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Survey of Studies and Analysis Tools Used for Assessment of Distributed Generation Integration in Canadian Distribution Systems

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Canada

Survey of Studies and Analysis Tools Used for Assessment of Distributed Generation Integration in Canadian Distribution Systems

CYME International T&D

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DISCLAMER

ACKNOWLEDGMENT

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1. Executive Summary

The purpose of this survey is to assess the use of distributed generation in Canadian distribution systems, modeling tools' adequacy, and the associated need for knowledge and research. More specifically, the objectives of this work are to: characterize Canadian distribution systems; identify the level and types of existing distributed generation (DG); provide a measure of the experience and competency of distribution engineers in handling this technology. The survey, also, aimed at identifying gaps in knowledge, in modeling requirements and in analytical tool necessary to address the interconnection and interoperability of DG with distribution networks.

Out of the 30 questioners sent out, 18 answers were received representing 9 provinces and 2 territories serving over 7 million Canadian customers. Although it cannot be taken as a complete representation of the Canadian industry, there responses supplied very useful information and a good insight into the situation of DG in Canada.

Overall, DG is present in most networks; however with a relatively small penetration. In most cases there seem to exist a degree of uncertainty surrounding the subject of interconnection with the mother network and how to incorporate the relevant issues into the traditional planning and operational approach.

The respondents indicated that technical training aimed at improving their staff capability in conducting analyses relevant to the integration of distributed generation in their systems is necessary in many areas of planning and operation of the distribution system. The most important needs are in the following areas:

- System operations
- Protection coordination
- Safety and maintenance
- System studies

Areas of software development and enhancements, identified in the responses, include the addition of features to facilitate the analysis of the aspects shown below in a descending order of importance:

- General distributed generation knowledge
- Impact of DG on distribution system protection
- Anti-islanding protection and new technologies
- Voltage regulation and operation with DG

In general utilities believe that they can adequately conduct steady state analyses but have substantially less expertise in conducting power quality assessment, system dynamics and electromagnetic transient studies necessary for the analysis of interface issues.

1. Sommaire exécutif

Le but de cette enquête est d'évaluer le degré d'utilisation de la production distribuée par les réseaux de distribution canadiens, l'adéquation des modèles ainsi que les besoins de connaissance et de recherche qui en découlent. Les objectifs spécifiques de ce travail sont donc: la caractérisation des réseaux de distribution canadien, l'identification du niveau et du type de production distribuée (DG) existante, la mesure de l'expérience et de la compétence des ingénieurs de distribution à maîtriser cette technologie. Cette enquête tente aussi d'identifier les déficiences dans les connaissances, dans les exigences de modélisation et dans les outils d'analyse nécessaires pour effectuer le raccordement et l'exploitation de la production distribuée dans un réseau de distribution.

Sur les 30 questionnaires qui ont été envoyés, 18 réponses ont été reçues, ce qui représente les résultats de 9 provinces et 2 territoires desservant plus de 7 millions de clients canadiens. Bien que ces réponses ne soient pas un échantillon parfait de l'industrie électrique canadienne, elles fournissent des informations très valables et donnent un bon aperçu de la situation de la production distribuée au Canada.

Globalement la production distribuée est présente dans la plupart des réseaux avec cependant un taux de pénétration relativement faible. Dans la plupart des cas il semble y avoir une certaine incertitude au sujet du raccordement avec un réseau principal ainsi que sue la façon d'intégrer les différentes problématiques liées à la planification et l'exploitation traditionnelles.

Les réponses ont montré que la formation technique pour améliorer la capacité du personnel à faire les études d'intégration de la production distribuée dans leur réseau s'avère nécessaire sur les questions de planification et d'exploitation du réseau. Les besoins les plus importants sont dans les domaines suivants :

- L'exploitation du réseau
- La coordination de la protection
- La sécurité et l'entretien
- Les études de réseaux

Le développement et l'amélioration des logiciels, soulignés dans les réponses, incluent des fonctionnalités additionnelles pour faciliter l'analyse des questions suivantes, par ordre d'importance décroissante :

- La connaissance générale sur la production distribuée
- L'impact de la production distribuée sur la protection du réseau
- La protection anti-îlotage et les nouvelles technologies
- La régulation de tension et l'exploitation en présence de productions distribuées

De façon générale, les utilités ont confiance d’être parfaitement capable de faire les études de réseau en régime permanent mais elles ont beaucoup moins d’expertise pour réaliser les études de qualité de l’onde, les études de la dynamique des réseaux et les études des transitoires électromagnétiques requises pour les études d’intégration.

2. The Survey

2.1 Background

Natural Resources Canada (NRCan) manages a coordinated research program to foster the advancement of renewable energy technologies and in order that they become the preferred energy options on the basis of reliability, cost effectiveness and social and environmental advantages. In the course of this program, NRCan and its partners are involved in assessing the impact on power quality of high-penetration of distributed energy resources on the electrical grid.

NRCan recognizes that one of the primary drivers, or impediments, of the growth of distributed generation in Canada is the distribution engineer's familiarity with the subject.

This survey is conducted by CYME International T&D on behalf of NRCan to achieve the objectives below.

2.2 Objectives

- The primary goal of this survey is to understand what experience and tools Canadian distribution planning engineers currently have at their disposal in order to address the interconnection issues of distributed generation in their systems.
- The survey should also provide insight into the direction in which distribution system planning is heading in Canada, and its effect on the need for further studies and enhanced tools to address emerging issues.

2.3 Survey Structure

In order to achieve the above-defined goals, the survey covers the following items:

1) Identifying the most common characteristics of Canadian distribution systems in terms of:
    - Area served
    - Number of customers
    - Peak load
    - Load factor
    - Capacity to supply load
    - Load composition
    - Primary feeder voltages
    - Types and length of distribution feeders

- Configuration of typical distribution stations
- Typical size of distribution stations
- Typical number of feeders
- Grounding arrangements

2) Existing and planned distributed generation in Canadian distribution utilities in terms of:
    - Degree of penetration of DG
    - Plans to add distributed generation
    - Type and number of distributed generation resources
    - Policies on islanding operation
    - Perceived advantages and disadvantages of DG

3) Performed analysis in terms of:
    - Studies conducted for the analysis of issues related to interfacing of distributed generation in distribution systems.
    - In-house ability to conduct the needed studies versus depending on outside consultants.

4) Available analysis tools, interconnection codes and staff training in conducting:
    - Steady state analyses
    - System dynamics analyses
    - Electromagnetic transient analyses
    - Power quality and reliability analyses
    - Surveyed utilities were asked to identify areas of enhancement of the utilized analytical tools, applicable standards and training needed.

5) General comments.

The utilities were given the opportunity to provide comments and views on the general subject of distributed generation.

2.4 Survey Response

The survey was sent to 30 utilities. 18 answers were received representing 9 provinces and 2 territories serving over 7 million Canadian customers. Not every utility responded to all questions of the survey, for inapplicability or lack of information.

Although it cannot be taken as a complete representation of the Canadian industry, these responses supplied very useful information and a good insight into the situation of DG in Canada. The sample size, and more importantly, the number of answers received are large enough to provide a good picture of prevailing conditions in the survey topics.

Valuable information can be extracted about the experiences of Canadian distribution planning engineers and the tools they have at their disposal to address the interconnection issues of distributed generation in their systems

The survey content and results are presented in the following five sections

3. Distribution System Characteristics

3.1 General Characteristics

3.1.1 Area Served

Figure 1 shows the distribution of the served area in square kilometers per utility. There were 14 answers covering a broad range of situation from a medium size city to a very large territory up to 2 million square miles. The answers represent situations in 9 out of 10 Provinces and in 2 territories. The average area served is **329,782 square kilometers** per utility.

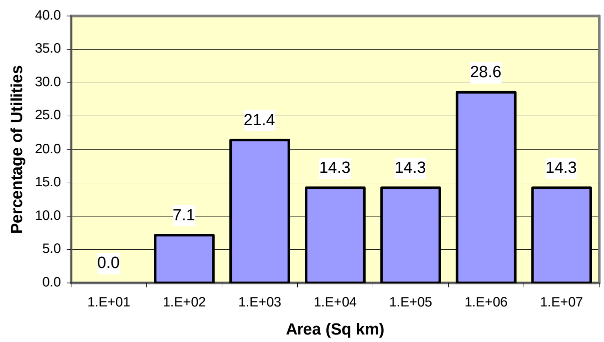

Figure 1 - Area Served

3.1.2 Number of Customers

Figure 2 shows the statistical distribution of the number of customers served per power utility. The 18 answers received represent a total of 7 165 233 customers representing approximately 50% of all customers in Canada with again a broad range of situation from a few thousands to a few millions of customers with an average value of **398,083 customers** per utility.

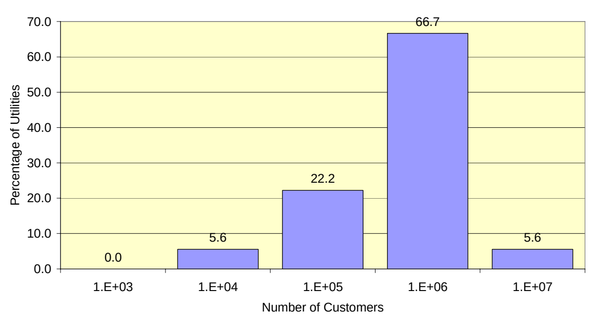

Figure 2 - Number of Customers

3.1.3 Peak Load and Load Factor

Figure 3 depicts the distribution of the present time peak power delivered by each of the surveyed utilities. There were 17 responses with an average value of **3202 MW** per utility.

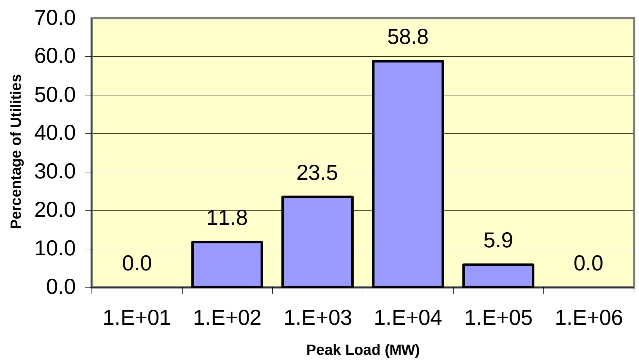

Figure 3 - Peak Load (Present)

Figure 4 portrays the predicted future peak power to be supplied in 5 years by the power utilities. The average value of the 15 answers is **3452 MW** per utility. This represents an increase of 7.8% in the next 5 years with respect to current conditions. The rate of increase per year is **1.5%.**

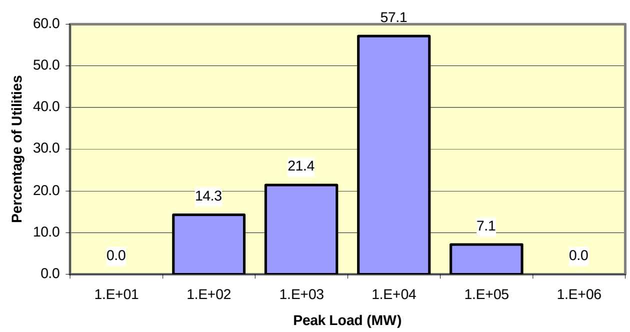

Figure 4 - Peak Load in 5 Years

Figure 5 shows the predicted peak power delivered in 10 years. 14 utilities responded to this point in the survey with an average value of **3867.7 MW** in 10 years. This corresponds to an increase of **20.79** for the next ten years. This represents a rate of increase of supplied load per year of **1.2%** which indicates that the utilities anticipate a slower rate of increase in future years.

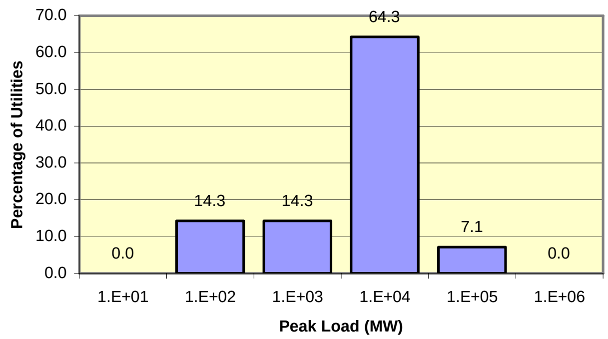

Figure 5 - Peak Load in 10 Years

Load Factor

Figure 6 below shows the distribution of the load factor for current system conditions. Among the 14 utilities that responded to the survey, the average value is **59.6 %**.

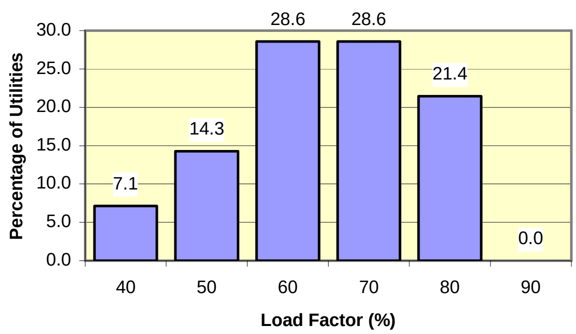

Figure 6 - Load Factor (Present)

Figure 7 illustrates the predicted load factor for the distribution system in 5 years. Twelve utilities responded to this question in the survey having an average value of **65.3%**, which shows only a slight change from current value.

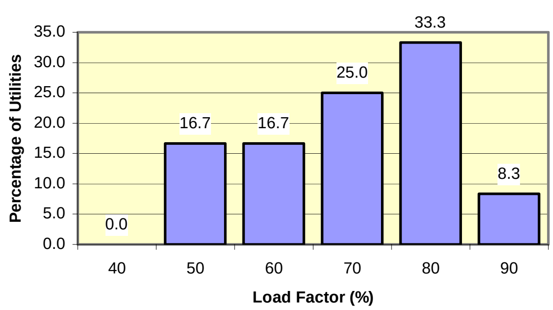

Figure 7 - Load Factor in 5 Years

The distribution of the load factor of the system in 10 years is shown in Figure 8. There were 11 responses with an average value of load factor of **66.9%**. Thus, only a minor change in load factor, over, current conditions is anticipated.

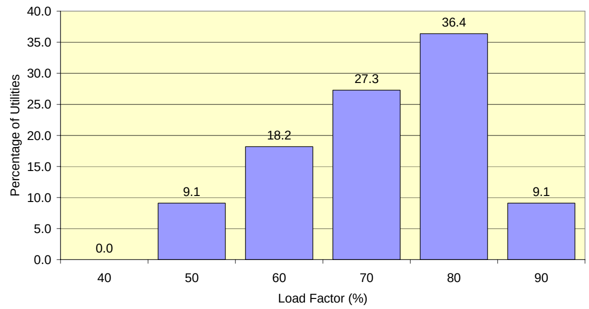

Figure 8 - Load Factor in 10 Years

Capacity to Supply Load

Figure 9 shows distribution systems capacity to supply load for the current system conditions. The average value among the 9 utilities that responded is **2066.3 MW** per utility.

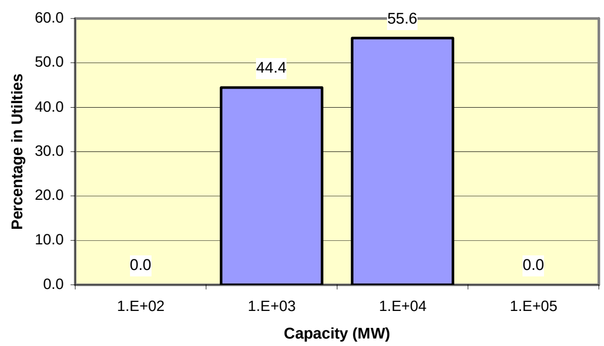

Figure 9 - Capacity to Supply Load for Present

Figure 10 gives the predicted capacity to supply load for the system 5 years into the future. Nine utilities responded to this question. The average supply capacity is **2156.2 MW** per utility, which represents an increase of 4.5%. The rate of increase per year is **0.88%.**

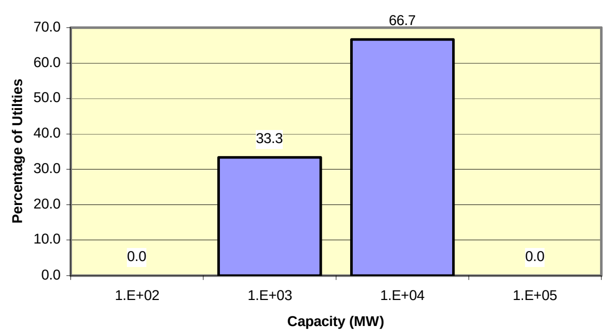

Figure 10 - Capacity to Supply Load in 5 Years

Figure 11 portrays the predicted capacity of the distribution system in 10 years from now. The average of the 8 utilities that responded to this question is **2336.2 MW** per utility. Thus the predicted increase in the next ten years is expected to be 13.21%. The corresponding rate of increase per year is **1.13%**

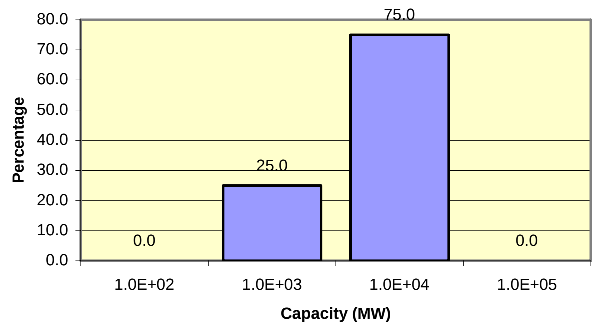

Figure 11 - Capacity to Supply Load in 10 Years

Results shown in Figures 10 and 11 indicate that the predicted increase in capacity is slower than the predicted increase in load in the first five years and higher in the next five years with an overall result of increase in supply capacity, almost, matching the increase in load.

3.1.4 Load Composition

Figure 12 to Figure 15 show the load composition of the surveyed distribution utilities. There were 16 responses. As shown in the pie chart in Figure 15, the distribution utilities have 40% residential load, 31% industrial load and 29% commercial load, of their peak loads, on average.

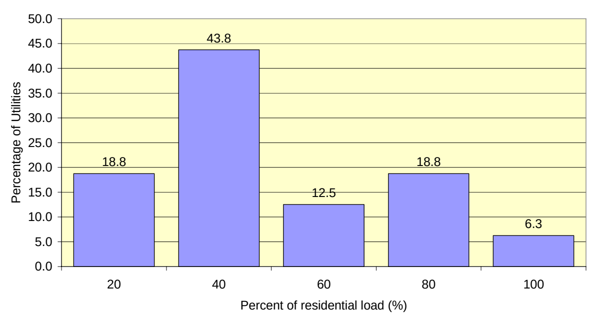

Figure 12 - Residential Load

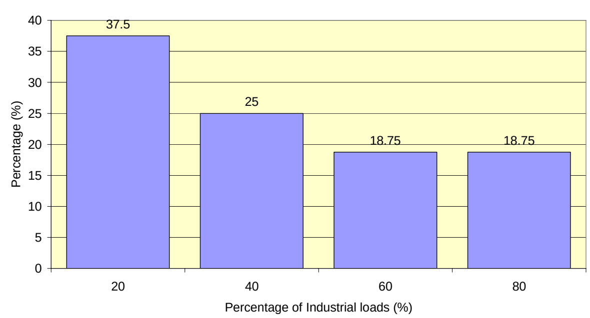

Figure 13 - Industrial Load

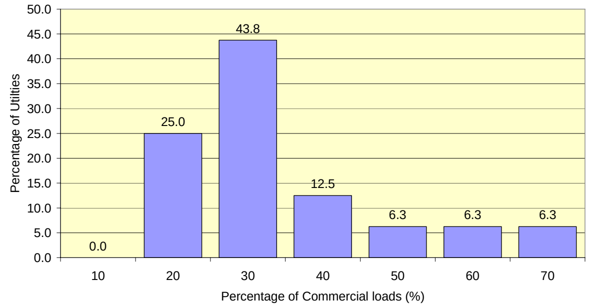

Figure 14 - Commercial Load

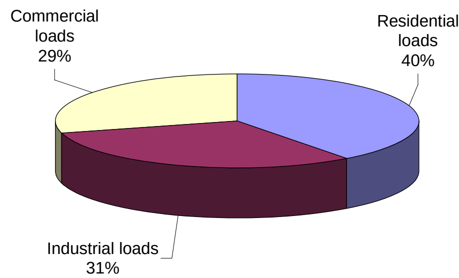

Figure 15 - Load Composition

3.2 Feeder System

3.2.1 Primary Feeder Voltages

Figure 16 below shows the range of primary voltages used by the 18 utilities that responded to the survey. The primary voltages vary widely and fall within the range of **2.4 kV** to **46 kV**.

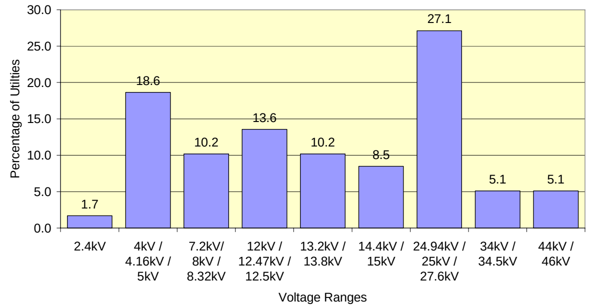

Figure 16 - Primary Feeder Voltages

3.2.2 Types and Lengths of Distribution Feeders

<u>Overhead</u>

Figure 17 portrays the variation in the total length of overhead lines per utility. The number of utilities that provided the total length of the overhead lines in their systems was 17 indicating an average total length of overhead lines of **27,640 km** per utility.

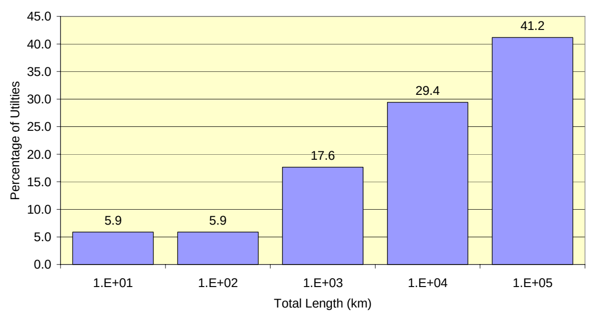

Figure 17 - Total Lengths of Overhead Lines

Figure 18 to Figure 20 present the percentage of single, double and three-phase overhead lines in the distribution systems. Single-phase lines constitute, 47.3 percent, two-phase lines constitute 2.3 percent while three-phase lines constitute 50.4 percent of the total overhead line length.

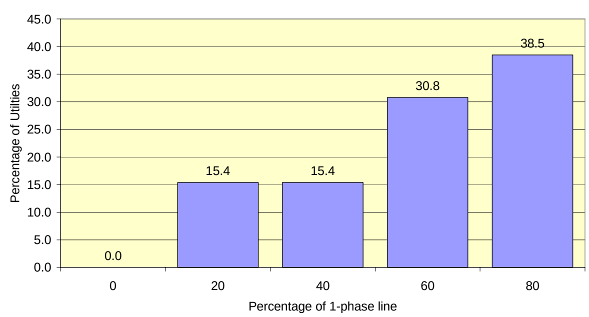

Figure 18 - Percentage of 1-phase Line on Total Length of Overhead Lines

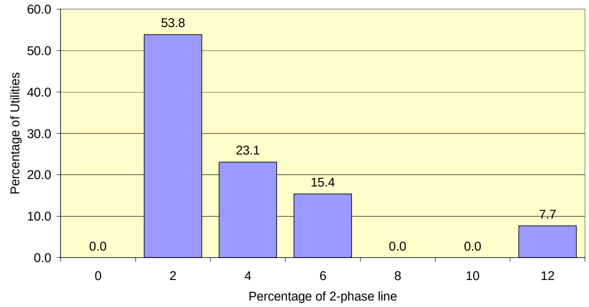

Figure 19 - Percentage of 2-phase Line on Total Length of Overhead Lines

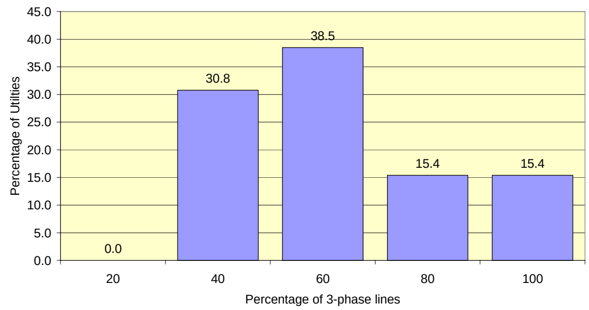

Figure 20 - Percentage of 3-phase Line on Total Length of Overhead Lines

Underground

Figure 21 shows the distribution of the total length of underground cables per utility. The total length of underground cables is **5,656 km** per utility. There are 54.2% of the underground lines that are single-phase, 0.6% are two-phase and 45.4% that are three-phase.

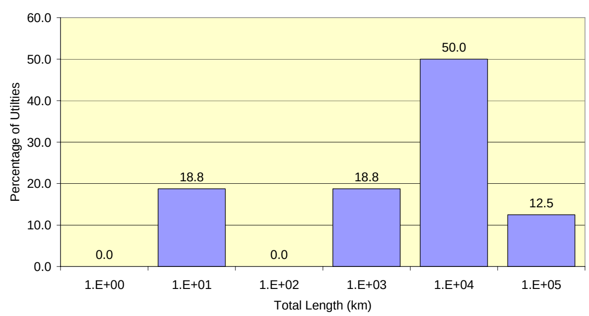

Figure 21 - Total Length of Underground Cables

Figure 22 to Figure 24 present the percentage of single, double and three-phase underground cables in the distribution system per distribution utility.

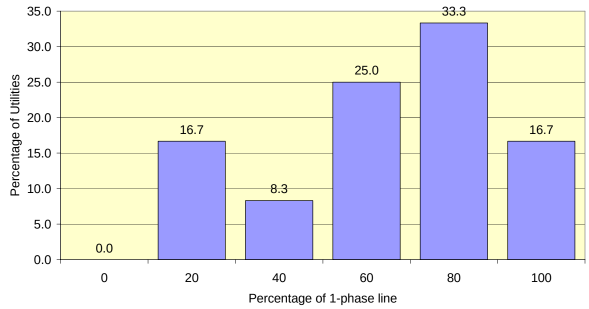

Figure 22 - Percentage of 1-phase Line on Total Length of Underground Lines

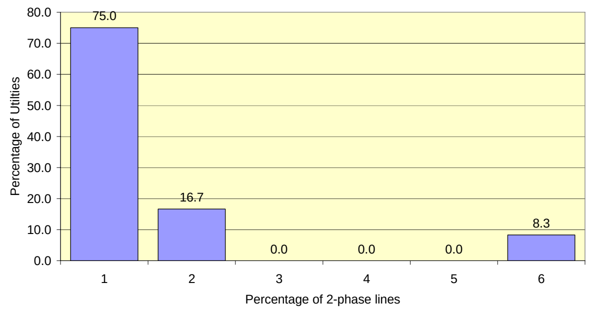

Figure 23 - Percentage of 2-phase Line on Total Length of Underground Lines

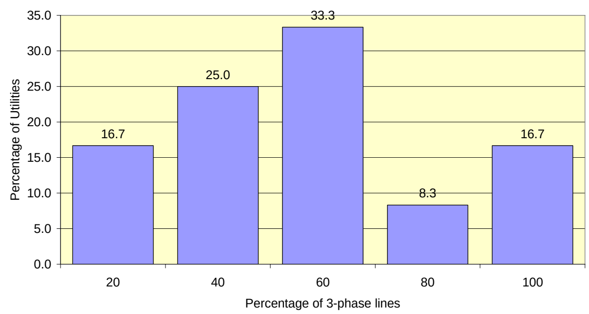

Figure 24 - Percentage of 3-phase Line on Total Length of Underground Lines

Ratio of Underground to Overhead

There were 16 responses. The total length of overhead lines is **469,886** km and the total length of underground lines is **90,498** km. This gives a **ratio** of 1/5.16= **0.19** underground to overhead.

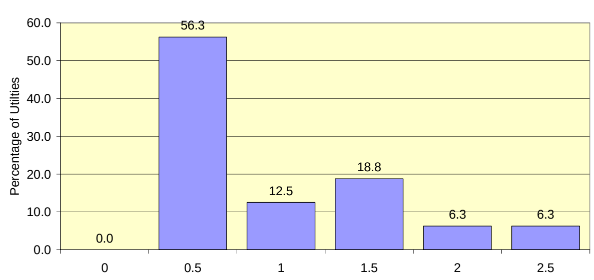

Figure 25 - Ratio of Underground Cables to Overhead Lines

3.3 Distribution Stations

3.3.1 Configuration of Typical Distribution Stations

There is a large variety of system configurations. Utilities tend to have different arrangements for urban substations than for rural substations. Differences exist in the bus configurations, and in the protection equipment and breaker configurations. There are too many different types of distribution station configurations to be classified into groups of typical configurations.

3.3.2 Typical Size of Distribution Stations

Figure 26 shows the typical substation size of the surveyed power utilities. There were 16 responses. It can be seen that most of the distribution station have small capacity with a majority of a typical size of under **50MVA**.

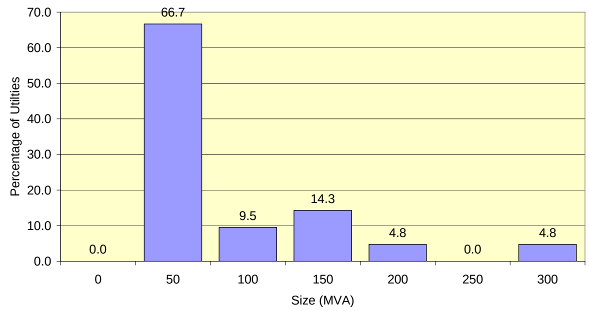

Figure 26 - Typical Size of Distribution Stations

3.3.3 Typical Number of Feeders

Figure 27 gives the distribution of the typical number of feeders per distribution station. There were 17 responses; most of the utilities have from one to five feeders per station.

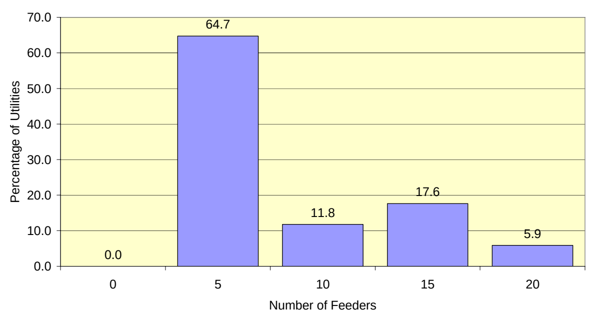

Figure 27 - Typical Number of Feeders

3.3.4 Winding Connection Groups of Station Transformers

Number of respondents: 13 and the indicated transformer connection groups are as indicated in the following table.

Winding	Wye-Wye	Delta-wye	Delta-delta	Zig-Zag	Wye-grounded – zzY/zzY
Number of Utilities	6	10	2	1	1

3.3.5 Grounding Arrangements of Distribution Stations

Figure 28 shows that 70.7% of the 13 utilities that responded to this item in the survey have solidly grounded arrangement. There are few utilities that use isolated neutral grounding and none have indicated the use of compensated grounding.

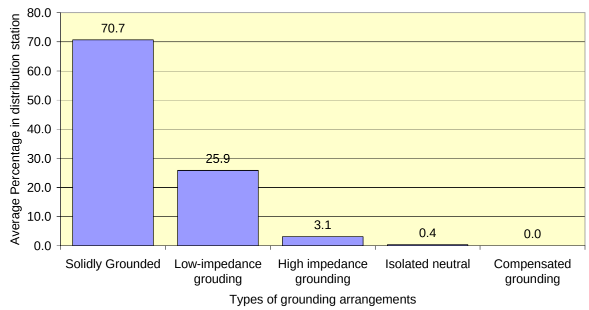

Figure 28 - Grounding Arrangements of Distribution Stations

4. Distributed Generation in Distribution Systems

4.1 Presence and Plans for Distributed Generation in Distribution Systems

1) Utilities with distributed generation

The majority of the respondents, 14 out of 15, indicated that they currently have distributed generation.

2) Degree of penetration

Figure 29 presents the distribution of the degree of penetration in percent of the peak load for the responding utilities. Most utilities have a penetration of distributed generation of less than 5% of the of peak load.

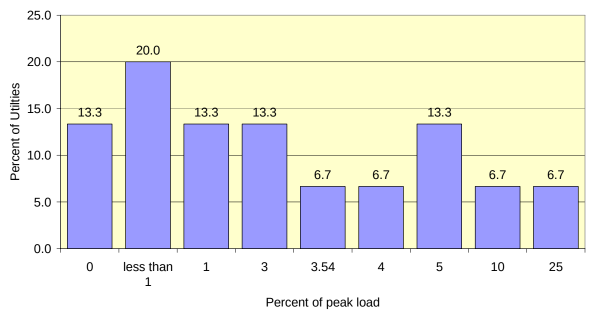

Figure 29 - Degree of Penetration of Current DG Facility

3) Plans to add distributed generation

There were 17 responses, of which 5 utilities plan to add distribution generation to their systems.

4) Degree of penetration target

Figure 30 depicts the target degree of penetration for future distributed generation facilities. There were 7 responses for this section, 4 of the responding utilities do not have specific targets for the degree of DG penetration. The rest of the utilities have penetration targets of less than 10% of their peak load.

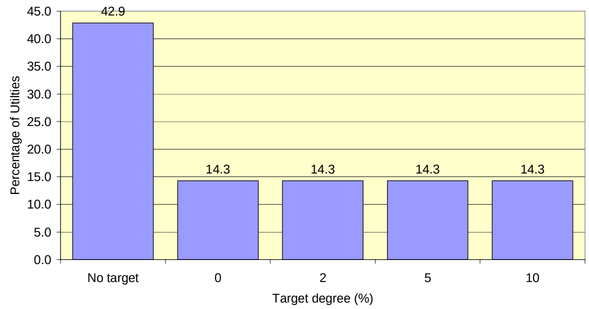

Figure 30 - Target Degree of Penetration of DG Plan

4.2 Types of Distributed Resources

Figure 31 and Figure 32 show the types and capacities of the distributed generation currently installed. There were 15 responses to this question in the survey, 53% of the number of distributed generation units installed are induction generators. Although the number of electronically connected DG units is only 10% of the total number, the power (MW) of these units is as much as the power of the induction generator units installed. This is attributed to the fact that the newly added distributed generators tend to have lager capacities, per generator, than the earlier ones.

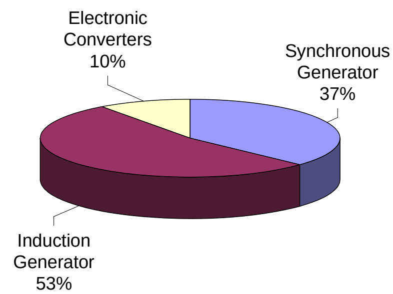

Figure 31 - Types of Distribution Resources Installed

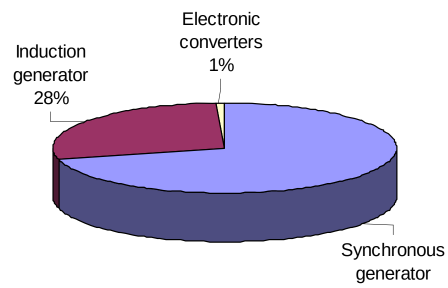

Figure 32 - Power of Installed Distributed Resources

Figure 33 and Figure 34 give an indication of the type and the power of the distribution generation contemplated. There were 8 responses to this point in the survey, 47% of the total number of distributed generation units contemplated are induction generators. However, it is worth noticing that synchronous generators capacity constitutes 45% of the total power contemplated.

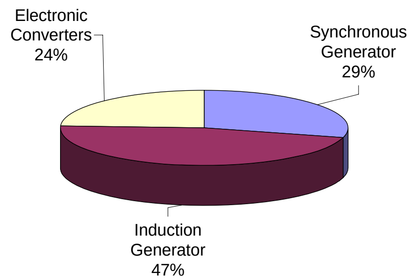

Figure 33 - Number of Distributed Resources Contemplated

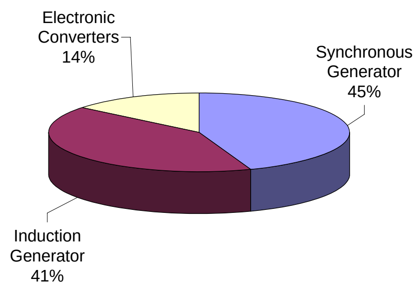

Figure 34 - Power of Distributed Resources Contemplated

4.3 Islanding Operation

1) Island formation detection

Figure 35 presents the methods used to detect island formation. There were 16 responses. From the methods given, 37% of the utilities use 3 indicators (change in voltage, change in frequency and breaker position). Few utilities use only one indicator to detect island formation.

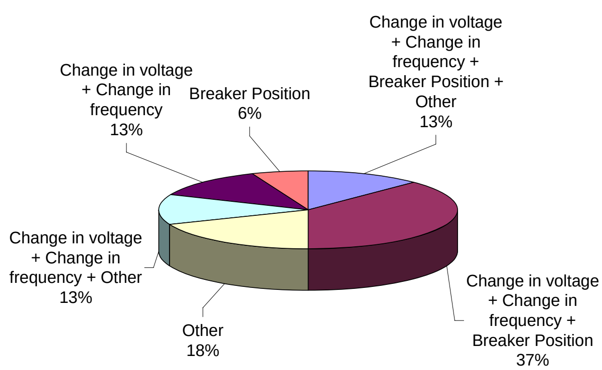

Figure 35 - Methods Used to Detect Island Formation

Other methods mentioned are quoted below:

- "Tele-protection signaling, vector jumps."
- "Depends on technology (inverter VS rotating machine)."
- "Generator is responsible to detect islanding."
- "Negative sequence current, zero-sequence voltage."
- "Customer outage at installed location."
- "Depends on load VS production capacity."

2) Utilities allowing islanding operation

The number of responses was17; 76.5 % do not (and would not) allow islanding operation.

3) Methods of voltage and frequency control under islanding operation

For the four utilities allowing islanding operation their responses indicate that this operating condition is permitted only if the distributed generation supplies the generators' owners own load. Under these conditions the responsibility of controlling voltage and frequency within the island lies with the generator owner.

4.4 Distributed Generation Impact on Distribution Systems

4.4.1 Advantages of Distributed Generation

The following table presents the advantages of having distributed generation as perceived by the respondents. There were 17 responses. Most of the utilities believe that there is more than one advantage to having distributed generation in their system.

It is clear from the table that the most cited advantages are:

- Reduction in losses
- Provision of back up power.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
Reduction in losses	√	√	√		√				√		√	√	√			√	√	**10**
Improved reliability											√	√		√				**3**
Improved Power Quality											√							**1**
Provision of backup power	√	√	√		√	√		√			√	√		√				**9**
Other				√	√		√			√				√	√	√		**7**
Total	**2**	**2**	**2**	**1**	**3**	**1**	**1**	**1**	**1**	**1**	**4**	**3**	**1**	**3**	**1**	**2**	**1**	**30**

Other advantages mentioned are:

- ''Voltage support''
- ''Residual heat recovery''
- ''Reduce purchase power from supplying utility''
- ''Fuel savings''

4.4.2 Disadvantages of Distributed Generation

The following table presents the disadvantages perceived by respondents of having distributed generation. There were 17 responses. The most common disadvantages cited are:

- Complication of operating procedures
- Protection coordination problems
- Voltage control problems
- Safety of personnel concerns

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
Complication of operating procedure	√	√	√	√	√	√		√	√	√	√	√	√	√	√	√	√	**16**
Protection coordination problems	√	√	√	√	√	√		√	√	√	√	√	√				√	**13**
Increase in short circuit level		√		√		√		√				√				√		**6**
Voltage control problems		√		√	√	√			√			√	√			√	√	**9**
Deterioration of delivery point reliability												√						**1**
Deterioration of power quality		√													√		√	**3**
Safety of Personnel	√		√	√		√		√				√	√				√	**8**
Other			√	√			√						√	√	√			**6**
Total	**3**	**5**	**4**	**6**	**3**	**5**	**1**	**4**	**3**	**2**	**2**	**6**	**5**	**2**	**3**	**3**	**5**	**62**

Respondents mentioned other disadvantages of distributed generation; these are quoted below:

- "Shortage of manpower and resources to conduct interconnection studies."
- "Increased complication in distribution planning."
- "Connection is mandated by the government."
- "DG is impacting the low voltage ride through capability of the transmission system."
- "Environmental concerns to adhere to."
- "Operating difficulties with light loads on diesel engines and complicated control systems."

5. DG Interface Conducted Studies

5.1 Planning and Operation

5.1.1 In-house Studies

The respondents were asked to rate their ability to conduct, in-house, system studies on a scale 1-5. The number of responses was 18. Figure 36 shows the average ranking perceived by utilities for their ability and experience to conduct each of the following types of studies according the mentioned scale:

- Steady state analysis
- System dynamics analysis
- Electromagnetic transients studies
- Power quality assessment
- Reliability and economic operation investigations

The type of studies that received the highest average score of 4.4 is steady state studies. The studies that received the lowest score is electromagnetic transients analysis with a score of 2.2.

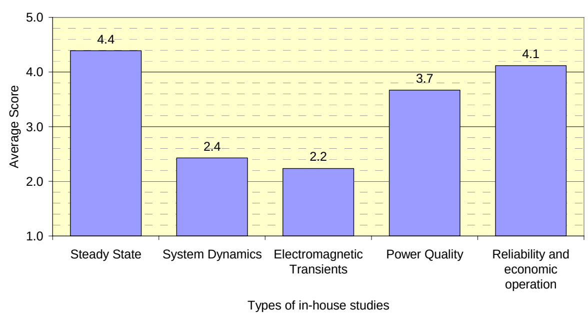

Figure 36 - Average Score for Ability and Experience in Conducting In-house Studies

5.1.2 Studies Conducted by Consultants

The question about the ability of utility staff to interpret consultants conducted studies was raised. Eleven utilities responded to this question. Figure 37 shows the average score for the ability and experience to interpret each type of studies conducted by consultants. The studies with the highest average score of 4.5 are, again, steady state. The study that received the lowest score of 2.7 is system dynamics studies.

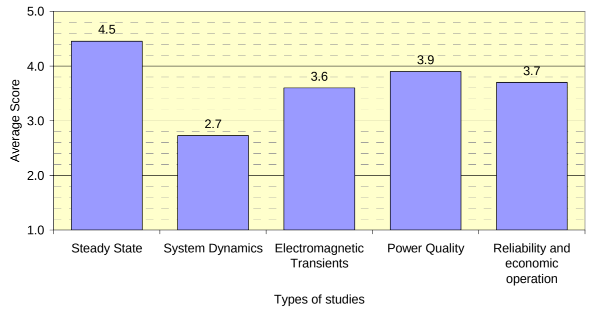

Figure 37 - Average Score for Ability and Experience in Interpreting Results of Studies Conducted by Consultants

The results show that some utilities rated their own ability to perform studies is higher than their ability to evaluate the studies conducted by consultants, in particular in the areas of reliability and economic operation.

6. Tools, Standards and Training

6.1 Analytical Tools

6.1.1 Tools Utilized and their Adequacy.

Utilities were asked to identify the analytical tools they use for different studies and rank their adequacy on a scale 1-5. Eighteen utilities responded to this question and the summaries of their answers are shown below.

Steady-state

The tools used by utilities for steady-state studies are shown in Figure 38.

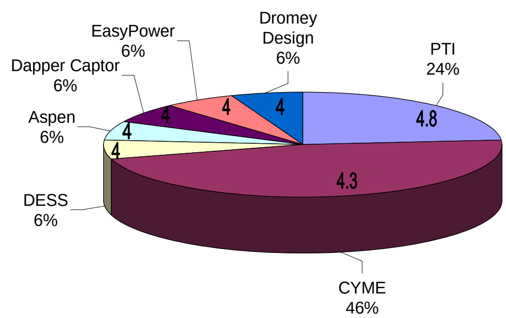

Figure 38 - Analytical Tools Used for Steady-state Studies

As the figure shows, the programs used by utilities for these studies were ranked, in a descending order of number of users as follows:

- CYME: 46%
- PTI: 24%
- Aspen, Dapper Captor, DESS and Easy Power: 6% each

System Dynamics

The tools used by utilities to perform system dynamics studies are shown in Figure 39.

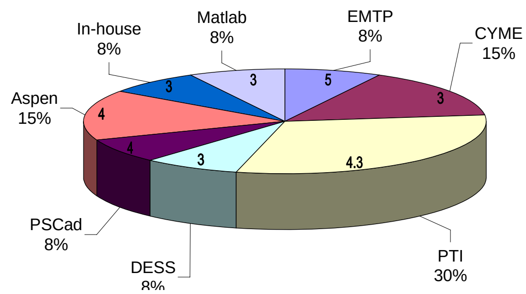

Figure 39 - Analytical Tools Used for System Dynamics Studies

As the figure shows, the programs used for these studies were ranked, in a descending order of number of users as follows:

- PTI: 30%
- Aspen and CYME: 15% each
- In-house applications, DESS, EMTP, Matlab and PSCad: 8% each

Electromagnetic Transients

The tools used by utilities to perform electromagnetic transients studies are shown in Figure 40.

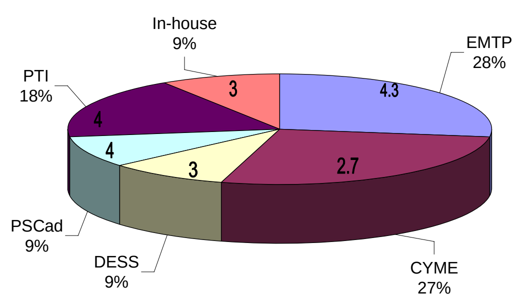

Figure 40 - Analytical Tools used for Electromagnetic Transients Analyses

The programs used for these studies were ranked, in a descending order of number of users as follows:

- EMTP: 28%
- CYME: 27%
- PTI: 18%
- In-house applications, DESS and PSCad: 9% each

These answers should be taken with caution since neither CYME nor PTI can perform electromagnetic transients as described in the survey document.

Power Quality

The tools used by utilities to perform power quality studies are shown in Figure 41.

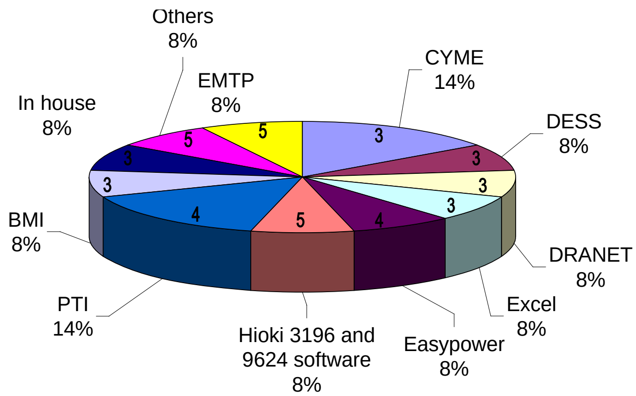

Figure 41 - Analytical Tools Used for Power Quality Analyses

As the figure shows, the programs used for these studies were ranked, in a descending order of number of users as follows:

- CYME and PTI: 14% each
- All others: 8% each. (BMI, DESS, DRANET, Easypower, Excel, EMTP, Hioki, in-house applications, and other applications)

Reliability and economic operation

The tools used by utilities to perform reliability and economic operation studies are shown in Figure 42.

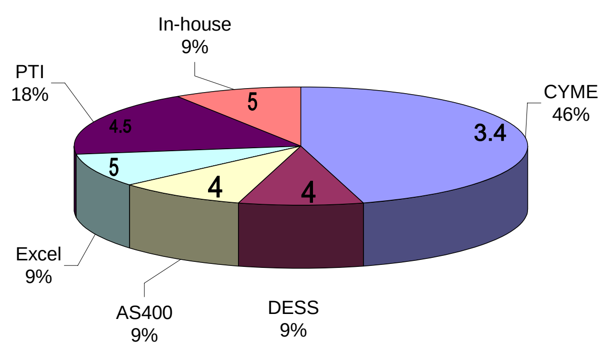

Figure 42 - Analytical Tools Used for Reliability and Economic Operation Analyses

As the figure shows, the programs used for these studies were ranked, in a descending order of number of users as follows:

- CYME: 46%
- PTI: 18%
- AS400, DESS, Excel and in-house applications: 9% each

6.1.2 Areas of Enhancement

Twelve utilities indicated that they would like to see enhancements of the available analytical tools. The identified areas of enhancement, as defined by the respondents, are quoted in the following table in the perceived order of importance.

Importance Rating	Analytical Enhancements
5	– Short circuit current distribution between DG(s) & System – Protective device coordination – System planning – Load forecast including weather normalization – Dynamic stability of synchronous generators – Compatibility with existing records databases
4	– Protection software to model UVP/OVP* protection, OFP/UFP*, rate of change of frequency and impedance relaying – Transient stability – Steady state – Power quality and harmonic mitigation issues – Production profile throughout the year and type of production – Long term economic analysis for losses
3	– Transients – A system dynamics tool quick and simple to use for small generators – Power quality – Electromagnetic transients – Inverter connected DG – Single phase generators – Impedance profiles up to 50th harmonic – Flicker calculations

* UVP: Under Voltage Protection
OVP: Over Voltage Protection
UFP: Under Frequency Protection
OFP: Over Frequency Protection

6.2 Standards

6.2.1 Standards Applied

Sixteen utilities provided answers to this question. Standards used in DG application cited are listed in the following table. The indicated score ranks the utilities perceived adequacy of the standard.

Standard	Number of Users	Average Score
IEC		
– Standards for power quality	1	4
– Flicker Standards	1	4
IEEE		
– IEEE 519	6	4.1
– IEEE 929	2	3.5
– IEEE 1547	7	3.4
– IEEE 142	1	5
– IEEE 242	1	5
– IEEE Flicker Standards	1	4
CSA		
– CAN3-C235-83	2	4
– 107.1/UL1741	1	5
– C22.2	1	4
– C22.3	2	5
– C22.1	1	5
UL1741	2	3
In-house	13	4.35
Micro Power Connect Interconnection Guidelines	2	4.5
ESA Code Requirements	1	4
CEC	2	2.5
Distribution System Code	2	4

6.2.2 Standards Applied – Areas Lacking

Five utilities identified the following areas of the applied standards as inadequate and provided suggestions to their improvement as shown in the following table according to the degree of importance assign by the utilities.

Importance Rating	Areas Lacking in Available Standards
5	– How utility distribution systems operate – Interconnection protection – Flicker
4	– Application of present standards – Interconnection requirements
3	– Commissioning

6.3 Training

Eleven utilities identified the following areas of training as inadequate and provided suggestions to their improvement as shown in the following table according to the degree of importance assigned by the utilities.

Importance	Application
5	– Interconnection protection – Steady state analysis – Protection coordination – Operations – Impacts of generation connection – System study methodology – Generator modeling, both static and dynamic – Generator short circuit contribution – Safety Operations and Maintenance Issues – How utility distribution system operate (for consultants) – Technical studies performed as per typical supply arrangements
4	– System dynamics – System impacts as a result of DG – Protection Coordination – Power Quality – Electromagnetic – Application of present standards – Interconnection Requirements (for Electrical Inspectors)
3	– Power quality – Transient analysis – Electromagnetic transient

Based on the above table it can be concluded that training was deemed necessary in many areas of planning and operation of the distribution system. The largest needs identified by the responding utilities are in the following areas:

- System operations:
    - Protection coordination
    - Safety
    - Maintenance
- System studies:
    - Steady state analysis
    - Short circuit studies (especially generator contribution)
    - Dynamic analysis (particularly generator modeling)

Training in the following areas were also identified as necessary but was assigned a lower degree of importance:

- Power quality
- Electromagnetic transient studies

7. General Comments

Comments provided by the responding utilities are quoted below.

7.1 Need of Training Distribution Planners/Operators

- "Many people have a problem understanding how distributed generation effects voltage regulation on distribution feeders and on the substations. The mode of operation of the DG unit is also confusing too many (they don't understand the constant voltage, constant of modes)."
- "Most distribution planners have never dealt with generation and they struggle to understand it."
- "In many companies the protection engineers are used to working with transmission projects and apply the same principles which are often overkill. The protection engineers with a distribution background are unfamiliar with generator protection and how the generators can effect the distribution protection."
- "Many proponents believe that adding distributed generation will improve the reliability and power quality of the distribution system, when often they degrade both. Training is required in this area."

7.2 Need to Improve Islanding Protection

- "So far, we haven't seen much technology to assist in islanding protection."
- "There is a need to develop a relatively inexpensive and reliable anti-islanding protection system. Currently used transfer trip schemes are too expensive for most small generators."
- "Fault contribution by DG needs to be better understood for analysis on protection coordination and anti-islanding evaluations."

7.3 Need to Develop Standards for Interconnection and Operation

- "I think a national standard needs to be developed to guide utilities in the proper operation of cogeneration. This should apply to all energy cogeneration, such as waste heat and water. With a formalized process, it would promote safety and standard operation procedures."
- "I am a member of this committee (CSA C22.3 #9) which is currently developing a national standard for interconnecting DG with distribution system. This standard will be comprehensive and address many of the technical issues associated with DG interconnection."

7.4 Unavailability of DG models and data

- "Appropriate public domain generator models are difficult to obtain from many generator manufacturer's (i.e. wind generators)."

7.5 Not Classified in Technical Areas

- "Hydro serves 35,272 retail distribution customers 53 individual Distribution systems. There are 27 grid-connected systems with peak loads ranging from 46 kW to 12.5 MW. Additionally, there are 3 grid-connected systems with peak loads ranging from 15 MW to 57 MW and 23 isolated diesel systems with peak loads ranging from 50 kW to 3700 kW. Load growth is very low."
- "Hydro has five distributed generators. Three on its interconnected island system and two on its isolated diesel systems at present. One is a 176 kW small hydro unit connected to a diesel system with a peak load of 814 kW. The other is a 390 kW (6x65 kW) demonstration wind farm connected to a diesel system with a peak load of 1400 kW. There is a 400 kW mini-hydro in (…) and two mini-hydro plants in close proximity totaling 1000 kW in (…).
- "In addition to PSS/ADEPT Hydro's System Planning Group uses PSS/E and EMTP for system analysis."

8. Survey Analysis

The distributed generation survey was distributed to 30 distribution utilities from different parts of Canada. Answers were received from 18 utilities representing 9 provinces and 2 territories serving 7.13 million Canadian customers. Not every utility responded to all questions of the survey, for inapplicability or lack of information.

Although it cannot be taken as a complete representation of the Canadian industry, the responses supplied very useful information and a good insight into the situation of DG in Canada.

The sample size, and more importantly, the number of answers received are large enough to provide a good picture of prevailing conditions in the survey topics.

However, valuable information could be extracted about the experience and tools that Canadian distribution planning and operation engineers have and use for analysis of distributed generation interface issues.

8.1 Distribution System Characteristics

The obtained results portray the natural diversity of geographical, weather and demographics of different parts of the country. On one hand there are largely populated urban centers with heavy loads served by utilities with many customers in small areas. On the other hand there are large land extensions scarcely populated.

There is in excess of 5 times more overhead lines than underground cables. About 48% of the total are single-phase lines, 2% are two-phase lines and 50% are three-phase lines. Primary voltages are many and varied, ranging from 2.4 kV to 46 kV. Several configurations are used in the distribution substation with respect to the number of transformers, circuit breakers and bus bars.

On average, the load is composed by 40% of residential, 31% industrial and 29% commercial. It is predicted that the peak load will increase 34.3% in the next five years and 53.5% in ten years. The load factor is expected to grow slightly from the current 65% over the coming ten years. The growth rates of load and system capacities seem to match, on average, over the same period.

8.2 Distributed Generation in Distribution Systems

Most surveyed utilities have distributed generation (15/18). The degree of penetration is less than 5% of peak load. About 30% of the utilities are planning to add distributed generation to their system. Half of the utilities do not have established targets for DG penetration. The DG penetration of the other half is less than10%.

More than half of the number of distributed generation units installed is of the induction generator type. Only 10% of DG units are connected to the system using power electronic interfaces, however, the output power of these units is as high as the power of the induction generator units directly connected to the network.

It is estimated that about half of the new DG units would be based on induction machines. However, in terms of power the synchronous generators will amount to 45% of the total power produced by DG.

About 80% of utilities do not allow islanding operation. There are many and varied methods for detecting island formation and almost always more than one indicator is used for this purpose.

Most of the utilities indicated that there are certain advantages in having distributed generation in their system. The most frequently cited advantages are:

- Reduction of losses
- Provision of backup power

The utilities also believe that there are disadvantages. The most common disadvantages cited are:

- Complication of operating procedures
- Protection coordination problems
- Voltage control problems
- Safety of personnel

8.3 Studies Conducted

The following important remarks can be made regarding the different power system analysis tools and studies performed either by distribution engineers themselves or their ability to interpret studies done externally:

- Steady state analysis: Most utilities are able to execute or interpret consultants' results for these studies.
- System dynamics: Many utilities are unable to execute or interpret consultants' results for these studies.
- Electromagnetic Transients: Many utilities seem to be able to interpret consultants' results but are unable to execute the studies themselves. Lack of knowledge of necessary software and their capabilities could be the problem as is shown in section 6.1 where many utilities believe erroneously that electromagnetic transient analysis can be performed with CYME or PTI software.
- Power quality: Most utilities seem able to execute or interpret consultants' results for these studies.

- Reliability and economic operation: Most utilities are able to execute or interpret consultant's results for these studies. Some utilities rated their own ability to perform studies higher than their ability to evaluate the studies conducted by consultants.

In general utilities believe that they can adequately conduct steady state analyses. Reliability and power quality studies received also a fairly high score. It is considered that there is substantially less expertise to conduct system dynamics and electromagnetic transients studies.

Similar answers were obtained when judging the ability to interpret studies conducted by consultants.

8.4 Tools and Training

- The most used computer tool for steady state analyses is CYME (46%) with an adequecy score of 4.3 over 5. The next most popular is PTI (24%) with a score of 4.8 over 5.
- For system dynamics, PTI is the most popular tool (30%) with a score of 4.3 and the second is CYME (15%) with a score of 3.
- For electromagnetic transient studies the most popular is CYME with 28% and a score of 4.3 while EMTP is second with 27% and a score of 2.7. The latter answers should be taken with caution because CYME software cannot perform electromagnetic transients studies.
- For power quality studies the most commonly used programs are PTI and CYME both at 14% with a score of 4 and 3 respectively.
- For reliability studies CYME is used by 46% of the respondents having a score of 3.4. The second is PTI with 18% and a score of 4.5.

The most important areas of software enhancements mentioned are quoted below:

- ''Short circuit current distribution between DG(s) & system''
- ''Protective device de-sensitivity''
- ''System planning''
- ''Load forecast which includes weather normalization''
- ''Dynamic stability of synchronous generators''

Training was judged to be necessary in many areas of planning and operation of the distribution system. The largest needs are in the following areas (rated 5):

- Interconnection of DG
- System operation
- Protection coordination
- Safety and maintenance
- System studies: steady state analysis; short circuit studies (especially generator contribution);

- Dynamic analysis (particularly generator modeling).
- System impacts as a result of DG (power quality);
- Electromagnetic transient studies.

8.5 General Comments

General comments received from respondents mostly cover the following areas:

1) The need of training distribution planners/operators in the particular issues of the DG operating procedures, voltage regulation, protection and reliability.
2) The need to improve islanding protection for DG.
3) The need to develop standards for interconnection and operation of DG.
4) Unavailability of DG models and data.