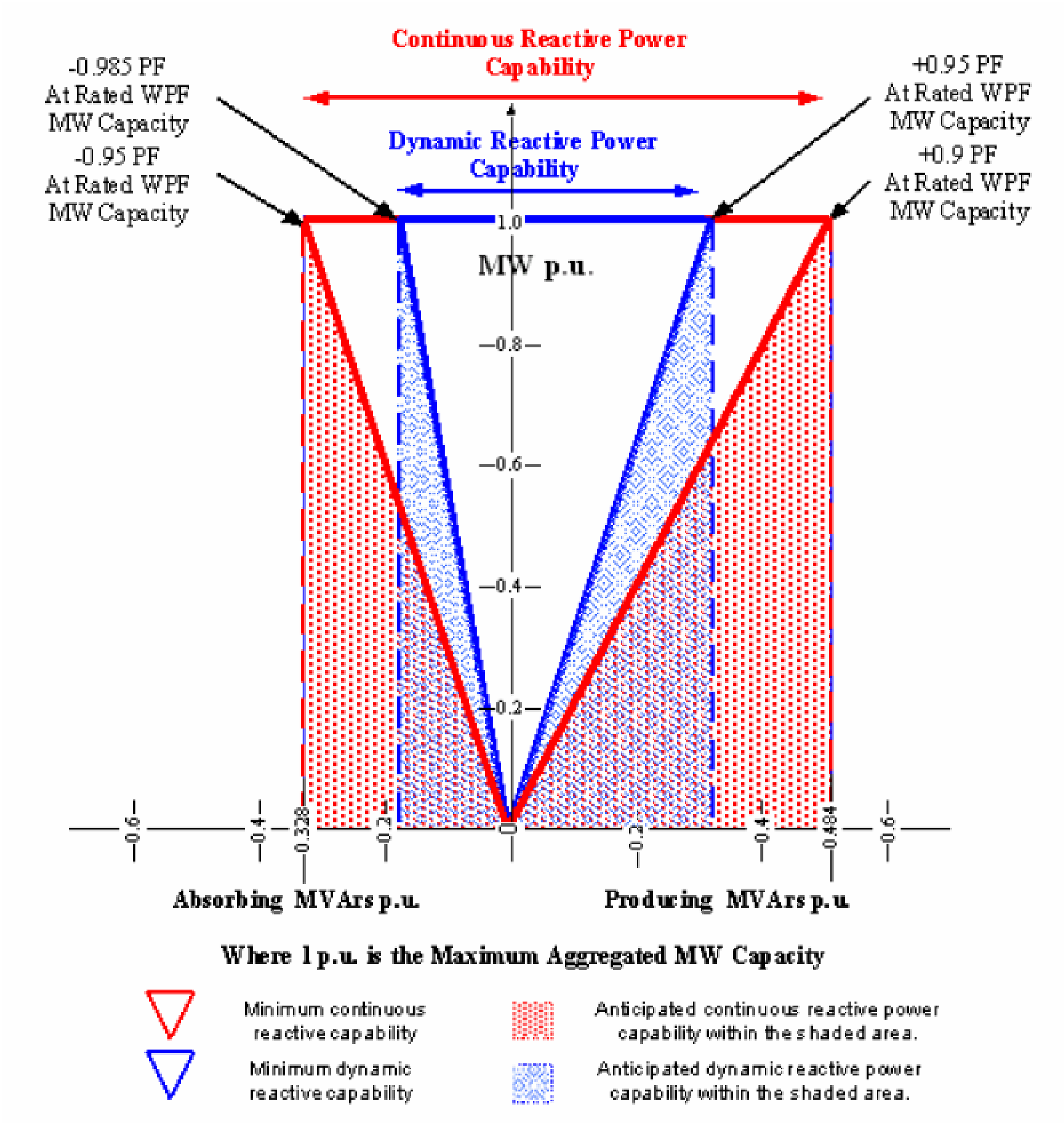


Figure 4.5: Alberta AESO reactive capability requirements [4.2]

Ontario

The IESO requires that asynchronous generators have the same capabilities as synchronous generators according to Appendix 4.2 Reference 1 of the Market Rules [4.6]. At full MW output this requirement is for the provision of 30MVAr of reactive power for every 90MW of real power, i.e. a power factor of approximately 0.95 at the connection point. The Market Rules [4.6] more fully define this requirement as 0.90 lagging to 0.95 leading capability based on rated MW output at rated voltage, which appears contradictory. IESO does not explicitly detail how this requirement varies with MW output, or is allowed to vary with voltage and frequency.

IESO also extends these requirements to wind farms not connected to the transmission system but considers an operating power factor of unity as the most desirable for normal circumstances.

IESO also states that additional shunt capacitance may be required to offset the effects of the collection system, i.e. the requirements are at the connection point and not the generator terminals.

Turbines are also required to have a dynamic reactive power capability defined in Appendix 4.2 Reference 1 of the Market Rules [4.6] and in cases where this capability is not present the project should install a dynamic device (such as a dynamic VAr compensator) to provide the equivalent capability. The quoted reference does not appear to set out any requirements on dynamic capability.

Québec

Hydro Québec TransEnergie specifies that synchronous generators connected to the grid via a power converter, or doubly-fed asynchronous generators, must be capable of 0.95 leading to 0.95 lagging power factor at the grid side of the converter of the machine. This applies to rated operation and Hydro Québec TransEnergie further states this level of reactive power must be available over the full output range of the machine which GH takes to imply the full MVAr reactive capability at full MW load must also be available right down to zero MW load. This gives a characteristic not dissimilar to Alberta's (shown as shaded area in Figure 4.5) although Alberta's AESO does not insist this capability is required.

Production of full equivalent rated VAr even at zero MW output is a relatively onerous requirement requiring most, if not all, manufacturers to modify existing turbine designs often with the installation of separate reactive compensation equipment. It should be noted that the control of the reactive power still needs to meet Hydro Québec TransEnergie's voltage control requirements.

Summary

Reactive capability is important, primarily for local system voltage control. These two issues have been identified in virtually every province as critical concerns, and appear in all the four codes considered. GH considers that the CanWEA Base Code must therefore contain some form of requirement on reactive capability and voltage control. Voltage control is dealt with separately in Section 4.5.6.

Before drawing any conclusions on the CanWEA Base Code for reactive capability, there are several important requirements within reactive power control/capability to consider as follows:

1. Definition of capability at full MW loading.
2. Definition of capability at reduced MW loading down to zero.
3. The extent to which the capability should be dynamic.
4. The extent to which the capability can be met from a combination of reactive devices and the turbine.

Item 1.

Taking item 1, which is the most commonly defined variable, the Québec and AWEA codes require a 0.95 leading to 0.95 lagging capability at full load, whereas the Ontario and Alberta requirements require 0.95 leading to 0.90 lagging. All are defined at the grid side of the main transformer(s), usually the point of interconnection, except Alberta which defines the low voltage side of the main grid transformer. These two sets of figures are the most commonly required internationally.

In most cases a capability of 0.95 leading to 0.95 lagging is sufficient although as the AWEA code notes the required capability is site specific and may often be less than this. It can be considered that extension to 0.90 lagging is very much a worst case and will be very rarely required. In regards to AWEA's comments, GH considers these as very sensible and concludes that the required capability should be allowed to vary on a site by site basis and on a provincial basis according to minimum system operator requirements.

GH therefore considers that a reactive capability should be included as a "variable" type of requirement. Wind farm project developers must expect to provide it but the exact limits will be determined by a) the province, and b) the site conditions. As a worst case for projects, and as a standard which would allow automatic access regardless of a) and b) any project providing a 0.90 lagging to 0.95 leading capability should be allowed automatic connection rights throughout Canada under the terms of the CanWEA Base Code.

CanWEA may wish to consider the value of discussing a range of 0.95 leading to 0.95 lagging which would be significantly easier for turbine manufacturers to meet. GH considers that such a range is likely to be satisfactory but that there may be issues in equality as other synchronous generators may be required to provide to 0.90 lagging.

GH further considers that this capability should be defined at the point of interconnection which will generally be the high voltage side of the main grid transformer. Alberta is currently specifying the lower voltage side but GH does not see how this can be appropriate to the transmission system and recommends this is discussed with Alberta's AESO via the ongoing discussion process.

Item 2.
Regarding the capability of the turbines to provide reactive power at reduced MW loading it is common for power converter connected variable speed machines to be able to do this but not necessarily to be able to maintain the equivalent VAr at full output right down to zero output. Insistence on such a requirement may result in the need to fit extra reactive compensation plant.

Québec requires this full MVAr capability throughout the MW output range, whereas Alberta asks for it only if it is available. The AWEA and Ontario Grid Codes are unclear about reactive provision at reduced output.

GH does not see any issues in extending the required reactive capability down to zero MW load as a power factor requirement ("V" shape as in Figure 4.5) and as noted above considers that many turbines can already provide reactive capability beyond this.

The key question is really whether the additional capability required by Québec is justified. Clearly with the wind farm generating there is a case to claim it must also assist the system with voltage regulation. However, if the wind farm were removed from the system – either by disconnection or by simply not have being built, the effect would be similar to a characteristic giving VAr of zero at zero MW output. This suggests that Québec's requirements place requirements on the wind farm over and beyond those of interconnection and that the wind farm is to be used for system control purposes regardless of its function as a power producer. This may be justified at high penetrations but is not easily justified at lower penetrations.

GH therefore considers that the best solution might be to introduce a requirement meeting Alberta's in that the minimum is specified in terms of power factor ("V" shape) but that it is noted that capability beyond this is desirable. Once again, Québec would need to be excepted as a special case. GH considers that Québec's position should be discussed within the ongoing CanWEA Base Code development process.

Item 3.
Given that the provision of reactive power is largely required for voltage control it is clear that at least part of the control and part of the reactive provision must be dynamic (i.e. rapid) rather than slow. It is not necessary to provide a wholly dynamic capability provided the control strategy can manage the dynamic part to be active over and above a base of static or slow reactive provision.

The AWEA Grid Code makes no requirements of dynamic provision. By way of contrast Alberta's code is relatively prescriptive defining a minimum allowable dynamic range within the total reactive range. Québec and Ontario both call for dynamic capability but in these cases the definition is put in terms of the intention – that is to provide control similar to a synchronous machine or a dynamic reactive device.

GH considers that a dynamic capability should be present within the total reactive capability and that it should be available such that the turbine (or wind farm) can provide suitable smooth and fast reactive power provision. Alberta's code seems overly prescriptive in this respect although it does create a benchmark regarding required dynamic capability. GH considers that the CanWEA Base Code should include a dynamic requirement in the form of its intention but that this should be further discussed as to its definition. This may require Alberta to reconsider the current definitions whereas it will bring clarity to those of Québec and Ontario.

Item 4.
All the current codes recognise that part of the capability may be provided from the turbines and part from separate reactive compensation devices, probably located at the turbines or point of interconnection.

GH considers that flexibility is useful in that it allows projects to meet the reactive requirements considering a variety of turbines of different types and capabilities together with the use of separate reactive compensation. From the perspective of the system operator this has to be acceptable provided the wind farm provides the required capability at the defined point. GH therefore considers a clause to this effect should be included within the CanWEA Base Code.

Recommendations

A requirement for reactive capability should be included within the CanWEA Base Code but should be allowed to vary by a) province, and b) site. The recommended form of requirement is as follows:

1. Reactive capability at full output.

   A capability providing 0.90 lagging to 0.95 leading at full MW output, and meeting the further requirements of reactive capability as set out below will allow automatic interconnection regardless of a) province or b) site specific conditions.

   If a reduced capability is sought then this is to be determined by the following:

   a) In accordance with fixed provincial rules.

   b) In accordance with the findings of System Impact Studies developed for the specific site and which show the actual maximum capability that is required.

   The intention of this clause is to allow the actual reactive capability to be varied according to needs thereby avoiding unnecessary costs.

2. Reactive capability at reduced output.

   A capability providing reactive power up to the power factors 0.90 lagging to 0.95 leading throughout the power output range, and meeting the further requirements of reactive capability as set out herein will allow automatic interconnection regardless of a) province or b) site specifics. In addition to this the wind farm should offer a capability beyond this to the system operator if reasonably available through the turbines.

   If a reduced capability is sought then this is to be determined by the following:

   a) In accordance with provincial rules

   b) In accordance with the findings of System Impact Studies developed for the specific site and which show the actual maximum capability that is required.

   The intention of this clause is to allow the actual reactive capability to be varied according to needs thereby avoiding unnecessary costs.

   It should be noted that Québec currently requires the MVAr defined by item 1 to be available throughout the MW output range.

3. Dynamic reactive capability.

   Subject to the findings of 1a) and 1b), at least a portion of the reactive capability should be dynamic. The control system for the reactive capability should provide that the dynamic capability is always available such that the provided capability at the point of interconnection appears to the system operator as similar to either a synchronous machine or a dynamic reactive device and hence is capable of meeting any dynamic reactive requirements most notably in regards to voltage control.

4. Balance of reactive sources.

It is wholly satisfactory to provide all or part of the reactive power capability from the turbines or separate reactive devices located within the wind farm provided the other requirements pertaining to reactive capability are met. In some cases this may extend to reactive compensation devices on the system operator's network where this has been identified as a solution and agreed through 1a) and 1b).

5. All reactive capabilities are defined at the point of interconnection. This is normally the high voltage side of the main grid transformer. It is noted that Alberta currently defines the requirements on the lower voltage side of the main grid transformer.

GH also recommends that the detailed characteristics of this requirement be taken forward by a working group or similar. In particular there is a need to identify the necessary extent of the dynamic capability and the detailed performance requirements in the other categories. CanWEA may also wish to consider discussions on reducing the lagging range to 0.95, which GH considers likely to be realistically sufficient for system operators, and further opening discussions on the required MVAr capability at reduced MW loading noting Québec's requirements. The effect of frequency and voltage variations on reactive power capability should also be discussed and identified. This is an important point as it is generally agreed that a full lagging capability at high system voltage will not be required and a full leading capability at low system voltage will not be required. This latter is recognised in the detail of some Grid Codes such as that of Great Britain, see also Section 4.7.

4.5.6 Voltage control

As noted in Section 4.5.5, voltage regulation and the ensuing need for reactive power control are common features in the existing Canadian interconnection requirements for wind and the AWEA Grid Code. Voltage control has also been identified by many other provinces as a major concern. It is therefore important that voltage control is considered within the Base Code and that the requirement is related to any requirements on reactive power capability.

AWEA
The AWEA Grid Code does not specify any detailed requirements for voltage control but instead notes that it may be required on a site by site basis and that a reactive power capability may therefore be necessary. As voltage control is largely a local system issue GH considers this a reasonable approach.

Alberta
The Alberta AESO requirements are more prescriptive than the AWEA Grid Code, specifying minimum reactive capabilities and definite voltage regulation capabilities applicable to the low voltage side of the transmission connecting transformer (generally MV). AESO requires a wind farm to have a continuously acting, continuously variable, closed loop controller for voltage regulation with the following salient features:

- Controllable set point between 95% voltage and 105% voltage.
- A band width of +/-0.5%.
- A droop adjustable between 0% and 10%.
- Calibrated such that a change in reactive power will achieve 95% of its final value no sooner than 0.1 seconds and no later than 1 second following a step change in voltage.

AESO also make further clarifications including the requirement for a wind farm operator to be available, and the extent to which external voltage regulation may be relied upon.

Ontario
The IESO requires wind farms to have the capability to control voltage but gives no further detail. Some information pertaining to voltage regulation is given as part of the IESO's requirements on reactive power provision, see also Section 4.5.5.

Québec
In 2003, Hydro Québec TransEnergie required all wind farms that are capable to do so to assist with transmission system voltage control.

In the most recent update of their requirements in December 2004 [4.4] this is superseded by a requirement for all generators to provide voltage control which must be continuous, dynamic and rapid, and comparable to that of a synchronous generator. Projects are required to control voltage according to the range of VAr specified, see Section 4.5.5.

No quantified specific technical detail as to the expected performance is given.

Summary

It is clear that turbine manufacturers and wind farm developers should be able to provide a voltage control facility although GH considers that this is, as the AWEA Grid Code considers, should be site specific both in terms of necessity and extent of capability.

GH therefore recommends that voltage control is included within the Base Code but made an optional requirement to be included at the System Operator's discretion as applicable to a) provincial requirements, and b) the site. If it is to be included then a common form of control is preferable and should be agreed such that manufacturers and wind farm developers can develop and use standard packages for the requirement. Such detail is not considered appropriate to this work but would be appropriate to the ongoing development of the Base Code.

GH considers that specifying a definite extent of capability has various pros and cons and this decision is probably best left to CanWEA and its members. Clearly a defined capability will also lead to standardisation and reduction of costs, but is likely to require a design to meet the most onerous requirements. An intermediate solution might be to define the control requirements (see AESO comments below) and leave the physical capability open, perhaps with two or three pre-defined capabilities thereby capturing the benefits of both standardisation and flexibility. It is worth noting that voltage control capability is largely defined by reactive capability, discussed in Section 4.5.5.

Although AESO's requirements at first appear prescriptive, GH considers that they are typical of the detailed requirements that are set out for voltage regulation and as such are useful in providing turbine manufacturers and wind farm developers with the performance requirements they should aim for with voltage control. In some ways this is similar to specifying the detailed behaviour of turbines during LVRT (see Section 4.5.8). As noted above, GH sees benefits in standardising the minimum control performance requirements across Canada.

Recommendation

A requirement for voltage control should be included in the CanWEA Base Code but should be open to variation according to a) province, and b) site specifics.

1. Voltage Control at the point of interconnection (or otherwise agreed) is a requirement. If the control is capable of utilising the agreed reactive capability of the project defined elsewhere then interconnection is automatic regardless of a) province, and b) site specifics.

   A reduced requirement for voltage control may be sought in accordance with the following:

   a) Provincial rules.

   b) The findings of System Impact Studies developed for the specific site and which show the actual maximum capability that is required.

   It should be noted that either a) or b) may define a reduced requirement which may in some circumstances become no requirement at all.

The intention of this clause is to allow the actual required voltage control capability to be varied according to needs thereby reducing over design and unnecessary costs. This voltage control requirement must be related back to reactive capability requirements.

GH also recommends that the detail of the voltage control system performance be discussed through ongoing discussions. Alberta's specification would make a suitable starting point.

4.5.7 Frequency response

AWEA
The AWEA Grid Code makes no comments or requirements on frequency response.

Alberta
The Alberta AESO interconnection requirements make no requirements on frequency response. However, a clause is included stating that if found necessary in the future a requirement for curtailment in response to abnormally high system frequencies might be implemented.

Ontario
Ontario's IESO does not specify any requirements for frequency control.

Québec
In their December 2004 update on requirements [4.4], Hydro Québec TransEnergie states that they may require the addition of a frequency control system to reduce output at times of high frequency. No further detail is provided and hence the extent to which this represents a frequency response system or simply a mechanism for high frequency curtailment is not clear.

Summary
None of the current codes specify frequency response requirements at present, although GH notes that such requirements are being put in place in other parts of the world. Both Alberta and Québec note that curtailment during high system frequencies may be required and Québec further notes that the implementation of a frequency control system may be required.

GH considers that the implementation of a frequency response requirement is not, at present, necessary. Such a requirement may become necessary in the future if and as penetrations of wind energy increase significantly and it is therefore pertinent to at least note this. It is also worth noting that frequency response will require turbine power control capability which GH has already recommended is not made a requirement but is noted as desirable.

Regarding curtailment during abnormally high frequencies, GH views this as a system emergency action which is not relevant to frequency response requirements. This may best be dealt with as part of the frequency tolerance issue discussed earlier.

Recommendation
GH recommends that frequency response is not implemented as a requirement within the CanWEA Base Code but instead is noted as a probable future requirement for new projects, which will require a capability to control output power in accordance with frequency variations.

As and when the time arises, this requirement should be implemented in a variable manner according to province. The requirement should be only introduced as and when each province requires it.

GH further recommends that the performance requirements of frequency response and its associated control system are discussed through the ongoing CanWEA Base Code development process.

The need for curtailment due to abnormally high frequencies should be treated as a separate issue, possibly as part of the frequency tolerance issue.

4.5.8 Low Voltage Ride Through

Low Voltage Ride Through (LVRT) requirements appear in all the transmission interconnection requirements currently in place for wind farms in Canada and in the AWEA Code. In addition, LVRT has been identified as a concern in other provinces yet to develop any interconnection requirements, e.g. Prince Edward Island. Developing a consensus over what can be a difficult and contentious requirement is therefore essential.

AWEA
The AWEA requirements define LVRT as the ability to ride-through low voltage events caused by power system disturbances outside of the wind plant, see [4.1]. The requirements apply to voltage measured at the point of interconnection. The point of interconnection is understood to be at the transmission voltage (i.e. on the high voltage side of the wind plant substation transformer(s)).

Key points of the requirement are a voltage dip depth to 15% retained at the interconnection point, with a linear recovery to 90% retained voltage after 3s from the fault incidence. The requirement also clearly states that plant not meeting the characteristic of Figure 4.6 should still be allowed to connect provided System Impact Studies show the full requirement is not necessary and the plant does meet whatever is necessary, i.e. the requirement does not apply unilaterally.

GH understands this requirement is likely to move to that defined by Hydro Québec TransEnergie as of 2007. This requirement is detailed further on.

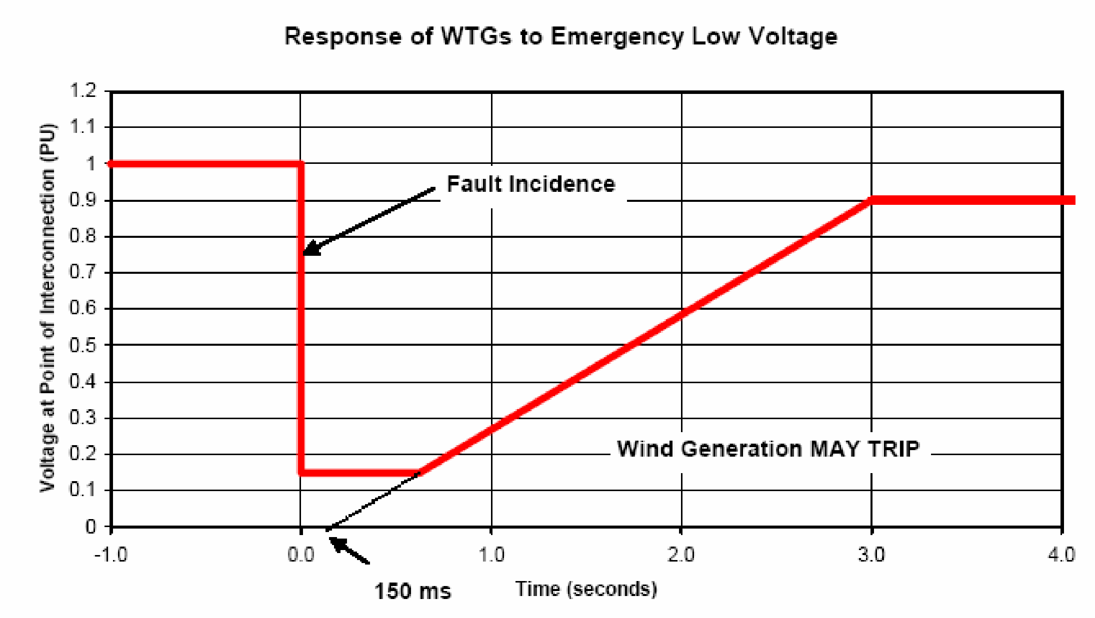


Figure 4.6: AWEA Low Voltage Ride Through capability until end 2006 [4.1]

Alberta

The Alberta AESO LVRT requirement is shown in Figure 4.7. It is identical to the AWEA requirement although AESO does not allow for variation on a case by case basis. It also applies to voltage at the point of connection and all transmission connected wind farms above 5 MW capacity. GH notes that this is inconsistent with Alberta's reactive capability and voltage control definitions which specify the low voltage side of the main transformer. Figure 4.7 also shows the continuous voltage tolerance requirements which are +/-10% of system nominal voltage, see also Section 4.5.3.

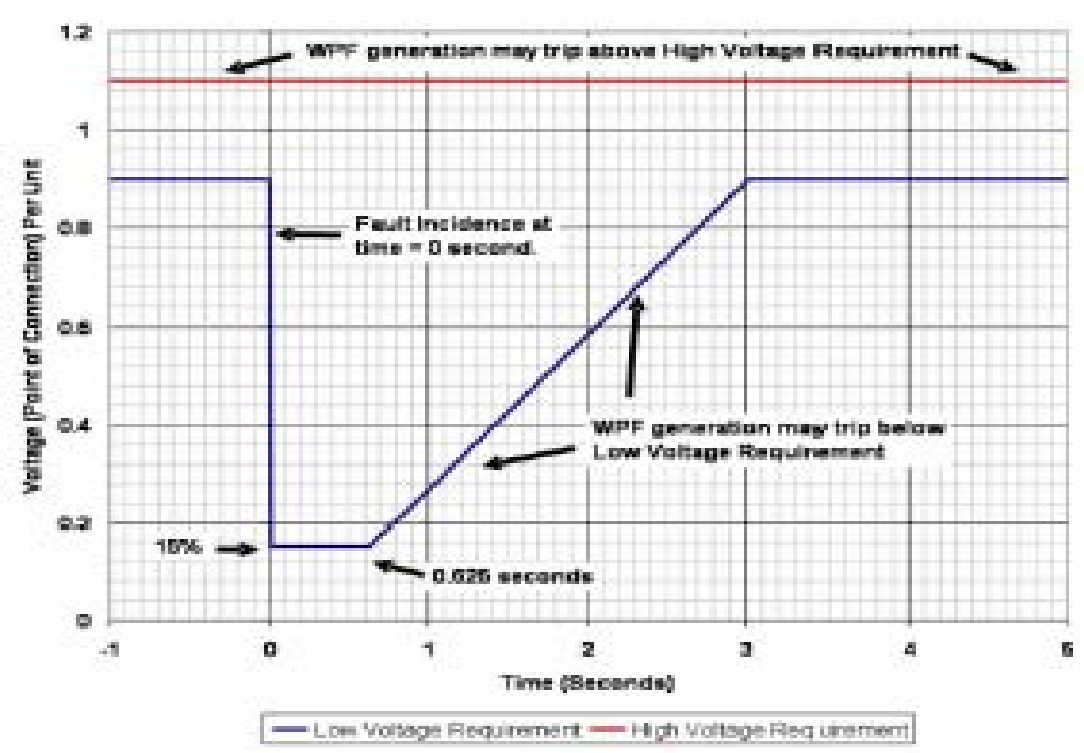


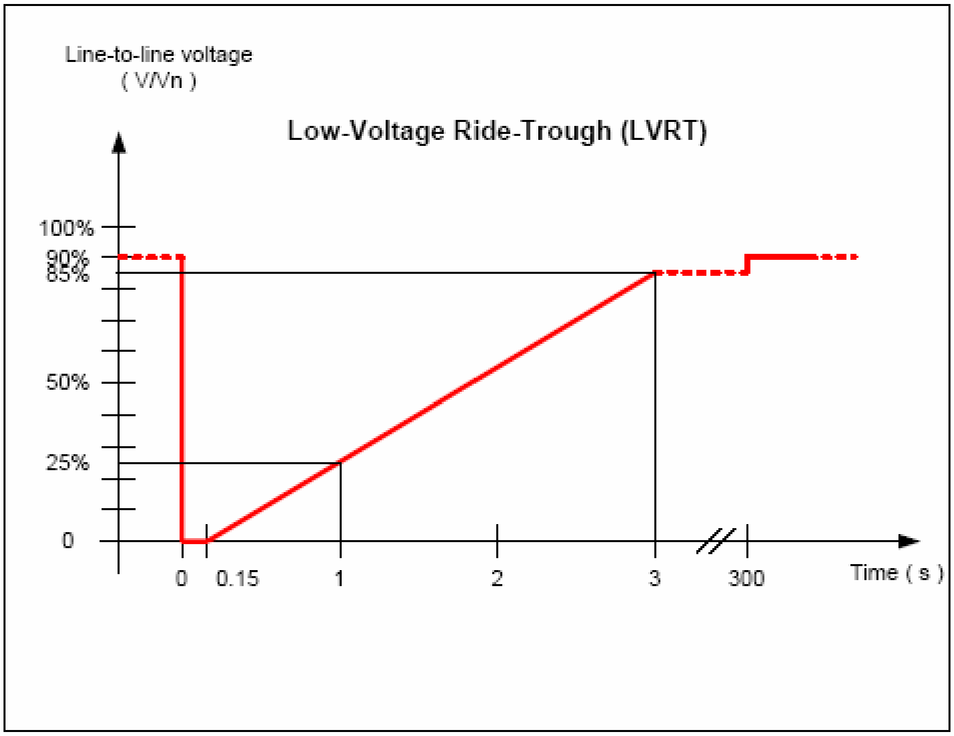
Figure 4.7: Alberta AESO Low Voltage Ride Through capability [4.2]

Ontario

The IESO states in [4.5] that the generation units are required to ride through contingencies on the system resulting in low voltage (and high voltage – see also Section 4.5.3). No further detail of the requirement is given. In GH's experience with IESO this requirement is defined through the System Impact Studies and hence the level of LVRT that needs to be provided is defined on a case by case basis, but in any case is unlikely to require a capability beyond that defined by the Alberta and AWEA Grid Codes.

Québec

In December 2004 Hydro Québec TransEnergie issued an addendum [4.4] which set out an explicit LVRT requirement shown in Figure 4.8 which applies at the point of interconnection. The requirement is similar to Alberta and AWEA's requirements if extended to zero percent voltage, although the recovery limit is slightly slower reaching 85% voltage in 3s, whereas Alberta and AWEA's current requirement reach 90% in 3s. Hydro Québec TransEnergie's initial and final recovery voltages reflect their voltage tolerance requirements (i.e. banded at 85% for 300s and other points – see also Section 4.5.3). The requirement in Québec is thus more onerous on turbines than the current AWEA and Alberta requirements.



Note: Positive sequence voltage at the fundamental frequency

Figure 4.8: LVRT requirements in Québec [4.4]

A note on NERC

At time of writing agreement had been reached with NERC in respect of the AWEA Grid Code that as of 2007 the requirement would be extended and be the same as that in Québec. As many provinces are members of NERC in some form this implies that the Québec requirement is likely to see (voluntary) enforcement as of 2007 across Canada.

Summary

LVRT has been identified in Section 2 and 3 as a major concern for system operators since it is essential for both local and global security considerations. All three of the current Canadian codes and the AWEA Grid Code also set out an LVRT requirement. GH considers that an LVRT requirement should be a mandatory requirement of the CanWEA Base Code but that there is scope to make it a variable requirement on according to the requirements of a) provinces, and b) individual sites.

With the exception of Ontario the current codes show a good degree of commonality. Key similarities are:

- The shape of curve that is defined in terms of instantaneous dip, flat minimum voltage level and linear recovery.

- Québec's code extends the requirements to zero voltage but retains the time and voltage relationship of AWEA and Alberta.
- A common 3s recovery time to "steady state" voltage limits, albeit a 300s 85% limit in Québec rather than 90%.

GH considers that the similarities cannot have been arrived at independently and that each has examined other codes in developing their LVRT requirements. It is noteworthy that Québec developed their LVRT capability last of the three and appears to have taken a view to extend the other codes.

GH considers that the Québec LVRT requirement is likely to become a standard across many Canadian provinces and that Alberta and other codes will cede to this. The CanWEA Base Code should thus reflect the current Québec LVRT requirement.

GH also considers that the LVRT capability defined from the above should be a standard allowing automatic interconnection regardless of a) province or b) site specifics, but that the requirement is phrased similar to the AWEA Grid Code to allow for less onerous requirements if shown to be acceptable due to a) provincial requirements, or b) site specific System Impact Studies. Such variability would also allow for the short term relaxation of LVRT requirements that will be in place until the end of 2006.

Finally, GH considers that a 3s recovery is suitable but a footnote is made in respect to the 85% voltage 3s recovery of Québec. In Section 4.5.8 GH commented that a movement towards a +/-15% limited time duration voltage tolerance may be justified, and this should be noted in respect to the LVRT requirements.

None of the current Codes identify explicit requirements on the turbines during the fault. Other parts of the world have seen similar requirements on fault ride through develop into more detailed descriptions of how turbines should behave during faults rather than just "ride through". Such detail may include issues of whether stator and rotor must remain connected to the power system, whether fault current is required, issues with pitching and adjusting prime-mover power throughput, and the balance of real and reactive power that should ideally be produced. GH does not at this time see a need to specify such detail as part of the Base Code, but cautions on this point since turbine manufacturers have not been clear on exactly what they are required to do or aim to achieve by riding through faults. Hence, GH recommends this issue is discussed as part of the ongoing Base Code development to ensure system operators get what they need from LVRT and turbine manufacturers are clear on what turbine behaviour is expected. GH considers this should be progressed as part of the ongoing process once a Base Code LVRT requirement is agreed.

None of the existing codes deal well with the cause and characteristics of the voltage depression. A particular issue is when the depression is not phase balanced and there exists significant negative phase sequence. GH considers that a sub-clause should be developed to make it clear as to what extent tolerance to negative phase sequence is required during LVRT. This is best dealt with through the ongoing discussions regarding the Base Code, and the LVRT requirement initially implemented based on a phase balanced voltage depression.

A further issue is the fault clearance time. It is implicit that this is the duration of the maximum dip (minimum voltage) but not stated. CanWEA should seek clarity from the transmission system operators on this point.

Recommendation
GH recommends that LVRT is included in the CanWEA Base Code as a mandatory requirement but allowed to vary according to a) province, and b) site specifics.

1. An LVRT capability is required. Any project meeting the requirements set out by AWEA from 2007 – that is to remain connected for voltages reduced to 0% for up to 0.15s, thereafter followed by a linear recovery to 85% voltage after 3s – shall be allowed automatic interconnection regardless of a) province or b) site specifics.

2. A reduced requirement for LVRT may be sought in accordance with the following:

   a) Provincial rules.

   b) The findings of System Impact Studies developed for the specific site and which show the actual maximum capability that is required.

   It should be noted that either a) or b) may define a reduced requirement which may in some circumstances become no requirement at all.

   The intention of this clause is to allow the actual required LVRT capability to be varied according to needs thereby reducing over design and unnecessary costs.

3. The requirements apply at the point of interconnection which is normally defined as the high voltage side of the main grid transformer unless otherwise agreed.

4. It is noted that LVRT may require tolerance to significant negative phase sequence for short periods and the plant should be capable of this. Items 1 -3 apply primarily to voltage depressions under balanced phase conditions.

GH recommends that the detail of the turbine behaviour be discussed through ongoing discussions such that system operators and turbine manufacturers can come to a consensus on what behaviour is required of the turbines, if any, during LVRT.

GH has added item 4 following the considerations of Section 4.5.10 and recommends the detail of this requirement is discussed as part of the ongoing CanWEA Base Code discussions.

4.5.9 Power System Stabilisers

Power System Stabilisers have been noted within Section 2 as a possible future requirement on wind farms in certain areas of the world including North America.

AWEA
The AWEA Grid Code does not set out any requirements in regards to Power System Stabilisers.

Alberta
It is noteworthy that the Alberta AESO interconnection requirements note they may be required if wind farms employ synchronous machines, which is unlikely (although synchronous machines may well be used via full AC/DC/AC conversion). It is also noteworthy that other countries

around the world have looked at the use of Power System Stabilisers but at present not required this function from wind farms.

Ontario

The Ontario requirements set out no Power System Stabiliser requirements.

Québec

In their December 2004 set of requirements update [4.4] Hydro Québec TransEnergie note that stabilisers may be required. No detail other than this simple statement is given.

Summary

Given the current status in North America and the rest of the world with implementation of Power System Stabilisers on wind farms, GH does not recommend that requirements for wind farm Power System Stabilisers are at present developed within the Base Code, but considers that turbine manufacturers and the wider wind industry should be made aware that requirements may start to appear at some point in the future.

Recommendation

GH recommends that the CanWEA Base Code contain a Power System Stabilisers note but that no requirements are implemented. As and when the time may arise, this requirement should be implemented in a variable manner according to province and the site as it is likely to be specific to certain regions, e.g. Québec. The requirement should be only implemented as and when each province requires it.

GH further recommends that the performance requirements of Power System Stabilisers are discussed through the ongoing CanWEA Base Code development process at an appropriate time in the future ahead of any possible implementation and that this discussion need consider whether wind farms provide suitable damping and system stabilisation without additional equipment or the requirements of the system operators in this respect can be met in some other way. GH considers that the ultimate need for Power System Stabilisers on wind farms is not clear and that there is some evidence to suggest wind farms provide adequate stabilisation without them.

4.5.10 Negative phase sequence voltage withstand

AWEA
The AWEA Grid Code makes no requirement for negative phase sequence withstand.

Alberta
The AESO require (under power quality) that system imbalance shall not exceed 3%. This is not a negative phase sequence requirement per se but does imply a withstand to 3%. AESO also notes in their LVRT requirements that it applies to all transmission faults on any combination of phases implying a transient negative phase sequence withstand is required.

Ontario
Although not noted within [4.5], the Ontario Market Rules [4.6] state continuous operation is required within an imbalance range of 2%. Generators are required to not contribute more than 1% with the units unsynchronised.

Québec
Québec makes no specific requirement for Negative phase sequence withstand. GH suspects that any such requirements are subsumed into Québec's other requirements.

Summary
Negative phase sequence withstand is identified within the Alberta and Ontario codes and is a common requirement around the world.

It can be considered part of power quality when taken on a continuous basis (usually system limits are 2% or 3%) and usually appears within this category. Modern turbines are easily able to withstand 2% and most 3% without significant issue. GH considers that continuous negative phase sequence withstand is thus probably best subsumed into the general power quality requirements on projects.

Regarding negative phase sequence withstand during short durations, and specifically as part of LVRT, GH considers that a note is made within the CanWEA Base Code LVRT requirement that the requirement applies to all faults including unbalanced faults and that the turbines may therefore need to ride through significantly unbalanced voltages with high negative phase sequence currents for short periods of time. The extent to which LVRT capability should accommodate negative phase sequence should be discussed as part of the ongoing CanWEA Base Code development process.

Recommendation
GH recommends that no explicit negative phase sequence requirement is written into the CanWEA Base Code. Instead, GH considers that continuous withstand can be considered part of the ongoing power quality standards and that negative phase sequence withstand arising during LVRT events should be noted within the CanWEA Base Code requirements on LVRT, see

Section 4.5.8. The extent to which the LVRT capability should accommodate negative phase sequence should be discussed as part of the ongoing CanWEA Base Code process.

4.5.11 Provision of inertia

Provision of inertia has not been identified as a major concern in North America at present and is not identified in any of the current codes. GH therefore recommends this is not included in the CanWEA Base Code but may be introduced as a discussion point through the ongoing development process.

4.5.12 Information provision

AWEA
The AWEA Grid Code concentrates on two aspects of data provision – Turbine models, and data exchange allowing project developers to “self-study” interconnection.

Regarding models, the Code recognises that models are in need of constant update and improvement and details that this should be undertaken on a federal basis whereby the same model will be developed in conjunction with and be equally satisfactory to all system operators. This would seem a very sensible approach to the modelling issues that abound around the world with different system operators applying different levels of stringency to the models that turbine manufacturers are providing them with.

Regarding self-study, the Code requires that project developers are allowed to enter an interconnection queue and self-study the interconnection. This would normally attract the standard fee for queue entry and require a level of data exchange with the system operator. This is largely aimed at overcoming the difference in design timescales that a wind farm and a transmission system operator work to and the fact that wind farm design (and turbine selection) iterates with the system it connects to and is often only completed months before connection. Once the project developer has completed self-study to a point where a turbine and reasonable design are established then this is provided to the system operator for their System Impact Studies.

GH considers that this is a useful approach to a very common problem with interconnection studies. Clearly there is a liability on the developer in that they must identify any grid issues to the grid operator within their self-studies. Failure to do so would result in the system operator’s studies revealing the issue rather too late resulting in additional cost and delay to the project.

Alberta
The AESO requires that a PSS/E model of the turbine is provided for use in system studies, and that this model may be provided to other WECC members for interconnected system studies.

AESO put the onus upon the wind farm to provide studies to demonstrate the LVRT requirement is met and the reactive power requirements are met.

AESO require supplementary data demonstrating validation through physical testing that the turbine model is correct and the voltage regulation works and is compliant.

AESO also requires performance testing to show compliance with the interconnection requirements in respect of the following:

- Voltage regulation capability.
- Reactive capability.
- Voltage regulation to set point.
- Compliance with voltage flicker and harmonics standards.

Ontario
IESO requires the project to complete their facility registration process which implies data provision to common levels of detail for transmission system connections. IESO also requires evidence that not only the loadflow and stability data and models are valid but also the equipment installed meets or exceeds the performance predicted with the information used in the connection application and studies. GH is aware that IESO does have reservations over models being provided and used for wind turbines at the present time and this clause does support and indicate value in the AWEA Grid Code's call for an ongoing development and validation process of turbine models.

IESO also require evidence of validity via either type tests done in a controlled environment or commissioning tests done on-site.

Québec
Hydro Québec TransEnergie requires detailed wind turbine model data in IEEE model format or as a suitable PSS/E model for use. This is in addition to the data required in Appendix B of their May 1999 document [4.7].

Summary
GH considers that the requirements of data provision are largely non-performance related and can be dealt with outside of the CanWEA Base Code. However, GH also considers that data provision is always required with interconnection, and as the AWEA Grid Code identifies, is an issue at present. GH therefore considers that requirements on data provision should be included within the CanWEA Base Code as a route to gaining a consensus and resolving current issues.

The data provision requirements can be broken out into four categories:

1. Standard planning and operational data usually provided prior to connection and describing the technical characteristics of the plant.

2. Detailed wind turbine simulation models. This is really a subset of item 1 but as this is proving to be a problematic issue worldwide GH considers it merits a separate consideration.

3. System Impact Studies. These are the studies that are conducted to determine the impact of a wind farm on the system and the resultant site specific interconnection requirements.

4. Compliance testing. GH has chosen to add this as compliance testing is a rising issue and GH anticipates that there will be a need in Canada to determine what level of testing is appropriate to wind farms.

Item 1.
This data is not in general problematic and is provided by any project (wind or other) as a normal part of the interconnection process. Transmission system Grid Codes generally contain schedules of data requirements which can be used as a guide to the appropriate data provision, and these are generally provided by the system operator at time of connection application. GH considers that the CanWEA Base Code should just contain a clause to this effect.

Item 2.
Provision of wind turbine models in suitable simulation formats of either Siemen's PSS/E or General Electrics PSLF is proving to be an issue with all manufacturers continually updating and modifying their models for accuracy and with ongoing turbine design modifications. Partly as a result of this, but also as a result of some inadequate models being provided, system operators lack confidence in the models. The AWEA Grid Code identifies this issue and calls for an ongoing process whereby models are updated and system operators are involved in overseeing the process and to some extent approving the models. GH considers that this would be a good way to proceed with resolution of the modelling issues that currently abound. GH does not consider this relevant to the CanWEA Base Code, but worthy of note and worthy of progression as a separate workstream outside of this work.

Item 3.
The main issue here is not with the studies themselves, or the provision of the data (item 1) but with timing. This is noted within the AWEA Grid Code. It is quite common for wind farm projects to only select the turbine type and complete the detailed design in the months immediately prior to connection. Such project timescales are quite new and rather short to system operators who are used to working in timescales of years both for interconnection procedures and grid works.

AWEA has proposed a bold approach to this whereby a project may enter the grid connection process and queue, but perform system impact studies itself. This allows projects to make design decisions and assess the works the system operator will need to undertake well in advance. These works can then be progressed on appropriate timescales. Once the project has reached a suitable design stage it can provide the data of item 1 and 2 to the system operator who can then confirm the works in progress with their own studies as required. This should largely avoid issues with timing. Clearly, if the project developer has ill advised the system operator, either by poor studies or poor interpretation, then they will be liable for the consequences. GH considers this as likely to offer a good route through connection where timing is going to be an issue. The detail of how this will work needs to be understood, and it will need agreement with system operators and hence discussions as part of the ongoing process of the CanWEA Base Code. GH considers it should be added to the CanWEA Base Code as a variable requirement for use by system operators once they are comfortable with it.

Item 4.

Compliance testing is becoming an issue as system operators seek proof that performance requirements are met not only via the System Impact Studies of item 3 but also through physical testing at the completed facility. Compliance testing is not uncommon with generation projects but for wind there is a need to determine what level of testing is appropriate and can be considered adequate. GH considers that the CanWEA Base Code should identify which tests a project developer should expect to be required by system operators. This is probably best dealt with through discussions as part of the ongoing Base Code development process.

Recommendations

GH recommends clauses on data provision are included in the CanWEA Base Code as follows:

The following clauses are mandatory requirements of the CanWEA Base Code as applicable.

1. Planning and anticipated operational data. Technical data will be provided to the system operator, generally in advance of connection and during application of the project for interconnection. The required data will encompass the technical and anticipated operational characteristics of the plant in detail suitable for System Impact Studies. Upon application the System Operator will provide the information pro forma.

2. Wind Turbine model. As part of item 1, the project will need to submit a detailed simulation model of the wind turbine(s) to be used in either PSS/E or PSLF format. The model shall be one that is approved by the "*AWEA/CanWEA/System Operator modelling group*".

3. Submission of an application for interconnection with preliminary data only, but with initial fees to secure registration and queue placement is allowable. In such a case the project developer will be allowed access to system data to self study the interconnection and advise the system operator appropriately to gain an interconnection schedule of works and date for interconnection. Subsequent to completion of the wind farm design and turbine selection, the project will submit the full requirements of item 1 and 2 to the system operator for assessment, and will be liable for any inaccuracies through the self study process.

   This clause is intended to ease the issues of timing with data provision and connection and is enabled only by consent of the system operator once the above process is approved. This clause is not currently enabled.

4. The completed wind farm, once interconnected, will be subject to compliance testing to physically demonstrate the wind farm performance meets that of the CanWEA Base Code. Agreement on testing is being sought and this clause is not currently enabled.

Further to item 2 GH recommends that an "AWEA/CanWEA/System Operator modelling group" be convened to oversee the production of "approved" turbine models, the validity of which cannot be queried by system operators through items 1 to 4. GH anticipates that the group will be self governing and that the various system operators will participate in the group such that all models approved are implicitly suitable for data provision without further question outside of the group.

Regarding data provision in item 1 and compliance testing in item 4, GH recommends that CanWEA seek agreement with system operators on suitable sets of data and tests and that these can be detailed within future revisions of the CanWEA Base Code for avoidance of doubt, continuity across provinces, and governance.

GH considers that item 3 should be progressed through the ongoing CanWEA Base Code development process as GH considers the detail of this process is not clear and needs careful consideration. GH notes that some provinces, such as Ontario, are virtually at the point where self study is in practice and that this clause can be enabled in accordance with provinces where agreement has been reached.

4.5.13 Operational monitoring

AWEA
The AWEA Grid Code requires the installation of a SCADA capability enabling remote command and control of:

- Limitation of maximum plant output during system emergency and system contingency events
- Telemetry communication for "automatic" forecasting/scheduling.

No detail as to what data should be made available is given.

Alberta
The AESO requires operational monitoring in accordance with its normal set of requirements for generators, items such as MW and MVAr output, and circuit breaker status, etc. These are common operational monitoring requirements across the world at transmission level. In addition, AESO requires wind speed and direction and "voltage control setpoint" (see also Section 4.5.6).

AESO also allows for provision of a monitoring/disturbance recorder.

Ontario
Projects are required to meet the operational monitoring requirements of Appendix 4.15 and Appendix 4.19 of the Market Rules [4.6]. Appendix 4.15 requires power, reactive power, voltage and (where applicable) frequency, and the status of any applicable special protection arrangements. Appendix 4.19 sets out the performance standards of the data monitoring.

IESO also allows for the provision of a monitoring/disturbance recorder.

Québec
Hydro Québec TransEnergie set out a requirement in the December 2004 requirements [4.4] for provision of data in accordance with their general rules [4.7] for the usual operational data provision but also on-site temperature, wind and ice condition data.

Summary
Operational monitoring is useful in providing the system operator with real time and historical data for system control purposes. Provision of links to the wind farm SCADA and control

systems also allow for remote control of parameters such as the required reactive capability. In addition to these points, operational monitoring provides functionality for future control implementations and forecasting. Since operational monitoring appears in all the current codes and is a normal part of Grid Codes worldwide, and provides clear benefits at relatively low cost, GH considers it should be included within the CanWEA Base Code. GH considers that wind farms should expect to provide a minimum set of data requirements and allow for control communications.

Recommendation
The provision of operational monitoring is mandatory and projects should liaise with the relevant system operator and expect to provide at least some of the following data through real time communications:

- MW import and export
- MVAr import and export
- Voltage
- Wind speed and direction
- Site temperature
- Status of circuit breakers and/or switches
- Number of turbines available/unavailable

Other data transmission may be required to be agreed on a) a provincial basis, and b) a site specific basis.

In addition to the above data the wind farm should expect to provide at least one automatic channel whereby control commands issued by the system operator can be received and acted upon. The requirements of the control channels and interface are to be agreed on a) a provincial basis, and b) a site specific basis.

4.5.14 Other current requirements

This section covers other requirements of the current suite of AWEA and Canadian provincial interconnection requirements not covered above.

AWEA
The AWEA Grid Code does not contain any further requirements.

Alberta
In the AESO set of interconnection requirements there also appear the following:

- Grid transformer requirements including winding, tap change and earthing.
- Situations requiring disconnection and the means by which it is achieved.
- Protection requirements in line with AESO standards.
- Power quality requirements in line with industry standards (qualified as IEC 61000-3-7 for voltage flicker, IEEE 519 1992 for harmonics, voltage unbalance to remain less than 3% in line with NEMA MG1 – 14.33, and resonances to be avoided).
- Grounding and lightning protection requirements.

- General operational and health and safety issues.
- Isolation and metering.

Ontario

The IESO interconnection rules also include the following:

- A note that special protection arrangements might be required, likely to be intertripping for load rejection situations.
- Auxiliary supplies are not to trip the wind farm due to excursions within the specified requirements, as with Québec.
- Requirements on items of plant in terms of specification and operation, including tap changer cycles, circuit breaker specification, double circuit connection requirements, and requirements of the applicable transmission and distribution codes among other items.

Québec

Hydro Québec TransEnergie requires the following additional items:

- Auxiliary supplies are not to trip the wind farm due to voltage and frequency excursions within the specified requirements.
- Protection must be selective enough to not trip the facility during voltage and frequency excursions within the specified requirements.
- A note is made on voltage flicker with reference to Hydro Québec TransEnergie's May 1999 document [4.7].

More importantly Hydro Québec TransEnergie states the following:

"The transmission provider may ask that the wind plant take part in providing such ancillary services as voltage control, network stability and speed or frequency control.

The intermittent nature of wind resources will have an impact on managing the short and medium-term supply-demand balance. The transmission provider may ask the power producer to obtain any appropriate third-party resources needed to ensure load following, backup supply services and other reserves."

Notes have been made in preceding sections in respect to Hydro Québec TransEnergie's requirements on voltage control, and frequency control, but not on stability and speed control. It can be assumed that this may require specific operation in terms of power and reactive power control and perhaps other items. The statement also implies that wind farms may expect to need to commercially contract to provide some or all of the services required if they cannot provide them. It appears the Hydro Québec TransEnergie is covering future contingencies with a blanket statement.

Summary

Most of the additional requirements set out by the codes relate to design issues in accordance with industry best practice and existing standards and codes and are not relevant to this work. GH does not therefore consider any of the above as needing attention within the CanWEA Base Code.

Recommendation

GH does not, at this time, recommend any additional requirements are placed in CanWEA's Base Code.

4.6 Summary of CanWEA Base Code proposals

Based on the qualitative proposals and the detailed analysis of requirements the proposed Base Code therefore takes the following structure. It will be based on security requirements as a minimum to ensure local and global security and cover the existing requirements. Such requirements will form a minimum access standard which if not achieved cannot allow connection.

Local and provincial differences will be dealt with through a variable set of requirements although each requirement will have a defined level which if achieved allows automatic access. It is anticipated that global issues will also be encompassed within this category but are unlikely to be implemented at present.

The Base Code is represented graphically in Figure 4.9 with Figure 4.10 showing how the provincial codes sit within the Base Code.

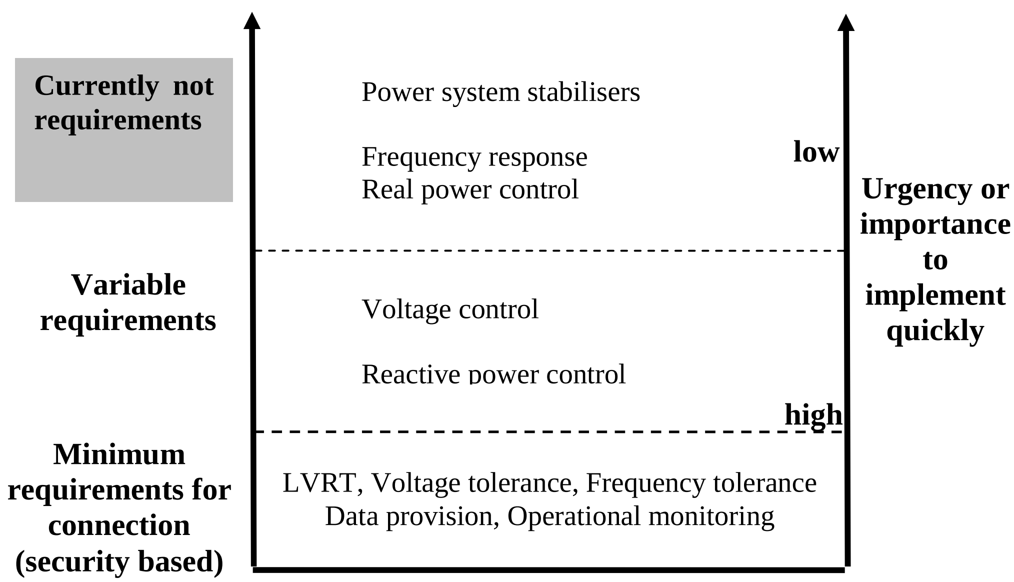


Figure 4.9: CanWEA Base Code

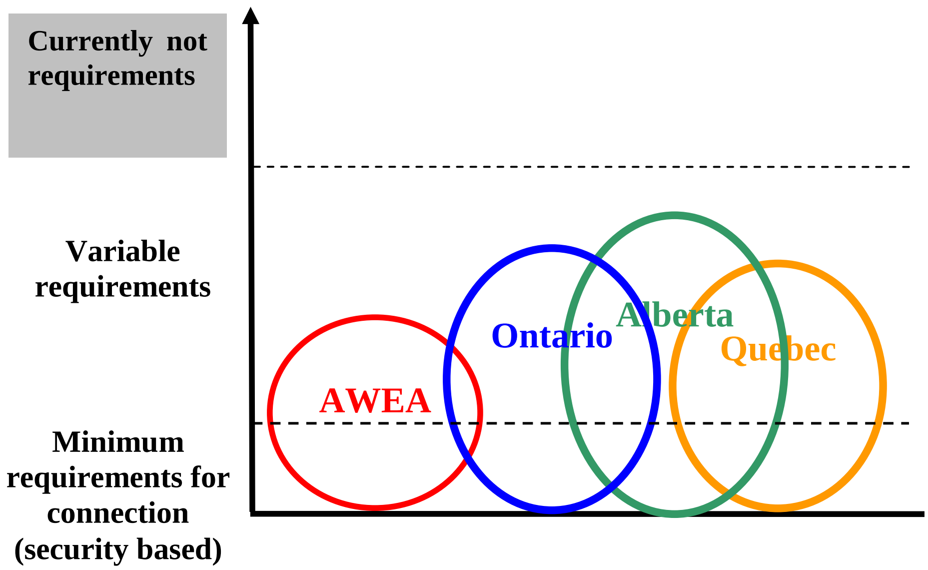


Figure 4.10: CanWEA Base Code with provincial interpretations

Once the content and structure of the Base Code are decided then the form and detail of each requirement must be decided. The existing requirements have been reviewed in the previous sections and conclusions drawn on the appropriate form of requirement for the CanWEA Base Code. Table 4.6 provides an overview summary of the requirements.

As noted previously, there is much detail to be discussed in any ongoing development process including the final form of the above proposed requirements and the finer detail of the requirements. The full set of recommended requirements are presented in Appendix C where they can be viewed together as a consistent set with the initial wording.

Base Code requirement		
Requirement	***Format***	***Detail***
Turbine reactive power control	Variable	Implement 0.95 lead to 0.90 lag at full load, and firm up dynamic and part load requirements. Actual implementation should be allowed to vary with a) province, and b) site. Suggest discuss 0.95 lag versus 0.90 lag.
Turbine power control	Noted but not required	Parked with no current requirement. Noted as desirable and likely to be required in the future.
System frequency response	Noted but not required	Parked with no requirement. Suggest discussions are opened to pave way for possible future implementation as and if it becomes necessary in the various provinces.
System voltage control	Variable	Implementation should be allowed to vary with a) province, and b) site. Suggest detailed performance requirements are discussed using Alberta requirements as a starting point.
LVRT capability	Mandatory but variable	Québec standard, but allowed to vary with a) province, and b) site. Detail to be discussed including phase unbalanced LVRT.
Frequency tolerance	Mandatory	Continuous operation between 59.4Hz and 60.6Hz. Further consideration should be given to under and over frequency requirements and the extent to which Québec can be accommodated.
Voltage tolerance	Mandatory	Continuous operation between +/-10%. Further consideration should be given to under and over voltage requirements possibly including Québec's +/-15% for 300s requirement and considering LVRT in relation to under-voltage.
Negative phase sequence withstand	No requirement	Subsumed into LVRT requirements and ongoing power quality requirements.
Data provision		Standard data to be provided. Strongly recommend adopt AWEA approach to convene ongoing modelling group and self study options. Recommend development of compliance testing requirements.
Operational monitoring	Mandatory	Selection from a standard set of real time data with variation according to with a) province, and b) site. Provision of open communication channel for system operator control instructions and similar.
Power system stabilisation	Noted but not required	Parked with no requirement. Possible discussion on the value and form of implementation in the future.
Provision of inertia	No requirement	Parked with no requirement. Possible discussion on the value and form of implementation in the future.

Table 4.6: Summary of CanWEA Base Code requirement recommendations

4.7 A note on interaction of requirements

GH has noted the need for ongoing development of the requirements and their detail. As part of the detail it is also important to understand and specify how the requirements relate to each other since they should not be taken as wholly stand-alone.

A good example of this can be seen when considering the enforcement of the full reactive power provision capability across the full voltage tolerance range. From a turbine manufacturer's perspective it is harder to import reactive power at low voltage and export at high voltage, and vice versa. From a transmission system perspective it would be very rare indeed to require reactive power export during high voltage periods since this tends to increase voltage further, and similarly to require reactive power import during low system voltages would tend to depress voltages further. It is evident that there is therefore a need to define a relationship between the two requirements to obtain something both reasonable and realistic.

This type of issue regarding interaction of requirements is often missed. In the specific case of reactive power provision and system voltage some Grid Codes do recognise and deal with this issue. One such code is that of Great Britain [4.8] and the defining relationship is shown in Figure 4.11. It can be seen that the leading (importing) power factor at low voltage is removed and similarly for lagging (exporting) power factor and high voltage.

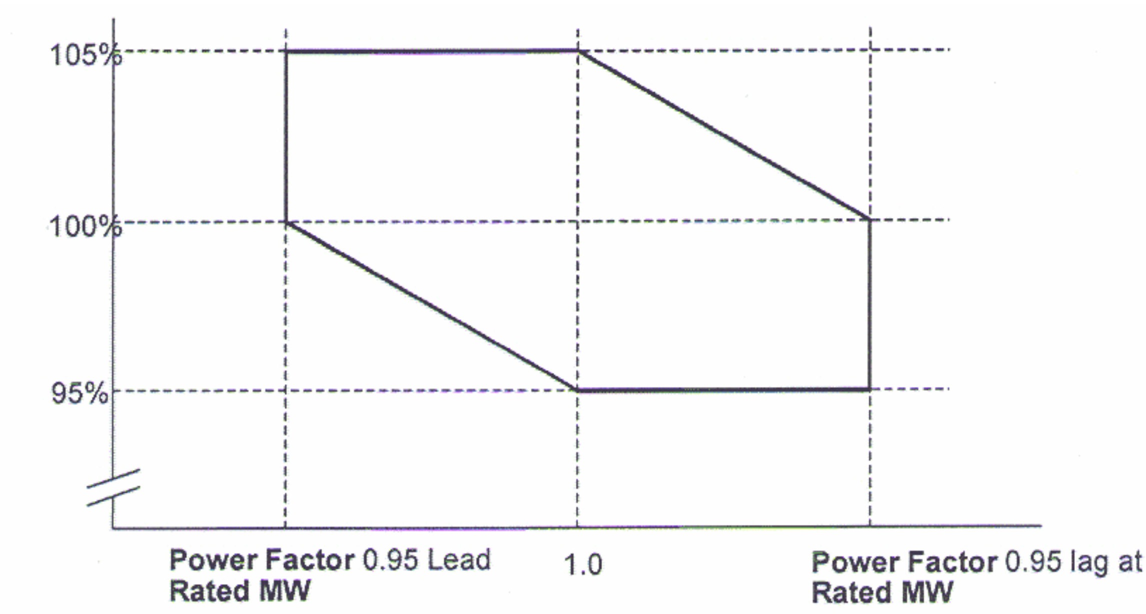


Figure 4.11: Great Britain Grid Code relationship between voltage and power factor [4.8]

Other critical points of interaction between the requirements can be identified and include tolerance to low frequencies at high voltages which is difficult for turbines and requires additional design expense.

4.8 A note on governance and legality

CanWEA should be aware that the CanWEA Base Code will need to be drawn up into a suitable legal framework which is suitable for the regulatory frameworks in place in Canada. In addition the legal text of the Code will also need to include matters such as governance of the Code, disputes and dispute resolution, and non-compliance matters.

5. IMPLEMENTATION RECOMMENDATIONS

5.1 Introduction

This report has reviewed the issues and current level of development within Canada of interconnection requirements for wind energy projects connecting at 69kV and above. Following this review GH has developed a set of ten requirements which it is recommended that CanWEA give careful consideration to for use as its Base Code.

This section of the report considers how CanWEA can implement the Base Code within the provinces where the utilities and system operators are the key stakeholders along with the wind industry.

5.2 Timing

Currently there are three defined “wind interconnection requirements” in Canada, those of Alberta, Ontario, and Québec. The capability of CanWEA to influence these Codes will be limited as the system operators who have implemented them will have given them much consideration and will likely be somewhat resistant to change them. Despite this, Grid Codes are not static documents and all of three are likely to change at some point in any case.

In addition to the above there are a number of provinces which have undertaken wind integration studies and are (probably) developing interconnection requirements although these are not yet published. Such provinces include at least BC, Saskatchewan, and Manitoba.

Even in the provinces where wind studies and interconnection requirements are currently least developed the system operators when contacted were interested in wind and were giving thought to interconnection issues. It is therefore evident that CanWEA should convene the process of implementation of its own Code as soon as possible before different provincial codes become too prevalent and too difficult to influence. GH considers that CanWEA should act upon the recommendations of this report immediately.

Time is of the essence.

5.3 Canadian working group

It is evident that Canada's provinces have strong identities and the electricity transmission systems are run by unique provincial utilities and/or system operators with largely individual markets and rules and regulations applied. The strength of identity and independence extends to the operation and regulation of the various transmission systems.

During discussions with GH no system operator identified an immediately suitable Canadian forum to discuss wind grid integration and the inception of a Canada-wide Grid Code. The task of forming such a forum therefore falls to CanWEA unless a suitable organisation, which already has the attention and respect of the various provincial system operators, comes forward.

GH considers that the best way forward is to invite the system operators to a workshop where the Base Code and CanWEA's intentions can be conveyed. The views of the system operators will dictate whether an ongoing workgroup is formed and how the Base Code will be adopted. GH considers that a process where adoption of the final code will be mandatory may be possible, but more likely will be a process leading to voluntary take up and a greater level of interaction with the wind industry when developing provincial codes. Figure 5.1 shows this process graphically.

GH considers that a suitable forum to commence this work might be the forthcoming Canadian Wind Energy Conference where a number of system operators will already be attending, or the first "transmission conference" where representatives will be together. If neither of these is suitable it may be necessary to seek an entirely separate meeting.

GH recommends that the Working Group should contain CanWEA, possibly AWEA or UWIG, the system operators, independent specialists, and perhaps provincial government or regulator representation. GH is not aware of any national organisation that can adequately represent the system operators, except perhaps the Canadian Electricity Association (CEA). An approach should only be made to CEA if sufficient of the system operators consider this to be a suitable organisation. The CanWEA representation should cover several provinces, and include project developers.

GH recommends that the Working Group considers the position of turbine manufacturers and suppliers carefully. GH has found that commercial considerations often prevent such people from contributing fully. CanWEA should be in a position to ask turbine manufacturers for assistance for specific technical issues.

CanWEA might also consider convening provincial meetings using their provincial offices. This is likely to be easier than getting all the system operators together in one forum to explain and discuss the CanWEA Base Code intentions. However this process will be more resource intensive and will not facilitate an open dialogue between system operators.

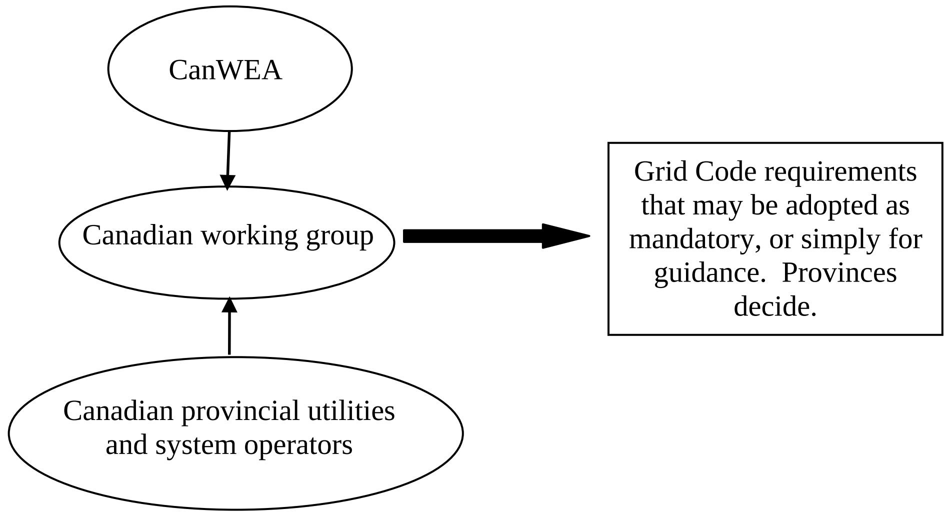


Figure 5.1: CanWEA route to Base Code implementation via a Canadian working group

5.4 North American working group

Most but not all of the provinces border and trade with the US. Interconnection and trade with the US results in participation in various regional markets and regional reliability councils. Canadian provinces are required to sign up to the requirements of various US based reliability councils, all of which are overseen by NERC. NERC set standards but these are currently voluntary although the role and jurisdiction of the various reliability councils is subject to change and NERC my take a more authoritative role in the future.

AWEA has recently filed a Grid Code with FERC which NERC has signed up to. As the requirements of NERC are passed through to its members Canadian provinces will, to some extent at least, be required to adopt NERC standards and requirements.

CanWEA therefore has an opportunity through NERC to implement the Base Code. This is probably best done with AWEA and with establishment of a relationship with NERC to develop an "agreed" Code. Unlike the route through a Canadian working group this offers a route where the Base Code is enforceable as a voluntary standard at present and possibly as a mandatory standard in the future.

This route offers a parallel path to the Canadian working group. CanWEA should note that the Canadian provincial system operators will have NERC members' rights and as such will have some consultative role. This is positive as it engages the provinces through two processes with the same aim. GH recommends this route is taken in parallel and that any working group is made well aware of both routes. This route should be initiated with AWEA as it affects the US and AWEA has already been through this route in part with the AWEA Grid Code. Figure 5.2 shows the parallel routes.

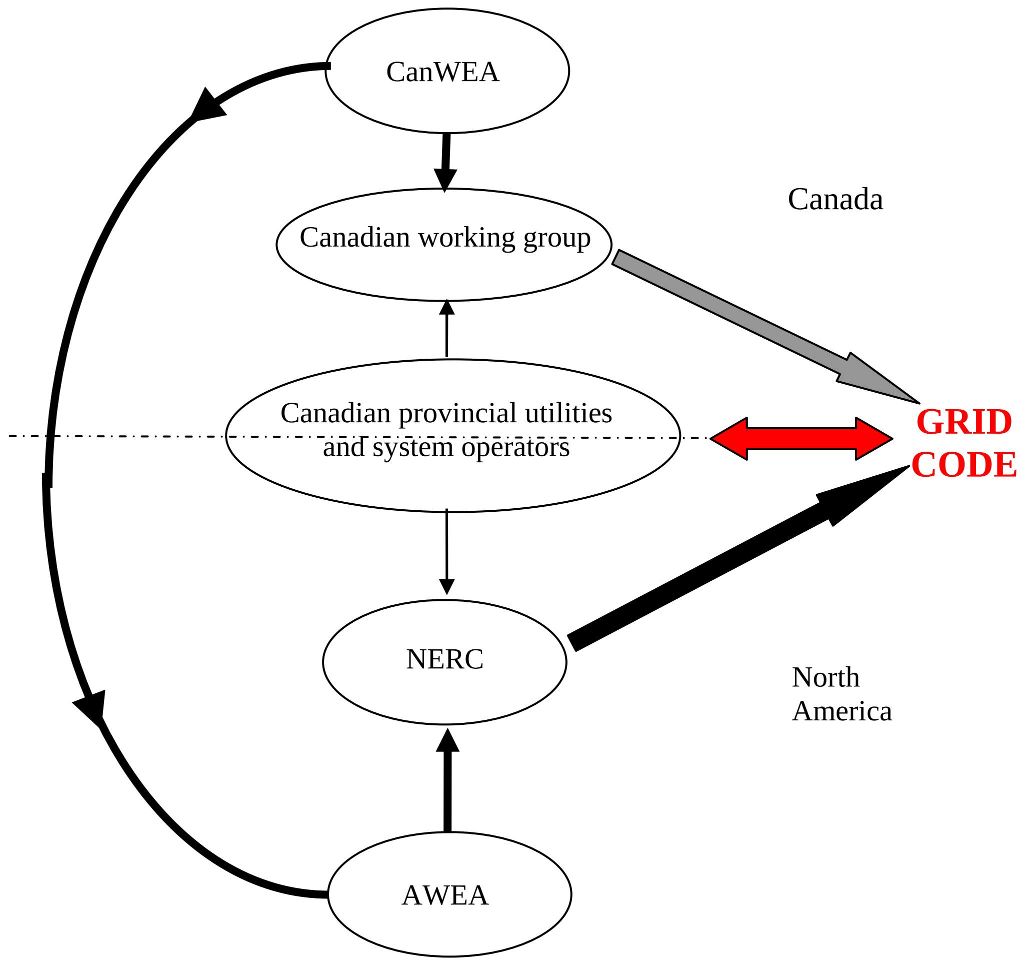


Figure 5.2: CanWEA routes to Grid Code implementation

5.5 Wind Grid Code

This document is written on the basis that the plain recommended Base Code clauses (Appendix C) are to be used as an addition to normal interconnection conditions and requirements. The Base Code is not intended to replace or supersede existing Grid Codes, although parts of it may supersede parts of existing documents.

The Base Code assumes that issues such as power quality, earthing, and protection (i.e. issues not specific to wind generation) are dealt with adequately through existing standards and design practices.

5.6 Summary recommendations

GH recommends CanWEA gives careful consideration to two routes to implementing the Base Code as follows:

1. Canadian Working Group

1. Convene a Canadian working group as soon as possible to discuss the Base Code and how it might be implemented across Canada.

2. Pending the results of 1 the working group should form the Base Code for implementation within Canada. This may be on an agreed mandatory basis or voluntary basis. The working group should continue in this form to further discuss and develop the code.

CanWEA should make it clear that the Base Code is one that the wind industry consider fair and appropriate, and is recommended good practice based on worldwide and Canadian experience.

2. North American Reliability Councils

1. CanWEA should contact AWEA to discuss working with NERC to implement the Base Code.

2. CanWEA and AWEA should jointly contact NERC to discuss working to implement the Base Code.

3. CanWEA (and AWEA) should seek to incorporate other working groups within the process. This might include WECC's "wind task force"[1] and UWIG.

Regardless of the outcomes of the recommendations GH considers that CanWEA should attempt to form a Canadian working group to discuss wind/grid integration and that this should contain system operators as well as industry representatives. GH also recommends that CanWEA work with AWEA to attempt to consolidate the current disparate working groups across North America.

---

[1] The Western Electricity Coordinating Council (WECC), which oversees the interconnected transmission system that includes Alberta, British Columbia, northern Mexico and all or portions of 14 western US states, has launched an initiative designed to improve the ability of transmission planners to predict the behaviour of wind turbines on the grid system. WECC is working to develop a basic set of generic computer models suitable for representing all types of utility-scale wind turbines in transmission planning studies.

6. SUMMARY

6.1 Outline

This report contains work undertaken by Garrad Hassan (GH) on behalf of the Canadian Wind Energy Association (CanWEA) to develop interconnection requirements for wind turbines and wind farms at the transmission level, 69kV and above. The purpose of the work has been to develop a set of basic interconnection requirements that CanWEA can take forward with Canadian provincial system operators with the aim of developing a consistent set of requirements across Canada rather than many disparate and province-specific sets of requirements.

6.2 Main findings of review

GH has undertaken a complete review of interconnection and grid integration issues in North America together with a more detailed examination of each Canadian province, its issues and progress towards a set of interconnection requirements for wind at transmission level.

Provinces operate separate markets and regulatory regimes, with individual provincial transmission system operators and rules, and no one body identified as over-seeing the system operators.

Provincial generation mix characteristics were found to vary from hydro rich provinces such as British Columbia, Manitoba, Québec and Labrador, to those dominated by fossil fuels such as Alberta and Saskatchewan. Nuclear was also found to be present in New Brunswick and Ontario where the generation mix is broader. In general, the hydro rich provinces benefit from hydro's responsiveness in integrating wind although Québec, and to a lesser extent Manitoba, are subject to some serious technical issues as most of the generation is located in the north far from demand in the south of the province.

The main issues relevant to this work were identified as follows:

1. System security issues requiring tolerance to system faults and low voltages (Low Voltage Ride Through), and tolerance to frequency variations and voltage variations.
2. Local system control issues requiring provision of reactive power primarily for voltage control. Power control to curtail output during system constraints was also identified but considered not relevant as system capacity is really an issue for the system operator in terms of reinforcement, and curtailment can be achieved by other means such as shut down of individual turbines.
3. Global system control issues, primarily frequency response, load following and generation scheduling, and the effect of perceived wind variability on these. It is recognised that scheduling and balancing the system are largely commercial matters and at lower wind penetrations frequency response can be undertaken by generators other than wind. However, frequency response is being implemented in other parts of the world and is recognised as a future issue worthy of consideration.
4. Other technical issues identified included provision of system inertia, power system stabilisation, and tolerance to negative phase sequence voltages both continuously and during system disturbances.
5. Other than the technical issues above, it is clear that simulation modelling and provision of accurate models of turbines is an ongoing problem, wind farm development timescales

are discordant with utility timescales, physical performance testing is going to become a problem area, and operational monitoring is a useful tool worth implementing.

In general terms, the technical issues identified by GH through the review of Section 2 and those identified by system operators through discussions (noted in Section 3) showed good commonality, even on more unusual issues such as low frequency oscillations (e.g. See section 2.3.10 of the review and Québec Hydro TransEnergie's comments in Section **Error! Reference source not found.**).

Other important findings included the rapid progress many provinces were making towards a set of interconnection requirements for wind and the fact that each province appeared to be doing so in isolation. Conversely to this, many provinces are interconnected with the US and trade in US markets. This means most provinces are members of NERC and as such are asked to adopt (currently voluntary) NERC standards. Action in the US by AWEA is leading to the imposition of US wide wind interconnection requirements through a federal process involving NERC.

Three provinces, Alberta, Ontario, and Québec were identified as having existing wind specific interconnection requirements. It also appeared that other provinces were either developing or giving serious consideration to developing interconnection requirements for wind.

Following on from this review work GH was able to draw recommendations on a Base Code for CanWEA to adopt, and how best to take it forward.

6.3 The CanWEA Base Code

Detailed discussions regarding the Base Code are contained in Section 4 of this report and reading this section of the work is important in understanding the final form of code GH has proposed. In addition to the basic structure and content of the Base Code, GH has made a number of recommendations with regards to the Base Code requirements and related issues, and these are also contained in Section 4.

In most cases GH has identified a set of simple Base Code requirements which must now be firmed up through a suitable forum. There is also a need to examine the interaction of the requirements and the deeper detail of how turbines are expected to perform in meeting the requirements (e.g. detailed control performance requirements, or detailed behaviour during LVRT).

The Base Code proposed by GH incorporates the existing codes developed in Alberta, Ontario, Québec, and through the American Wind Energy Association, and adopts a structure allowing variability in requirements to accommodate both provincial differences and site specific differences. The Base Code contains ten requirements, some of which are mandatory requirements, some of which are allowed to vary according to province and site specifics, and some of which are not enabled but are recommended for further discussion and development ahead of potential future implementation.

The Base Code is aimed to ensure system security as a priority with local system control issues dealt with by the variable requirements. GH has separated out global system control issues as these are not considered necessary for wind to need to deal with at present low penetrations, but ensuring requirements are noted as they may need to be implemented in the future.

The proposed Base Code is loosely defined as follows,

1.	Frequency tolerance	mandatory
2.	Voltage tolerance	mandatory
3.	Power control	not a current requirement
4.	Reactive power capability/control	required but variable
5.	Voltage control	required but variable
6.	Frequency response	not a current requirement
7.	Low Voltage Ride Through (LVRT)	mandatory but variable
8.	Power system stabilisers	not a current requirement
9.	Data Provision	mandatory
10.	Operational monitoring	mandatory

6.4 The way forward

GH concludes that CanWEA should take the Base Code implementation forward through a process of consultation with the Canadian transmission system operators within Canada but that this may not result in widespread adoption of the Base Code. GH therefore considers it important that CanWEA also adopt a parallel process with AWEA and the North American Electricity Reliability Council (NERC) which will also involve the Canadian transmission system operators but will be through established channels. More detail of the recommended way forward is provided in Section 5.

Time has been identified as of the essence due to ongoing developments throughout North America and it is recommended that CanWEA act on this work and its recommendations as soon as possible.

REFERENCES

Note: several documents are referred to in more than one section.

Section 1

[1.1] Canadian Wind Energy Association website, http://www.canwea.ca/en/

Section 2

[2.1] Géza Joós, An Overview of Wind Interconnection Codes in Canada, CanWEA Conference 2004.

[2.2] Géza Joós, Strategies for Interconnection, CanWEA/AWEA/UWIG Wind Power Transmission Workshop, Toronto 2005.

[2.3] Vestas et al, Comparison of International Regulations for Connection of Wind Turbines to the Network, undated.

[2.4] Bryan C, Smith JW, Taylor J, Zavadil B. Engineering Design and Integration Experience from Cape Wind 420 MW Offshore Wind Farm. *In Matevosyan J, Ackermann T (Eds), Fourth International Workshop on Large-scale Integration of Wind Power and Transmission Networks for Offshore Wind Farms, 20/21 Oct 2003, Billund, Denmark*

[2.5] Miller NW. Power System Dynamic Performance Improvements from Advanced Control of Wind Turbine Generators. *In Matevosyan J, Ackermann T (Eds), Fourth International Workshop on Large-scale Integration of Wind Power and Transmission Networks for Offshore Wind Farms, 20/21 Oct 2003, Billund, Denmark*

[2.6] Makarov YV, Hawkins DL. Scheduling of Wind Generation Resources and their Impact on Power Grid Supplemental Energy and Regulation Reserves. *In Matevosyan J, Ackermann T (Eds), Fourth International Workshop on Large-scale Integration of Wind Power and Transmission Networks for Offshore Wind Farms, 20/21 Oct 2003, Billund, Denmark*

[2.7] Deb S, Singh V. Modeling Wind in Deregulated Markets – Case Study: Electric Reliability Council of Texas. *In Ackermann T, Matevosyan J, (Eds), Fifth International Workshop on Large-scale Integration of Wind Power and Transmission Networks for Offshore Wind Farms, 7-8 April 2005, Glasgow, Scotland.*

[2.8] Sørensen P, Hansen AD, Thomsen K, Madsen H, Nielsen HA, Poulsen NK, Iov F, Blaabjerg F, Donovan MH. Wind Farm Controllers with Grid Support. *In Ackermann T, Matevosyan J, (Eds), Fifth International Workshop on Large-scale Integration of Wind Power and Transmission Networks for Offshore Wind Farms, 7-8 April 2005, Glasgow, Scotland.*

[2.9] Smith CJ, DeMeo EA, Parsons B, Milligan M, Wind Power Impacts on Electric Power System Operating Costs: Summary and Perspective on Work to Date. Proceedings AWEA Global Wind Power Conference, 28-31 March, Chicago, US.

[2.10] New York State Energy Research and Development Authority. The Effects of Integrating Wind Power on Transmission System Planning, Reliability and Operations. Report on Phase 2: System Performance Evaluation. 4 March 2005. (Prepared by GE Energy, Energy Consulting).

[2.11] Milligan M, Capacity Value and System Reliability Contribution from Wind Power, CanWEA/AWEA/UWIG Wind Power Transmission Workshop, 30-31 March 2005, Toronto.

[2.12] Miller NW, The Effects of Integrating Wind Power on Transmission System Planning, Reliability, and Operations of the New York State Power System. CanWEA/AWEA/UWIG Wind Power Transmission Workshop, 30-31 March 2005, Toronto.

[2.13] Saylors SW, Vendor Forum on Meeting Grid Voltage Standards. CanWEA/AWEA/UWIG Wind Power Transmission Workshop, 30-31 March 2005, Toronto.

[2.14] Moeller C, Wind In The Midwest ISO Market, Wind Integration: Focus On System Operation, Utility Wind Interest Group 2005 Annual Meeting, April 11-13, 2005, Minneapolis, MN.

[2.15] Hils D, Dynamic Scheduling Examples, Wind Integration: Focus On System Operation, Utility Wind Interest Group 2005 Annual Meeting, April 11-13, 2005, Minneapolis, MN.

[2.16] Piwko R, The Effects of Integrating Wind Power on Transmission System Planning, Reliability, and Operations of the New York State Power System, Wind Integration Workshop April 14-15 2005, Minneapolis, MN.

[2.17] Haller, M, Industry Initiatives Standards and Services, Wind Integration Workshop April 14-15 2005, Minneapolis, MN.

[2.18] Abernathy R, Wind And The Wires, AWEA Windpower 2005, May 16-18 2005, Denver, CO

[2.19] Kirby B, Milligan M, Methodology For Examining Control Area Ramping Capabilities With Implications For Wind, AWEA Windpower 2005 May 16-18, 2005, Denver, CO

[2.20] Krich A, Milligan M, The Impact of Wind Energy On Hourly Load Following Requirements: An Hourly And Seasonal Analysis, Windpower 2005, May 16-18, 2005, Denver, CO

[2.21] Milligan M, Porter K, Determining The Capacity Value of Wind: A Survey Of Methods And Implementation, Windpower 2005, May 16-18, 2005, Denver, CO

[2.22] S. Bernard, D. Beaulieu and G. Trudel of Hydro Québec TransEnergie, Hydro-Québec grid code for wind farm interconnection, January 2005.

[2.23] ABB, *Integration of Wind Energy into the Alberta Electric System – Stage 1: Voltage regulation study*. 5 May 2004.

[2.24] ABB, *Integration of Wind Energy into the Alberta Electric System – Stages2 & 3: Planning and interconnection criteria*. 5 May 2004.

[2.25] ABB, *Integration of Wind Energy into the Alberta Electric System – Stage 4: Operations impact*. 5 May 2004.

[2.26] ABB, Wind Farm Integration in British Columbia – Stages 1&2: Planning and Interconnection Criteria, 28 March 2005.

[2.27] ABB, Wind Farm Integration in British Columbia – Stages 3: Operational Impact, 28 March 2005.

[2.28] M Konig, M Luther, W.Winter, Offshore Wind Power in German Transmission Networks. *In Matevosyan J, Ackermann T (Eds), Fourth International Workshop on Large-scale Integration of Wind Power and Transmission Networks for Offshore Wind Farms, 20/21 Oct 2003, Billund, Denmark*

[2.29] SP Transmission & Distribution with Scottish Hydro-Electric, Guidance Note for the Connection of Wind Farms Issue No. 2.1.4, 17 December 2002.

[2.30] Eltra website, http://www.eltra.dk/composite-833.htm

[2.31] Jenkins N, Dynamic performance of DFIGs and system support. IEA Annex XXIII, meeting Manchester, UK, 12-13 September 2005

[2.32] Eltra website, http://www.eltra.dk/show.asp?id=15783

[2.33] L Dale, D Milborrow, R Slark, G Strbac, A shift to wind is not unfeasible, Power UK Issue 109, October 2003.

[2.34] Alberta Electric System Operator, Alberta Wind Power Variability Study letter, 11 August 2005.

[2.35] "Assessment of the energy potential and estimated costs of wind energy in British Columbia", GH report 4597/OR/01 Issue E, 25 May 2005.

[2.36] Alberta Electric System Operator website, http://www.aeso.ca/286.html

Section 3

[3.1] ABB, Wind Farm Integration in British Columbia – Stages 1&2: Planning and Interconnection Criteria, 28 March 2005.

[3.2] ABB, Wind Farm Integration in British Columbia – Stages 3: Operational Impact, 28 March 2005.

[3.3] British Columbia Transmission Corporation, 69 kV to 500 kV Interconnection Requirements for Power Generators, May 2004.

[3.4] Alberta Electric System Operator, *10-year Transmission System Plan (2005-2014)*. December 2004. www.aeso.ca

[3.5] ABB, Integration of Wind Energy into the Alberta Electric System – Stage 1: Voltage regulation study. 5 May 2004.

[3.6] ABB, Integration of Wind Energy into the Alberta Electric System – Stages2 & 3: Planning and interconnection criteria. 5 May 2004.

[3.7] ABB, Integration of Wind Energy into the Alberta Electric System – Stage 4: Operations impact. 5 May 2004.

[3.8] Alberta Electric System Operator, Wind Power Facility Technical Requirements, rev 0, 15 November 2004, www.aeso.ca

[3.9] IESO, Summary of IESO Reliability Requirements for Wind Generation Installations, 13 July 2005.

[3.10] U.S.-Canada Power System Outage Task Force, Final Report on the August 14, 2003 Blackout in the United States and Canada: Causes and Recommendations, April 2004.

[3.11] CanWEA, An Analysis of the Impacts of Large-scale Wind Generation on the Ontario Electricity System. 26 April 2005. (Prepared by AWS TrueWind).

[3.12] Gouvernement du Québec, Ministère des Ressources Naturelle et de la Faune, Évaluation de la Capacité d'Intégration du Réseau Intégré d'Hydro-Québec au regard de l'Ajout de Parcs de Production d'Électricité à partir d'Énergie Éolienne. June 2005. Document no. P44 0409 E021 DOC (Prepared by RSW Inc).

[3.13] FERC homepage www.ferc.gov

[3.14] National Energy Board, Outlook for Electricity Markets 2005 – 2006 An Energy Market Assessment, June 2005.

[3.15] National Energy Board, A Compendium of Electric Reliability Frameworks Across Canada, June 2004.

[3.16] http://www.jdfcable.com/

[3.17] United States of America before The Federal Energy Regulatory Commission - Standardizing Generator Interconnection Docket No. RM02-1-001 Agreements and Procedures - Petition for Rulemaking or, in the Alternative, Request for Clarification of Order 2003-A, and Request for Technical Conference of The American Wind Energy Association.

[3.18] BC Hydro Wind Energy White Paper. Prepared for BC Hydro by Garrad Hassan and Partners. Unpublished, to be published in September 2005.

Section 4

[4.1] United States of America before the Federal Energy Regulatory Commission - Standardizing Generator Interconnection Docket No. RM02-1-001 Agreements and Procedures - Petition for Rulemaking or, in the Alternative, Request for Clarification of Order 2003-A, and Request for Technical Conference of the American Wind Energy Association.

[4.2] Alberta Electric System Operator, Wind Power Facility Technical Requirements, 15 November 2004.

[4.3] Hydro Québec TransEnergie, Technical Requirements for the Connection of Generation Facilities to the Hydro-Québec Transmission System - Supplementary Requirements for Wind Generation, May 2003.

[4.4] Hydro Québec TransEnergie, Technical Requirements for the Connection of Generation Facilities to the Hydro-Québec Transmission System - Supplementary Requirements for Wind Generation Addendum 1, 23 December 2004.

[4.5] Independent Electric System Operator, Summary of IESO Reliability Requirements for Wind Generation Installations, 13 July 2005.

[4.6] Independent Electric System Operator, Market Rules for the Ontario Electricity Market, 9 March 2005.

[4.7] Hydro Québec TransEnergie, Exigences Techniques Relatives a l'Integration des Centrales au Reseau de Transport d'Hydro Québec, May 1999.

[4.8] National Grid Company, Great Britain Grid Code, 30 September 2005. http://www.nationalgrid.com/uk/indinfo/grid_code/mn_current.html.

APPENDIX A: SCOPE OF WORKS

Task 1. Review Existing Studies on Wind Power Interconnection

Review of previous studies of transmission interconnected wind farms (at 69 kV or higher voltages) to ensure that the most up-to-date information is available. Reference is made to at least the sources listed below:

- ABB studies for Alberta Electric System Operator (leading to the revised Alberta Grid Code).
- Studies for SASKPower and BC as available at time of writing.
- UWIG / AWEA Wind Integration and Interconnection Workshop, April 2005.
- UWIG/AWEA Annual Meeting – Wind Integration: Focus on System Operation, April 2005.
- AWEA Annual Conference, May 2005.
- KTH International Large-Scale Integration of Wind Power conferences, of which GH helped organise the 2005 Glasgow event.
- Any particularly relevant papers from other conferences and publications worldwide.

The review is focused on the US and Canada and only where particularly appropriate draws on worldwide experience of grid connection and integration issues to demonstrate agreement or significant variation with North America.

Task 2. Survey Current Status of Interconnection Guidelines in Canada.

The review discusses the status of utility-scale wind interconnection guidelines in each province with the various provincial Transmission System Operators (TSO) in Canada, except those provinces where large utility scale wind turbines are not relevant. Information made available by the various TSO or already in the public domain is also incorporated into the review. This task identifies:

- The key characteristics of the provincial networks and in particular the aspects that may affect application of a wind-specific grid standard.
- The market and regulatory frameworks and any factors from them that influence interconnection.
- Characterization of each system as it relates to issues such as generation mix and interties. This includes operational criteria that the systems and system operators have to deal with (e.g. from NERC, WECC and regional coordinating councils).
- Existing interconnection practices for installation of wind farms in terms of physical requirements, data provision, and simulation.
- Activities underway to develop specific wind interconnection guidelines.
- Anticipated timelines for introduction of these guidelines.
- Key parties involved in these developments.

The focus of this task is to draw together the common provincial threads for Base Code regulations, and identify the province specific threads that need to be considered in parallel with or above the minimum baseline requirements.

Task 3. Develop CanWEA Base Grid Code

The previous analyses of Tasks 1 and 2, together with wider international experience of Grid Codes and their application, common pitfalls and best practices is used to:

- Develop a full baseline Grid Code based on outlined types of technical requirements and the aim of the requirement rather than the technical detail.
- Identify minimum recommended requirements that can be applied immediately on a Canada-wide basis aiming to get initial wind developments on the grid and “keep the lights on” whilst more detailed and further Grid Code requirements are considered for future projects in the various provinces.
- Identify variable access requirements within the baseline Code which each province can apply as appropriate to its specific grid and market characteristics and state of development with wind energy.
- Subsequent to identification of minimum and variable access requirements, investigate whether it is possible to identify an “automatic” access level (fully Code compliant) which all provinces may aspire to introduce for wind energy at an appropriate point in the future, or indeed at present.

This tasks pays particular attention to the suitability of existing North America Grid Code developments (e.g. AWEA and Alberta) and the capability to roll them out on a Canadian-wide basis with consideration of North American harmony, and province-specific issues.

Task 4. Develop Recommendations on Next Steps for CanWEA Base Code

This task provides recommendations on the processes that CanWEA should follow to ensure that each Canadian province develops guidelines that follow best practices (i.e. the Base Code developed above).

These recommendations consider:

- The specific differences between market operators, the realities of available equipment, and best practices demonstrated by other jurisdictions (e.g. the AWEA code).
- The characteristics of provincial networks that will likely give rise to required adaptation of the baseline grid code.
- Appropriate processes such as conferences, workshops (national and/or provincial), the development of position papers, and targeted meetings with TSOs and other key organisations.

APPENDIX B TURBINE TECHNOLOGY AND CAPABILITIES

B.1 INTRODUCTION

There have been significant technical developments in the electrical systems incorporated within wind farms over recent years. In the early years these developments were mainly attributed to the improvement of the wind turbine design. This included efforts to reduce the mechanical stresses in the turbine drive train by introducing variable speed drives. In recent years the introduction of more stringent grid connection requirements and the high value of network capacity on the transmission system have been the drivers for manufacturers and developers to introduce further technical developments in order to overcome these issues.

The main aim of this section is to discuss the technological developments in the electrical design and grid connection of wind farms. This includes a brief introduction to the various wind turbine design types as well as the network reinforcement and support equipment used and proposed for use in wind farm implementations. Some comment on connection issues for significant wind penetrations are included.

B.2 HISTORICAL PERSPECTIVE

Over the years technical developments in wind turbine technology have resulted in a marked increase in the size and complexity of wind turbine designs. The main driver for these technological advances has been the desire to create turbines of ever increasing size and rating while maintaining a high level of reliability and minimising the costs.

Up until recently wind farm projects were only required to provide a “clean” power source interface to the network. This usually required a source which was devoid of excessive harmonic and flicker distortions and was balanced across the phases. In addition, it was a normal requirement for the facility to operate at a power factor close to unity, thus providing a connection which did not hamper or support the voltage at the point of connection to the network. There were usually no requirements for active voltage or frequency support for the network.

Recently there has been a significant increase in the level of penetration of wind power into the transmission systems of Europe and North America. As a direct result, grid operators have started introducing more stringent grid connection requirements specifically for wind farms, e.g. [1] [2] [3], in order to protect the security and operation of the transmission system. There are now requirements for wind farms to provide voltage and frequency support for the network at the point of connection as well as the requirement to provide a Low Voltage Ride Through (fault ride-through) capability in order to prevent the disconnection of the wind farm during transmission system disturbances.

Due to the fact that wind farms are often situated in isolated areas of a country, it is normal for most wind generation to interconnect with the grid in areas where there is a low level of electrical network infrastructure. As a result the significant increase in applications for wind generation has quickly used up the available capacity in the remote areas of many national grids. This creates a significant problem for prospective wind farm connections in remote areas as there is severe competition for the available capacity on the transmission network.

Consequently, due to grid code changes to protect the security and operation of the national grids wind turbine manufacturers and wind farm developers have been forced to make technical developments to the design of wind turbines and associated network facilities in order to tackle these issues. These technical developments are discussed below.

B.3 WIND FARM TECHNICAL DEVELOPMENTS

Like other electrical generators, wind farms need to comply with the grid connection requirements of the grid operator. These requirements vary slightly from region to region although fundamentally the following categories are sometimes required by system operators; real and reactive power control, frequency and voltage tolerance, Low Voltage Ride Through capability, voltage control and sometimes frequency response.

Over the years several competing wind turbine technologies have emerged, each with their own advantages and disadvantages. The majority of modern turbines can be categorised as either doubly-fed or direct drive variable-speed pitch regulated machines or fixed-speed stall regulated machines. There are also still a few fixed-speed pitch-regulated designs available although they are not common. These various turbine designs require different technical solutions in order to comply with the grid connection agreements. These solutions are discussed below.

B.3.1 Fixed-speed turbines

Fixed speed stall regulated machines were very common in the early development of the wind turbine. This design, pioneered in Denmark, usually incorporated an asynchronous induction generator and was seen as both simple and robust. These fixed speed turbines had no inherent ability to control real or reactive power. In order to provide these capabilities additional equipment was required.

Modern fixed speed stall regulated turbines are sometimes able to limit the power output of the turbine by active stall regulation. This method of regulation is achieved by the gradual, automatic adjustment of the blade pitch and in so doing the maximum power can be maintained at a pre-selected level. This functionality was initially incorporated to compensate for variations in air density although it can also be used to control the peak output of a wind turbine rotor. The response rate using active stall power regulation is very slow compared to pitch regulated turbines.

Fixed speed pitch regulated turbines can control output power similar to active stall regulated machines except the pitch control is generally faster over a wider range allowing better control of output power.

In order to comply with the power factor requirements of grid operators it was common practice to use switched capacitor banks at the turbine terminals as well as at the interconnection point. However, requirements for smooth reactive power control and voltage control mean that switched capacitors are not always acceptable, since a degree of smooth dynamic reactive power control is desirable. This has led to installation of additional equipment as described below.

The new Irish [2] and GB [3] grid codes both require continuous control of reactive power at the point of common coupling with the transmission or distribution network, effectively prohibiting the sole use of static switched capacitors. In order to accommodate these new requirements some fixed speed turbine manufacturers have incorporated static VAR compensation devices (SVCs) at the low voltage terminals of the turbine. This is achieved by providing zero crossing thyristor switched capacitors which allow for the continuous control of reactive power. These SVCs also provide LVRT protection from significant voltage depressions caused by major transmission network disturbances.

Using active stall regulation or pitch control to control active power, and low voltage SVCs for reactive power control and LVRT, modern fixed speed turbines have the capability to comply with the majority of the connection requirements of grid operators at present.

B.3.2 Doubly-fed turbines

Turbines with doubly-fed induction generators (DFIG) and blade pitch regulation have the inherent capability to control both real and reactive power. The reactive power capability is limited by the rating of the wound rotor and its associated converter. It has been common practice to use a converter rating which is approximately 25-35% of the power rating of the stator. It was generally accepted that this size of converter was a good compromise between cost and performance while giving a satisfactory speed range and allowing the turbines to maintain unity power factor under all load conditions.

Although the doubly-fed turbine can control the power factor at its own terminals, there is still a requirement to compensate for the reactive power of the cables and transformers comprising the wind farm collection system. For more compact collection systems, i.e. with short cable runs, the DFIG turbines usually have sufficient reactive power capability to compensate. For more extensive collection systems, i.e. long cable runs, it is common to incorporate switching capacitor and/or reactor banks at the interconnection point.

As stated previously, it is becoming more common place for grid operators to require that the wind farm provides continuous control of reactive power at the grid connection point (or an external point on the network). For DFIG turbines with limited reactive power control this can be achieved by using the available turbine reactive power to compensate for the step changes caused by static capacitor banks located at the grid connection point. A wind farm control function is required to provide a coordinated effort to ensure that the capacitors provide the bulk of the reactive power while the turbines compensate for the switching in/out of the capacitors and ensure a smooth reactive power control interface to the grid. Alternatively, the wind farm may opt to introduce dynamic VAR compensation equipment at the grid connection point, at some cost.

Finally, several manufacturers have recently modified (reinforced) the design of the electronic converters and controllers for the DFIG drives, specifically to allow the turbine to remain connected during severe voltage dips caused by major faults on the transmission system. This LVRT capability is required by most transmission grid operators to ensure the stability and security of the transmission system.

B.3.3 Full power electronic converters

A number of turbine manufacturers have recently taken the decision to incorporate a variable speed drive which incorporates an electronic converter for processing the full output power of the turbine. In so doing the turbine has a very wide variable speed range and has a large amount of controllable reactive power.

This ability to control large amounts of reactive power means that the turbines are more easily able to comply with the voltage control and power factor requirements of the grid operator without the need to implement further reactive power compensation equipment at the wind farm substation. In addition, surplus reactive power can be used to strengthen a weak transmission or distribution network. This capability will become more important when there are high penetrations of wind on the transmission network.

Finally, these turbines have the inherent capability of providing large amounts of reactive power very quickly in response to a severe voltage dip on the transmission network, effectively supporting the voltage at the turbine terminals and allowing the wind farm to ride-through the fault. This LVRT capability is essential in order to meet the stability requirements of the grid operators.

Historically, turbines which incorporated full power electronic converters were restricted to direct drive synchronous machines. The most common design of this type is the ENERCON turbine which incorporates a large synchronous multi-pole generator. More recently, other major turbine manufacturers are proposing to incorporate full variable speed drives; either as direct drive (no gearing) machines or provided with some form of gearing. GH is aware of synchronous, permanent magnet and squirrel cage induction machines used for this purpose. All of these designs incorporate a full electronic converter.

In summary, the majority of modern wind turbines have been adapted to provide the functionality which will ensure the wind farms can comply with grid code requirements. Due to the fact that wind farms are usually composed of multiple turbines and extensive collection systems, other major electrical plant and control systems need to be incorporated to allow the wind farm as a whole to comply with the grid connection conditions. The development of wind farm control systems are discussed below.

B.3.4 Wind Farm Control Systems

Some grid connection conditions require the continuous control of real and reactive power at the point of common coupling with the grid (normally at the wind farm substation) or at some remote point on the transmission or distribution network. More specifically, some grid operators now require that wind farms have the capability of providing voltage and frequency control services to the transmission or distribution networks.

These services can be provided if the wind farm is capable of coordinating the control of real and reactive power from all turbines as well as the control of other major items of electrical plant (tap changing transformers, switched capacitors, SVC’s etc). As a result of these new requirements future wind farms will often be required to provide a wind farm control system which has the functionality and capabilities of complying with the grid code requirements.

The majority of turbine manufacturers and third party systems now offer to provide the necessary grid connection services together with the existing wind farm Supervisory Control And Data Acquisition (SCADA) system. The turbines themselves have controllers which provide continuous control of real and reactive power, and the wind farm control system provides these controllers with set-points to coordinate the real and reactive power flows at the grid connection or other external point.

In summary, GH has discussed the technological development in wind turbines and wind farm control systems in order for modern wind farms to comply with the connection requirements of the transmission and distribution system operators. The next section discusses the most important issues facing future wind farm grid connections, the provision of grid support to enable greater wind penetration.

B.4 PROVIDING GRID SUPPORT

The marked increase of proposed wind generation projects in remote areas with insufficient grid capacity has led to the situation where a large number of new projects are having difficulty obtaining suitable connections. This situation can be alleviated in the long term by reinforcing the network, although the building of new transmission lines is expensive and can take many years to implement (usually much longer than development timescales for wind farms). This has led to serious queues and delays in a number of countries, e.g. West Texas, South West Alberta. As such it makes sense for wind projects to provide additional support to the network where possible.

There are a number of factors which can influence the ability of a wind project to generate into a particular grid. These can usually be categorised into voltage and power constraints, each of which can be alleviated by applying certain technical solutions. These are discussed below.

B.4.1 Overcoming voltage constraints

Grids which are severely stressed commonly experience voltage limit problems whereby a project's generating capability is constrained by the safe operating levels permitted by the grid operator. Wind generating facilities can reduce the impact of voltage constraints by supporting the voltage at their point of connection to the grid, or even at a point situated further into the network. Practically this can be achieved by control of reactive power, either by a single network connected device or via a distributed wind farm solution controlled by a SCADA or dedicated control system. Examples of network support devices are SVCs, STATCOMs or series voltage regulators.

B.4.2 Overcoming power constraints

There are two main mechanisms for dealing with power flows which approach the thermal limits of the transmission system. Either the electrical network can be reinforced by upgrading the network, or the wind generating plants can be constrained when the power flows on the system approach the thermal limit of the network plant. The network upgrade mechanism is fairly straightforward, hence only the wind farm constraint mechanism is discussed further.

When a network becomes congested with generation without significant load, such as in remote areas where wind farms tend to be built, then the wind generators might be constrained during periods of high generation and low demand. In order to accommodate more embedded generators in a congested network it is becoming more common for the grid operator to initiate some form of constraint program whereby the generators are obliged to limit their plant output under certain defined circumstances.

Currently, these constraints can either be planned, e.g. seasonal load variations, or can be initiated under emergency situations, e.g. a failure of one element of the transmission system. In the future, as congestion becomes a much more important factor, active monitoring of the system power flows combined with an intelligent strategy for constraining wind generation under high stress situations seems to be the obvious strategy in order to ensure high levels of wind penetration. This could be justified while waiting for transmission reinforcement, or possibly even as an alternative to transmission reinforcement. Constraint can be achieved directly by the system operator communicating with the wind farm SCADA system, or via the wind farm operator.

Similarly, it may be important for the system operator to be able to limit the rate-of-change of output power (ramp rate) on timescales of minutes. This can be done by wind farm SCADA systems, although the ability to automatically control negative ramp rates is far less. If negative ramp rates are an issue, it is necessary to implement some form of forecasting.

In summary, there have been a number of technical developments in the interface equipment for wind farm grid connections in order to overcome voltage and power constraints on the network. Overcoming these constraints is essential if very high levels of wind penetration are to be realised.

B.5 FURTHER INTO THE FUTURE

Issues of LVRT, voltage and frequency control are relatively new to the wind industry although transmission system operators have been dealing with them for many years. Current Grid Code developments seem set to allow moderate penetrations of wind, certainly to 20% by energy in most cases, without significant issue. Questions arise as to what additional measures, if any, will be required of wind farms at much higher penetrations, for example 40-50% of energy supply. As the industry is still largely working on implementing and improving the current requirements these questions remain largely unanswered. Some clues are given from systems with technical sensitivity such as the Republic or Ireland and Québec. Issues that are likely to arise include system inertia, power system stability and stabilisation and further requirements on real power control and frequency response. Other important issues centre around generation adequacy, scheduling and balancing which are largely commercial issues. GH has discussed these issues in Section 2 of this report but many of the questions still remain to be answered and there are likely to be issues that are not yet identified. GH has noted the relevant future issues in CanWEA's Base Code for discussion.

B.6 REFERENCES

[1] E.ON-Netz (Germany), "Grid Code – High and extra high voltage", August 2003

[2] ESB National Grid (Ireland), "Wind farm Power Station Grid Code Provisions" July 2004

[3] National Grid (GB), "The Grid Code – Issue 3, revision 12", 30 September 2005

APPENDIX C: CANWEA BASE CODE REQUIREMENTS

The following requirements are those proposed for inclusion within the CanWEA Base Code. They consist of the following:

21. Frequency tolerance
22. Voltage tolerance
23. Power control
24. Reactive power capability/control
25. Voltage control
26. Frequency response
27. Low Voltage Ride Through (LVRT)
28. Power system stabilisers
29. Data Provision
30. Operational monitoring

The requirements also have the following characteristics:

- *Mandatory* indicates the requirement must be implemented.
- *Automatic access standard* indicates that, if met, the requirement will allow interconnection regardless of a) province, and b) site.
- *Reduced access standard* indicates a level less than automatic is allowable according to a) province, and b) site, subject to agreement with the relevant system operator.
- *Noted but not a requirement* implies a requirement is not enabled at present but may be in the future.

The following provides text format for the requirements in plain form, i.e. the detail and recommendations to CanWEA are not included. Reference to Section 4 should therefore be made to understand the choices and issues with requirements which are not explicit.

C.1 FREQUENCY TOLERANCE

Frequency tolerance is a mandatory requirement. The requirement is for:

7. Continuous normal operation between 59.4Hz and 60.6Hz.
8. Under-frequency time based capability.
9. Over frequency time based capability.

C.2 VOLTAGE TOLERANCE

Voltage tolerance is a mandatory requirement. The requirement is for:

7. Continuous normal operation between +10% and -10% of nominal voltage at the interconnection point (high voltage side of transformer). Note that in Northern Ontario this range may be exceeded.
8. Over-voltage time based capability.
9. Under-voltage time based capability.

C.3 POWER CONTROL

Power control, including the capability to limit maximum power output and control ramp rates, is useful and desirable but not a requirement. It is likely to become a requirement for new projects further in the future as wind penetration starts to become high.

C.4 REACTIVE POWER CONTROL/CAPABILITY

Reactive capability is a requirement but is allowed to vary by a) province, and b) site. The requirement is as follows:

11. Reactive capability at full output.
    A capability providing 0.90 lagging to 0.95 leading at full MW output, and meeting the further requirements of reactive capability as set out below will allow automatic interconnection regardless of a) province or b) site specific conditions.

    If a reduced capability is sought then this is to be determined by the following:

    a) In accordance with provincial rules.

    b) In accordance with the findings of System Impact Studies developed for the specific site and which show the actual maximum capability that is required.

    The intention of this clause is to allow the actual reactive capability to be varied according to actual requirements. Variation according to a) or b) should be agreed with the system operator.

12. Reactive capability at reduced output.
    A capability providing reactive power up to the power factors 0.90 lagging to 0.95 leading throughout the power output range, and meeting the further requirements of reactive capability as set out herein will allow automatic interconnection regardless of a)

province or b) site specifics. In addition to this the wind farm should offer a capability beyond this to the system operator if reasonably available through the turbines.

If a reduced capability is sought then this is to be determined by the following:

a) In accordance with provincial rules.

b) In accordance with the findings of System Impact Studies developed for the specific site and which show the actual maximum capability that is required.

The intention of this clause is to allow the reactive capability at reduced MW loading to be varied according to actual requirements. Variation according to a) or b) should be agreed with the system operator.

It should be noted that Québec currently requires the MVAr defined by 0.95 lead to 0.95 lag power factor at full MW load to be available throughout the MW output range.

13. Dynamic reactive capability.
    Subject to the findings of 1a) and 1b), at least a portion of the reactive capability should be dynamic. The control system for the reactive capability should provide that the dynamic capability is always available such that the provided capability at the point of interconnection appears to the system operator as similar to either a synchronous machine or a dynamic reactive device and hence is capable of meeting any dynamic reactive requirements most notably in regards to voltage control.

14. Balance of reactive sources.
    It is wholly satisfactory to provide all or part of the reactive power capability from the turbines or separate reactive devices located within the wind farm provided the other requirements pertaining to reactive capability are met. In some cases this may extend to reactive compensation devices on the system operator's network where this has been identified as a solution and agreed with the system operator.

15. All reactive capabilities are defined at the point of interconnection. This is normally the high voltage side of the main grid transformer. It is noted that Alberta currently defines the requirements on the lower voltage side of the main grid transformer.

C.5 VOLTAGE CONTROL

Voltage control is a requirement but is allowed to vary according to a) province, and b) site. The requirement is as follows:

3. Voltage Control at the point of interconnection (or otherwise agreed) is a requirement. If the control is fully capable of utilising the agreed reactive capability of the project defined elsewhere then interconnection is automatic regardless of a) province, and b) site specifics.

   A reduced requirement for voltage control may be sought in accordance with the following:

   a) Provincial rules.

b) The findings of System Impact Studies developed for the specific site and which show the actual maximum capability that is required.

It should be noted that either a) or b) may define a reduced requirement which may in some circumstances become no requirement at all.

The intention of this clause is to allow the actual required voltage control capability to be varied according to requirements. This voltage control requirement must be related back to reactive capability requirements. Variation according to a) or b) should be agreed with the system operator.

C.6 FREQUENCY RESPONSE

Frequency response is not a requirement. It may become a requirement for new projects further in the future as wind penetration starts to become high.

C.7 LOW VOLTAGE RIDE THROUGH

LVRT is a mandatory requirement but is allowed to vary according to a) province, and b) site. The requirement is as follows:

5. A LVRT capability defined at the point of interconnection (normally defined as the high voltage side of the grid connection transformer) and meeting or exceeding that shown – that is to remain connected for voltages reduced to 0% for up to 0.15s, thereafter followed by a linear recovery to 85% voltage after 3s – shall be allowed automatic interconnection regardless of a) province or b) site. The capability is shown in the following figure.

   A reduced requirement for LVRT may be sought in accordance with the following:

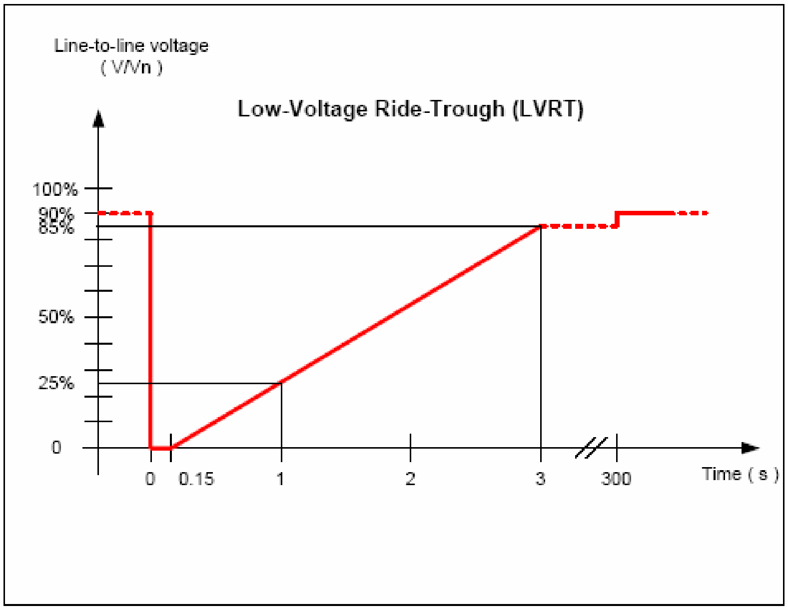
   a) Provincial rules.

   b) The findings of System Impact Studies developed for the specific site and which show the actual maximum capability that is required.

   It should be noted that either a) or b) may define a reduced requirement which may in some circumstances become no requirement at all.

   The intention of this clause is to allow the actual required LVRT capability to be varied according to requirements. Variation according to a) or b) should be agreed with the system operator.

6. It is noted that LVRT may require tolerance to significant negative phase sequence for short periods and the plant should be capable of this. Item 1 applies primarily to voltage depressions under balanced phase conditions.



Note: Positive sequence voltage at the fundamental frequency

C.8 POWER SYSTEM STABILISERS

The inclusion of a Power System Stabiliser is not a requirement. It may become a requirement for new projects further in the future as wind penetration starts to become high.

C.9 INFORMATION PROVISION

The following data provision clauses are mandatory requirements as applicable.

9. Planning and anticipated operational data. Technical data will be provided to the system operator, generally in advance of connection and during application for interconnection. The required data will encompass the technical and anticipated operational characteristics of the plant in detail suitable for System Impact Studies. The System Operator will provide the information pro forma upon request.

10. Wind Turbine model. As part of item 1, the project will need to submit a detailed simulation model of the wind turbine(s) to be used in either PSS/E or PSLF format. The model shall be one that is approved by the "*AWEA/CanWEA/System Operator modelling group*".

11. Submission of an application for interconnection with preliminary data only, but with initial fees to secure registration and queue placement, is allowable. In such a case the project developer is allowed access to system data to self study the interconnection and advise the system operator appropriately to gain an interconnection schedule of works and date for interconnection. Subsequent to completion of the wind farm design and turbine selection, the project will submit the full requirements of item 1 and 2 to the system operator for assessment, and will be liable for any inaccuracies through the self study process.

This clause is intended to ease the issues of timing with data provision and connection. This clause is enabled only by consent of the system operator once the above process is approved.

12. The completed wind farm, once interconnected, will be subject to compliance testing to physically demonstrate the wind farm performance meets that of the Code. Agreement on testing is being sought and this clause is not currently enabled.

C.10 OPERATIONAL MONITORING

The provision of operational monitoring is mandatory.

5. Projects should liaise with the relevant system operator and expect to provide at least some of the following data through real time communications:

    - MW import and export
    - MVAr import and export
    - Voltage
    - Wind speed and direction
    - Site temperature
    - Status of circuit breakers and/or switches
    - Number of turbines available/unavailable

    Other data transmission may be required to be agreed on a) a provincial basis, and b) a site specific basis.

6. In addition to the above data the wind farm should expect to provide at least one automatic channel whereby control commands issued by the system operator can be received and acted upon. The requirements of the control channels and interface are to be agreed on a) a provincial basis, and b) a site specific basis.