DEVON • OTTAWA • VARENNES

HOUSE MODEL IMPLEMENTATION FOR POWER QUALITY STUDIES

CETC CANMET ENERGY TECHNOLOGY CENTRE

CLEAN ENERGY TECHNOLOGIES
TECHNIQUES D'ÉNERGIE ÉCOLOGIQUE

CTEC CENTRE DE LA TECHNOLOGIE DE L'ÉNERGIE DE CANMET

Natural Resources Canada | Ressources naturelles Canada

Canada

HOUSE MODEL IMPLEMENTATION
FOR
POWER QUALITY STUDIES

Prepared by:

CANMET Energy Technology Centre - Varennes

Jean-Nicolas Paquin
Dave Turcotte

CITATION

Paquin, J.N., and Turcotte, D. *House Model Implementation For Power Quality Studies*, Technical Report #CETC 2008-007 (TR), CANMET Energy Technology Centre – Varennes, Natural Resources Canada, November 2007, 40 pages.

DISCLAIMER

This report is distributed for informational purposes and does not necessarily reflect the views of the Government of Canada nor constitute and endorsement of any commercial product or person. Neither Canada nor its ministers, officers, employees or agents makes any warranty in respect to this report or assumes any liability arising out of this report.

ACKNOWLEDGMENT

Financial support for this research project was provided by Natural Resources Canada through the Technology and Innovation Program.

SUMMARY

Natural Resources Canada (NRCan) manages for Canada a co-ordinated research program to foster the advancement of renewable energy technologies and grid integrated systems in order that they become the preferred energy options on the basis of reliability, cost effectiveness and social and environmental advantages. The impact of grid integrations of distributed generation is assessed in the Impact of Large-Scale Integration of Distributed Generation (IMPACT) project, including the study of high penetration of photovoltaic in a residential sub-urban neighbourhood. This study will be presented in three successive reports on: 1) Inverter modeling, 2) Residential load modeling and 3) Simulation results.

The objective of the present report is to describe the modeling technique and results for the house load to be used in the PV neighbourhood power quality study. The models are developed using MATLAB®/Simulink® and its power systems simulation toolbox, SimPowerSystems (SPS).

Modeling a residential load is very difficult due to the wide distribution of appliances and users behaviours. Various approaches have been surveyed in the literature for the modeling of this type of load. The selected approach uses a dynamic load for the fundamental in parallel with a current source for harmonic generation. The harmonic content is derived from the Canadian Power Quality Survey (CPQS) data using curve-fitting of harmonic current data points from the 3rd to the 15th component.

SOMMAIRE

Ressources naturelles Canada gère pour le Canada un programme de recherche coordonné visant à faire avancer le développement des technologies des énergies renouvelables et leur intégration sur le réseau afin qu'elles deviennent des sources de choix sur la base de leur fiabilité, coût et avantages environnementaux et sociaux. L'impact de l'intégration de la production décentralisée est étudié dans le cadre du projet IMPACT – Impact de l'intégration à grande échelle de la production décentralisée au réseau électrique, incluant un volet couvrant une haute pénétration de photovoltaïque dans un quartier résidentiel en banlieue.

L'objectif du présent rapport est de décrire la technique et les résultats de modélisation appliquée au modèle de charge résidentiel destiné à être utilisé dans le cadre d'étude de qualité d'onde. Le modèle est développé en utilisant MATLAB®/Simulink® et la palette d'outils SimPowerSystems (SPS).

La modélisation d'une charge résidentielle n'est pas une mince tâche considérant l'éventail très large d'appareils et de comportement chez les usagers. Différentes approches ont été explorées dans la littérature pour la modélisation de ce type de charge. L'approche retenue consiste un une charge dynamique pour la composante fondamentale mise en parallèle avec une source de courant pour la génération des harmoniques. Le contenu harmonique est dérivé du « Canadian Power Quality Survey - (CPQS) » (*Enquête sur la qualité d'onde au Canada*) en utilisant un lissage des données de courant harmonique entre la troisième et la quinzième.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

Natural Resources Canada (NRCan) manages for Canada a co-ordinated research program to foster the advancement of renewable energy technologies and grid integrated systems in order that they become the preferred energy options on the basis of reliability, cost effectiveness and social and environmental advantages. Adding generation at various locations on the transmission and distribution grid can potentially have an impact, positive or negative, on its operation. Consequently, as part of the Technology and Innovation programme, NRCan has launched its Impact of Large-Scale Integration of Distributed Generation (IMPACT) project to assess the various effects of the penetration of distributed energy resources on the electrical grid.

In the course of this project, a study of the power quality impact of high penetration of photovoltaics in a residential sub-urban neighbourhood was initiated. For this study, a model of a neighbourhood of in greater than 200 houses is to be modelled and simulated with various levels of photovoltaics and residential loads.

This report is the second of a series of three that will address successively:

- The modeling of a residential PV inverter;
- The modeling of a typical house; and,
- The power quality study using the PV neighbourhood model.

The objective of the present report is to describe the modeling technique and results for the development of a load representing a typical house for the purpose of power quality studies. The model is developed using MATLAB®/Simulink® and its power systems simulation toolbox, SimPowerSystems (SPS). This simulation and mathematical processing software was chosen for many reasons. Its flexibility and modeling capability for controls and power systems is an important asset. With multiple numerical solvers, toolboxes and libraries, this software can either be used for stability analysis, transient analysis (EMTP type of studies) and power flow. Moreover, with its specific, C-based, easy-to-use programming language, MATLAB® offers the possibility of automating and controlling multiple simulations and tests. A large amount of functions are also available for the automation and creation of results analysis and plotting.

After a description of the theoretical approach (Section 2), the actual implementation in MATLAB®/Simulink® is presented (Section 3). Finally, a short conclusion (Section 4) highlights the results, limitations and opportunities for improvement.

2 APPROACH

Modeling a residential load is challenging for many reasons. It is a very chaotic load because it varies so much from house to house and from time to time. A residential load will vary according to:

- Time of day;
- Season;
- Occupancy;
- Consumer behaviour; and,
- Type, number and usage of home appliances.

Literature reveals that various approaches are used to model this type of load. In most cases, the harmonic content is generated using a controlled current source while the fundamental component is either a constant impedance or constant power load connected in parallel with the harmonic generator. In [1], this method is denoted the Injected Current Method. This particular technique is said to be accurate for most nonlinear loads as long as the voltage distortion is below 10%. The major problem in modeling house loads is the availability of data for model calibration. For instance, to use a probabilistic model similar to the one presented in [2], a large amount of data is needed for reliability.

The bottom line is: decisions have to be made when modeling residential load. A load model is built depending on the particular case study and the available information. This section presents the load model that was built for the current study. The harmonic components were represented using a regression technique inspired by the one found in [3] whereas the fundamental component was modeled using a voltage dependant load principle found in [4].

2.1 Fundamental Component

The implemented fundamental component is completely parameterized and can operate in both voltage dependant and constant power modes.

2.1.1 Voltage Dependant

Voltage dependant, reactive and active powers are specified using the following equations:

$$P = P_0 \cdot \left(\frac{V}{V_0} \right)^{np} \tag{2.1}$$

$$Q = Q_0 \cdot \left(\frac{V}{V_0} \right)^{nq} \qquad (2.2)$$

where: P is the active power of the fundamental component absorbed by the house (W).

P_0 is the nominal active power of the fundamental component absorbed by the house (when the voltage across it is equal to V_0) (W).

Q is the reactive power of the fundamental component absorbed by the house (VAR).

Q_0 is the nominal reactive power of the fundamental component absorbed by the house (when the voltage across it is equal to V_0) (VAR).

V is the voltage across the residential load (V).

V_0 is the nominal voltage across the residential load (V).

np is the active power variation coefficient.

nq is the reactive power variation coefficient.

Typical values for np and nq are specified in Table 7.2, page 311 of reference [4]. For typical residential load during summer, values of $np = 1.2$ and $nq = 2.9$ are preferred. Values of $np = 1.5$ and $nq = 3.2$ should be used for winter residential load[1]. This type of fundamental load is very typical and is widely used in many simulation tools. A three-phase version is available in the SPS toolbox of MATLAB®/Simulink® [5], which inspired the implementation of the single-phase version of the house model.

2.1.2 Constant Power

In constant power mode, the active and reactive load imposed by the house are always equal to the P_0 and Q_0 values entered in the model mask, which is the equivalent of having $np = nq = 0$. Hence, the current drawn by the load will increase with respect to the voltage decrease. In steady state conditions where voltage is relatively constant, using constant power allows better control of power while introducing little inaccuracy. This mode is however to be used with caution for transient and stability studies, especially where large voltage swings are expected.

[1] It has to be noted that these parameters are denoted differently in [4] where $np \equiv \partial P / \partial V$ and $nq \equiv \partial Q / \partial V$

2.2 Harmonic Components

The harmonic components of a house are very difficult to determine and model. Because of the induced harmonic voltage components, the load variations and appliances type and usage, it is very difficult to accurately reproduce the real behaviour. Therefore there are a large number of ways to model them. An empirical based approach was employed using data provided in the Canadian Power Quality Survey, as described in the following sections.

2.2.1 The Canadian Power Quality Survey

The Canadian Power Quality Survey (CPQS) [6], published in 2001, explains the methodology and presents the results of a study that was conducted from 1996 to 2000 across Canada. In this report, the Power Quality Interest Group (PQIG) collected, recorded and analyzed the results from a total of 418 different sites, classified in 19 categories including residential, commercial, industrial and mixed load categories. The voltage and current was measured at the point of common coupling (PCC) in order to analyze the power quality on many aspects using multiple power quality indices.

In order to model the harmonic component of the load, two power quality indices for two different sites were considered: the *ICHI* and the *IVHI* where:

- *ICHI* is the steady-state RMS value of individual current harmonics calculated in a ten minute interval (A).
- *IVHI* is the steady-state RMS value of individual voltage harmonics calculated in a ten minute interval (V).

The indices from two interesting sites were retained for the modeling: sites 02-01 and 02-23. Both sites are in the residential, sub-urban category and consist of a single house. The measurements are presented on a per-phase basis. In order to take into account the harmonic currents in both phases of the 240V distribution loads, the induced voltage harmonics are extracted from the current data, assuming a resistive load. Therefore, we have:

$$I_{\{a,b\}\_h} = \left(ICHI_{\{a,b\}\_h} - \frac{IVHI_{\{a,b\}\_h}}{K_R} \right) \qquad (2.3)$$

$$K_R = \frac{IVHI_{\{a,b\}\_1}}{ICHI_{\{a,b\}\_1}} \qquad (2.4)$$

where: $I_{\{a,b\}\_h}$ is the computed RMS value of the hth harmonic component of the current, on phase a or phase b (A).

$ICHI_{\{a,b\}\_h}$ is the measured RMS value of the h^th^ harmonic component of the current, on phase a or phase b (A).

$IVHI_{\{a,b\}\_h}$ is the measured RMS value of the h^th^ harmonic component of the voltage, on phase a or phase b (V).

K_R is the calculated proportion factor between the fundamental component of the current and voltage (assumption: resistive load) (Ω).

Moreover, to take into account both legs of the split-phase load (see Figure 1), the following equation was used:

$$I_h = \frac{I_{a\_h} + I_{b\_h}}{2} \tag{2.5}$$

where: I_h is the RMS value of the h^{th} harmonic component of the current (A)

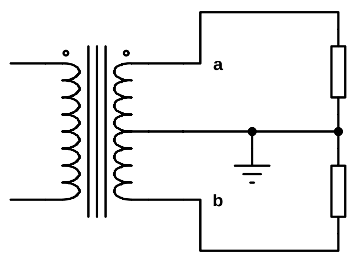

Figure 1: Split-phase configuration

The previous approach was used for both site 02-01 and site 02-23. It has to be noted that only the odd harmonics from order 3 to 15 were retained to be computed because they were the only significant components. Using the previous equations, the data has been processed and adapted for inclusion into the house model.

2.2.2 Modeling Using Harmonic Data

The pre-processed harmonic data from the CPQS was then used for its inclusion in the house model. The relationship between the ratio of the harmonic component and the fundamental $\left(I_h / I_1 \right)$ and the fundamental current $\left(I_1 \right)$ was characterized by fitting a polynomial equation to the CPQS data. Thus we have:

$$I_{ratio\_h} = \sum_{i=0}^{6} a_{i,h} \cdot \psi^i \tag{2.6}$$

$$\psi = \frac{I_1 - \mu_1}{\sigma_1} \tag{2.7}$$

where: I_1 is the RMS value of the fundamental component of the current (A)

I_h is the RMS value of the hth harmonic component of the current (A)

I_{ratio_h} is the current ratio I_h/I_1 for the hth harmonic (A/A)

ψ is a substitute used for the centering and scaling of the polynomial fitting

μ_1 is the mean value of I_1 in the processed data

σ_1 is the standard deviation of I_1 in the processed data

Then, the harmonic current's magnitude is calculated using:

$$I_h = \tilde{I}_{ratio\_h} \cdot I_1 \tag{2.8}$$

where: $\tilde{I}_{ratio\_h}$ is non-linear and governed by the limits given in Table 1 or Table **2** depending on the site (A/A)

When modeling using interpolation techniques, limits may be required in order to avoid operation in unrealistic or undesirable conditions. The curve fitting is an approximation of a pattern seen in the scatter plot of the harmonic data. Moreover polynomial fitting can be accurately used for interpolation, but never for extrapolation, since its behaviour is quite unpredictable beyond the provided data. Since in simulation it is undesirable to obtain infinite values in a function, the trajectory of the polynomials near zero was kept mathematically natural (trajectory dictated by the polynomial equation) nearby this boundary. For the upper boundary, to avoid undesirable polynomial oscillations and to respect a somewhat reasonable pattern, each $I_h/I_1(I_1)$ function is kept constant beyond a designated limit.

While fitting results show debatable accuracy, one must consider that in all cases a decision has to be taken in terms of mathematical representation. A house load depends on a large number of factors. Moreover, the present model is of the «black-box» type and does not represent every little load fluctuation caused by different appliances. The primary goal is to represent harmonics in a representative range for power quality studies involving the interconnection of multiple houses. The current approach using CPQS data is a reasonable one for that matter.

Table 1: House Harmonics Characteristics for Site 02-01

Harmonic Order	Polynomial Order	I_1 limit (A)	I_{ratio_h} limit (A/A)
3	6	35	0.0321
5	6	35	0.0122
7	6	35	0.0026
9	6	35	0.0004
11	6	35	0.0013
13	6	35	0.0007
15	6	40	0.0007

Table 2: House Harmonics Characteristics for Site 02-23

Harmonic Order	Polynomial Order	I_1 limit (A)	I_{ratio_h} limit (A/A)
3	6	40	0.02984
5	6	40	0.00733
7	5	35	0.00487
9	6	35	0.00074
11	6	40	0.00060
13	6	30	0.00129
15	6	40	0.00068

An example of the obtained results is illustrated in Figure 2. The illustrated example is the processed data for the 3rd harmonic measured at site 02-01. The boundary between the polynomial and the forced output of the simulated pattern is also illustrated. The complete results for all of the computed house harmonic components are found in Appendix A. The parameters for the computations of site 02-01 and 02-23 are found in Table 3 and Table 4, respectively.

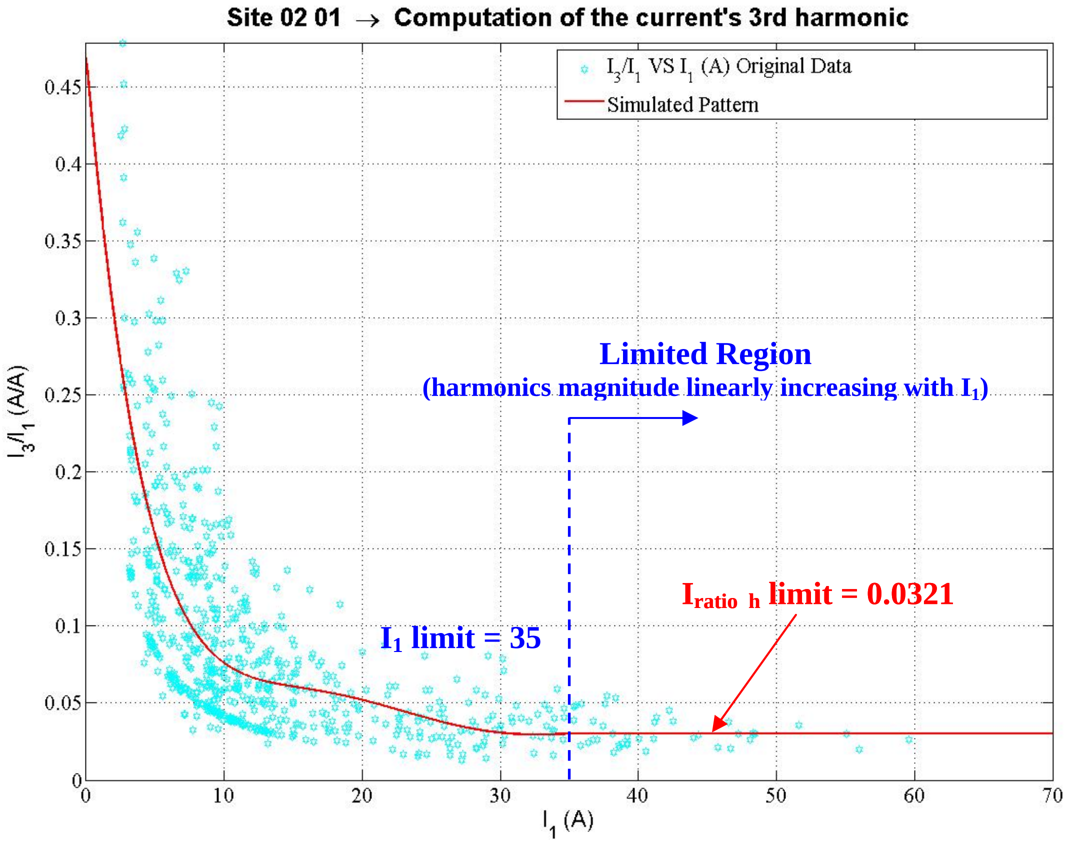

Figure 2: Graphical Example of House Harmonics Data Processing

Table 3: House Harmonics Polynomial Fitting Parameters for Site 02-01

h	μ_1	σ_1	a_6	a_5	a_4	a_3	a_2	a_1	a_0
3	25	14.4381	0.01074	-0.02264	-0.01409	0.03774	0.01655	-0.03487	0.03952
5	25	14.4381	0.00391	-0.00943	-0.00255	0.01365	0.00648	-0.01813	0.01844
7	25	14.4381	0.00222	-0.00490	-0.00197	0.00619	0.00491	-0.00810	0.00443
9	25	14.4381	0.00169	-0.00378	-0.00173	0.00578	0.00267	-0.00601	0.00191
11	25	14.4381	0.00071	-0.00181	-0.00034	0.00277	0.00070	-0.00326	0.00256
13	25	14.4381	0.00043	-0.00110	-0.00009	0.00129	0.00083	-0.00200	0.00145
15	25	14.4381	0.00040	-0.00107	-0.00010	0.00158	0.00042	-0.00185	0.00124

Table 4: House Harmonics Polynomial Fitting Parameters for Site 02-23

h	μ_1	σ_1	a_6	a_5	a_4	a_3	a_2	a_1	a_0
3	25	14.4381	0.00256	-0.01216	0.00645	0.02835	-0.02246	-0.02067	0.04683
5	25	14.4381	0.00174	-0.00801	0.00573	0.01218	-0.00806	-0.01291	0.01600
7	25	14.4381	0	-0.00288	0.00802	-0.00121	-0.00814	-0.00048	0.00939
9	25	14.4381	0.00129	-0.00490	0.00185	0.00918	-0.00485	-0.00788	0.00581
11	25	14.4381	0.00051	-0.00225	0.00127	0.00383	-0.00190	-0.00404	0.00293
13	25	14.4381	0.00069	-0.00224	0.00040	0.00387	-0.00142	-0.00269	0.00261
15	25	14.4381	0.00045	-0.00198	0.00102	0.00383	-0.00231	-0.00333	0.00281

Due to a lack of information, the phase angle of each harmonic component is not computed using empirical implementation. Instead, each phase angle is determined using a random value in the interval [-π, π] for each individual harmonic component. Using the *rand*() function in MATLAB®, the phase angles for a single house are generated using the following code:

```
rand('state', rand_seed);
for ii = 1:1:7; % FOR the 7 harmonics (3, 5, 7, 9, 11, 13, 15)
  K_rand = rand()*2 - 1;
  Phi(ii) = K_rand * pi; % a random phase angle in the interval [-pi , pi] (OR [0 , 2*pi])
end
```

The random seed[2] always being fixed using the command line «`rand('state', rand_seed)`», the randomization results can be repeated at each and every simulation. For the complete benchmark test, the random seed of a single house is its position index (i.e. the seed value for house 3 is 3).

[2] Random seed is the name given to the number used to initialize a pseudorandom number generator. The seed determines the sequence of numbers that will be generated.

3 MODEL IMPLEMENTATION

The house load was implemented using the aggregation/summation of the current's harmonic and fundamental components. Figure 3 illustrates how it was done.

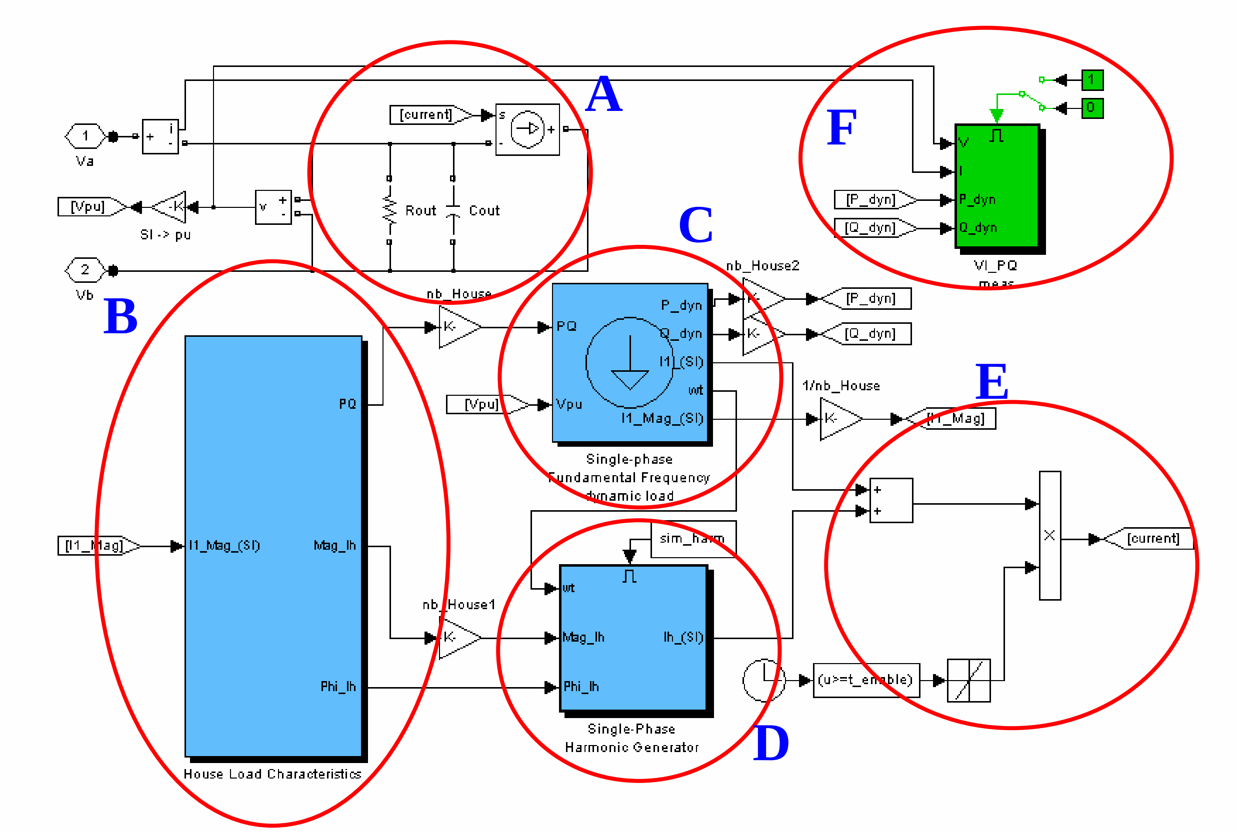

Figure 3: Implementation of the house load in SPS/Simulink®

The model illustrated in Figure 3 can be decoupled in six different parts:

A) The Simulink® to SPS interface.

B) The House load characteristics.

C) The single-phase fundamental frequency load.

D) The single-phase harmonic generator.

E) Current components summation and load start control.

F) House measurements (V, I, P, Q).

Subsystems A, B, C, D and F are further explained in the following sections.

3.1.1 Simulink® to SPS interface

The SPS electrical circuit sees the residential load as a simple controlled current source. The high parallel impedance connected to the current source is essential for numerical stability. Its effect on the output active and reactive power is compensated for in the single-phase fundamental frequency load (see section 3.1.3) using the following equations:

$$Q = Q_{in} + 2\pi f C_{out} V_1^2 \tag{3.1}$$

$$I_1 = I_{1\_comp} - \frac{V_1}{R_{out}} \tag{3.2}$$

where: Q is the equivalent, absorbed reactive power (VAR).

Q_{in} is the input reactive power given by the house load characteristics (VAR).

f is the measured frequency at the PCC of the house (Hz).

C_{out} is the output capacitor (F).

V_1 is the fundamental value of the voltage measured by the PLL (V).

I_1 is the resultant fundamental value of the output current (A).

I_{1_comp} is the computed fundamental value of the output current (A).

R_{out} is the output resistor (Ω).

Thus, the active and reactive power values of the fundamental component are not affected, in steady-state, by the presence of C_{out} and R_{out}. With a capacitor value chosen to be small, the effect on transients is negligible.

3.1.2 House Load Characteristics

This subsystem uses the fundamental voltage magnitude as an input and outputs the active and reactive power and the harmonic components magnitudes and phase angles. Using the equations (polynomial approximations) seen in section 2.2.2, this block calculates and outputs a vector, *Mag_Ih*, containing the magnitudes of:

- *Mag_Ih(1)*: DC component
- *Mag_Ih(2 → {length(h_orders) + 1})*: Harmonic components
- *h_orders* is a vector, parameter specified in the block's mask, that contains each simulated harmonic index.

However, for the present study, as explained in section 2.2.1, only the odd harmonics from the 3rd to the 15th have been implemented. The *h_order* vector is then equal to:

- h_order = [3 5 7 9 11 13 15]

The output named *Phi_Ih* outputs a vector containing the phase angles for every simulated harmonic component. For the present study, each phase angle is calculated at the initialization stage, in the block's mask, using the randomization code explained in section 2.2.2. The active and reactive powers, the output vector named *PQ*, are defined as constant values in the block's mask for the present study.

For further studies using this house model, it is recommended to respect the output vectors conventions since the single-phase harmonic generator (section 3.1.4) works using *Mag_Ih* and *Phi_Ih* as an input, as does the single-phase fundamental frequency load with the *PQ* vector. The model can be easily adapted by modifying the *House Load Characteristics* block. For instance, the *PQ* output could be calculated using a time/season varying consumption profile. Different harmonic profiles could be included as well.

3.1.3 Single-Phase Fundamental Frequency Load

This block outputs the necessary fundamental component of the current with respect to the active and reactive power conditions. The following equation computes the fundamental current value:

$$I_{1\_comp} = \left(\frac{P + jQ}{V_1} \right)^* \qquad (3.3)$$

Using a PLL, such as the one presented in [7], to synchronize to the voltage at the PCC, the block measures the voltage's magnitude, frequency and phase angle which are used for the output current calculation. This block can work either in dynamic power mode (voltage dependent) or constant power mode (see Section 2.1). In both modes, the resultant active and reactive power is calculated using the P and Q input values. In constant power mode (or voltage independent mode), the active and reactive powers are constant. The other mode is governed by the principles described in section 2.1.1, where the P and Q inputs correspond to the P_0 and Q_0 of equations (2.1) and (2.2).

Additional load dynamics can be added, when in dynamic load mode, using the included lead-lag compensators. The computed output power is therefore given below:

$$P' = P \cdot \frac{1 + T_{P1}s}{1 + T_{P2}s} \tag{3.4}$$

$$Q' = Q \cdot \frac{1 + T_{Q1}s}{1 + T_{Q2}s} \tag{3.5}$$

The initialization process requires the specification of the initial magnitude and phase angle of the voltage at the PCC. These values are the steady-state conditions of the residential load connected to a specific grid model. This initialization permits a faster steady-state response and avoids getting high undesirable starting transients. The following equations are used to determine the initial voltage and current:

$$V_{1\_init} = Mag\_V_0 \cdot V_{grid} \cdot \sqrt{2} \cdot \sin\left(2\pi \cdot f \cdot t_0 + Phi\_V_0\right) \tag{3.6}$$

$$I_{1\_init} = \left(\frac{\left(P_{init} + jQ_{init}\right) \cdot \sqrt{2}}{Mag\_V_0 \cdot V_{grid}} \right)^* \tag{3.7}$$

where: V_{1_init} is the initial value of the voltage at the PCC (V).

I_{1_init} is the complex (magnitude and phase angle) initial value of the current (A).

Mag_V_0 is the specified magnitude of the initial voltage at the PCC (p.u.).

Phi_V_0 is the specified initial phase angle of the voltage at the PCC (rad).

P_{init} is the specified initial active power of the load (W).

Q_{init} is the specified initial reactive power of the load (VAR).

t_0 is equal to zero (instant t=0) (s).

V_{grid} is the nominal RMS voltage of the grid (V).

f is the nominal frequency of the grid (Hz).

The parameters Mag_V_0, Phi_V_0, P_{init}, Q_{init}, V_{grid} and f are specified in the block's mask. The initial values are then pre-calculated by the mask's initialization function and transferred inside the block for simulation. Outputs P_dyn and Q_dyn are not used by the house model. They correspond to the resultant powers obtained from the equations in section 2.1 and are only available as outputs for future developers to observe the calculations.

3.1.4 Single-Phase Harmonic Generator

The harmonic generator utilizes the *h_order* parameter, the *Mag_Ih*, the *Phi_Ih* and the voltage phase angle (*wt*) provided by the fundamental frequency load to calculate the instantaneous harmonic currents. The following equation describes the harmonic generator:

$$I_{harm} = I_{h0} + \sum_{h=2}^{N} \hat{I}_h \sin\left(h \cdot \omega t - \phi_h\right) \tag{3.8}$$

where: I_{harm} is the instantaneous harmonic current (A).

I_{h0} is the DC component of the current (A).

$\hat{I}_h$ is the magnitude of the h^{th} harmonic component (refers to *Mag_Ih*) (A).

h is the harmonic index (or the *Mag_Ih* vector index).

N is the last harmonic component (or the length of the *Mag_Ih* vector).

ωt is the fundamental voltage phase angle at the PCC (refers to *wt*) (rad).

ϕ_h is the phase angle of the h^{th} harmonic component (refers to *Phi_Ih*) (rad).

The ouput *Ih_(SI)* is then added to the fundamental component of the current provided by the fundamental frequency load. The harmonic generator is auto-adaptive to any harmonic profile, as long as the *h_orders* parameter specifies the simulated harmonic patterns.

3.1.5 House Measurements

The house measurements can be enabled or not using the manual switch connected to it. Included inside the measurements block, three different scope blocks display the measurement of the residential load's instantaneous voltage and current and their magnitudes, the active and reactive power of the load measured at the PCC and the dynamically calculated active and reactive powers (*P_dyn* and *Q_dyn* outputs of the single-phase fundamental frequency load). It is recommended that these measurements be activated wisely when simulating large models since they can use large amount of computational and memory resources.

4 CONCLUSION

Using selected data from a Canadian survey on power quality, a house model was implemented. It is built on the principle of a fundamental current source in parallel with a harmonic current source. The active and reactive powers at fundamental frequency are specified either as constants or dynamically varying, depending on the chosen study, while harmonic currents are a function of the fundamental current. It has to be noted that a single house is one of the most chaotic and unpredictable loads and interacts differently with a distribution network depending on time of day, season, in-house consumers, connected appliances, etc.

Notwithstanding this individual stochastic behaviour, we know from experience that when aggregated on many feeders, as seen from the substation, residential loads are fairly predictable. This allows utilities to plan their generation and devise voltage compensation schemes and power quality standards. Hence, the next step for this model is for it to be added in multiple instances in a feeder model that will reveal its behaviour when aggregated and thus, provide an opportunity for validation against feeder data from utilities.

Finally, the resulting house model is one amongst millions of possible cases. The case is based on real data so it is representative of the sites monitored in the survey. However, the modeling was performed after a few assumptions and simplifications that in some cases would benefit from further investigation; amongst others, the susceptibility of the appliances to voltage harmonics existing on the grid. For this model it was assumed that below 10% of voltage harmonic distortion, which is the case in most locations, the effect of voltage pollution can be neglected. Nevertheless, it would be very helpful to know the extent of the immunity to harmonics of various appliances. This is however a study in itself.

REFERENCES

[1] Wang, Yen-Ju, O'Connell, R.M., Brownfield, G. (2001). Modeling and Prediction of Distribution System Voltage Distortion Caused by Nonlinear Residential Loads. *IEEE Transactions on Power Delivery,* vol. 16, no. 4, pp. 744-751

[2] Heunis, S.W., Herman, R. (2002). A Probabilistic Model for Residential Consumer Loads. *IEEE Transactions on Power Systems,* vol. 17, no. 3, pp. 621-625

[3] Cavallini, A., Gambelli, G., Invernizzi, A., Montanari, G.C. (1998). Analysis and Modeling of Harmonic Pollution Due to Consumer Electronics. *Proceedings of the 8th International Conference on Harmonics And Quality of Power,* vol. 2, pp. 865-871

[4] Kundur, P. (1994). *Power System Stability and Control*. New York, McGraw-Hill.

[5] The Mathworks (2006). *Matlab R2006b Release Notes*.

[6] Ethier, G. et al. (2001), Canadian Power Quality Survey 2000. *CEATI Project Report No. T984700-5103*.

[7] Paquin, J.N., Turcotte, D. (2007). PV Inverter Modeling for Power Quality Studies, revision 1.0. *CETC Varennes Public Report # CETC 2007-XXX.*

APPENDIX A
House Harmonics Data Processing

Generally, for site 02-01 data, it is visually clear that the polynomial approximation follows the data tendency where there is data profuse.

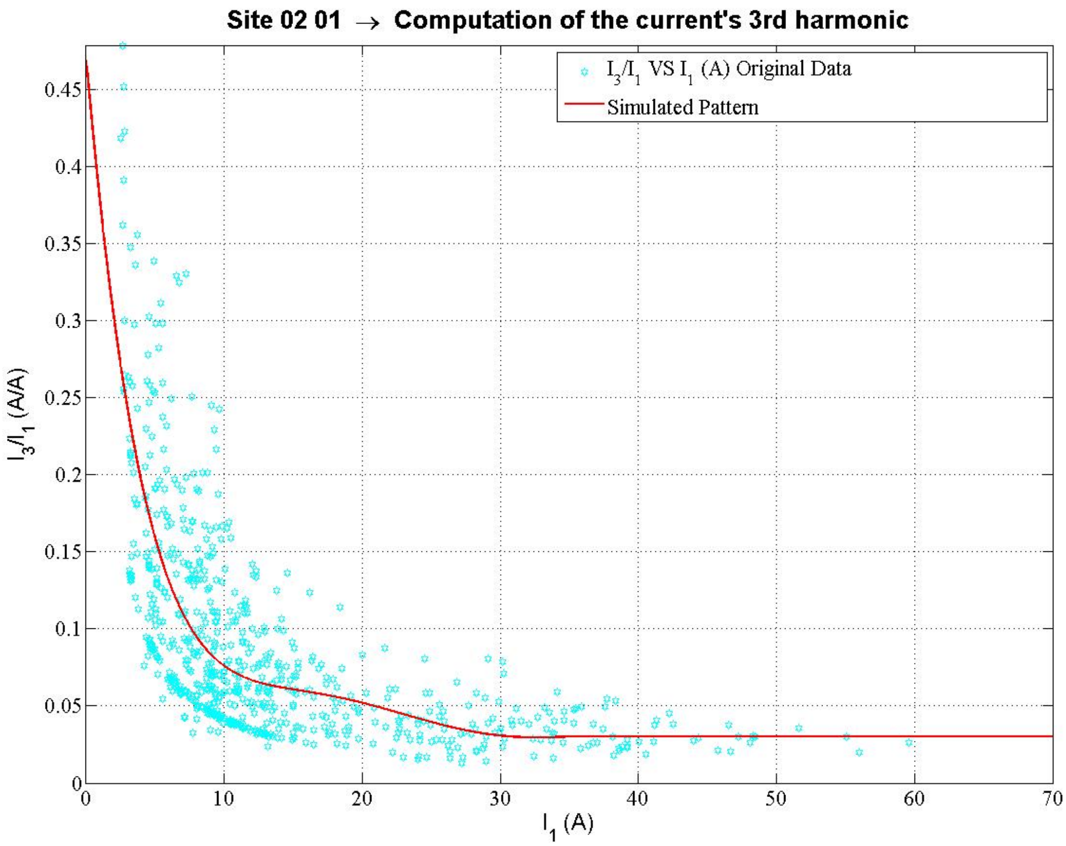

Figure 4: House Harmonics Data Processing for the 3rd harmonic – Site 02-01

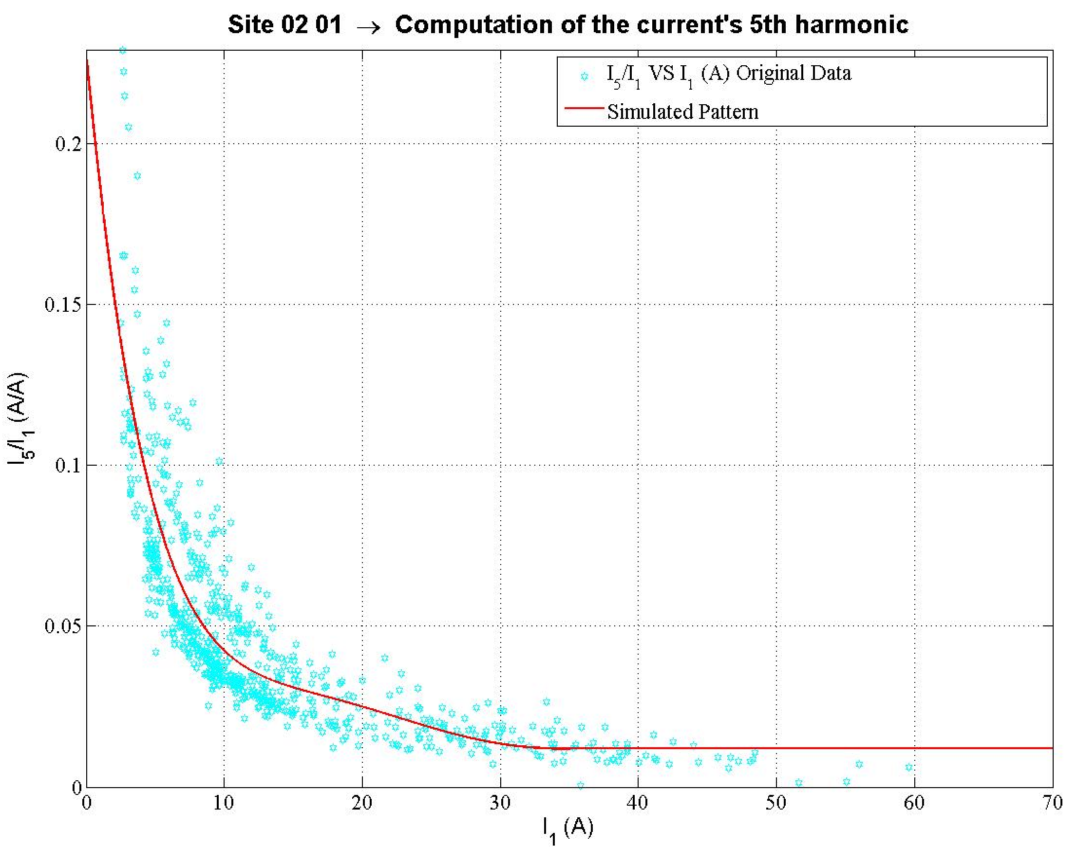

Figure 5: House Harmonics Data Processing for the 5th harmonic – Site 02-01

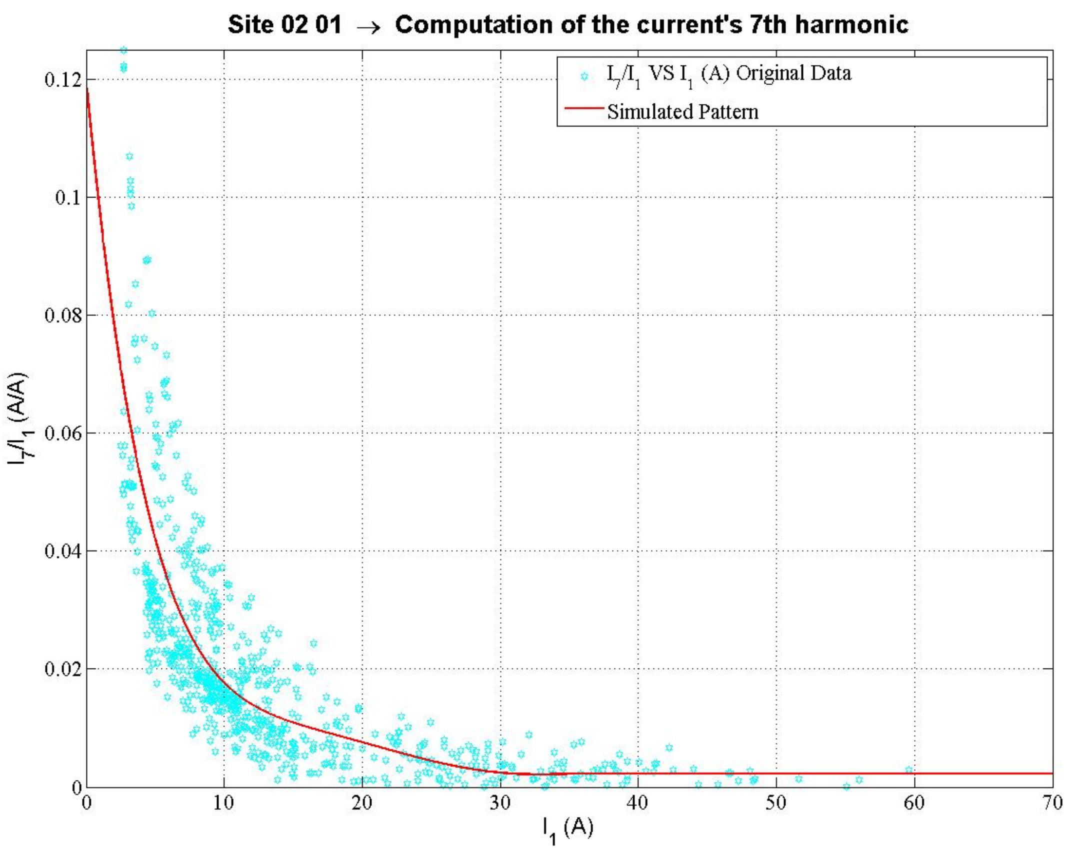

Figure 6: House Harmonics Data Processing for the 7th harmonic – Site 02-01

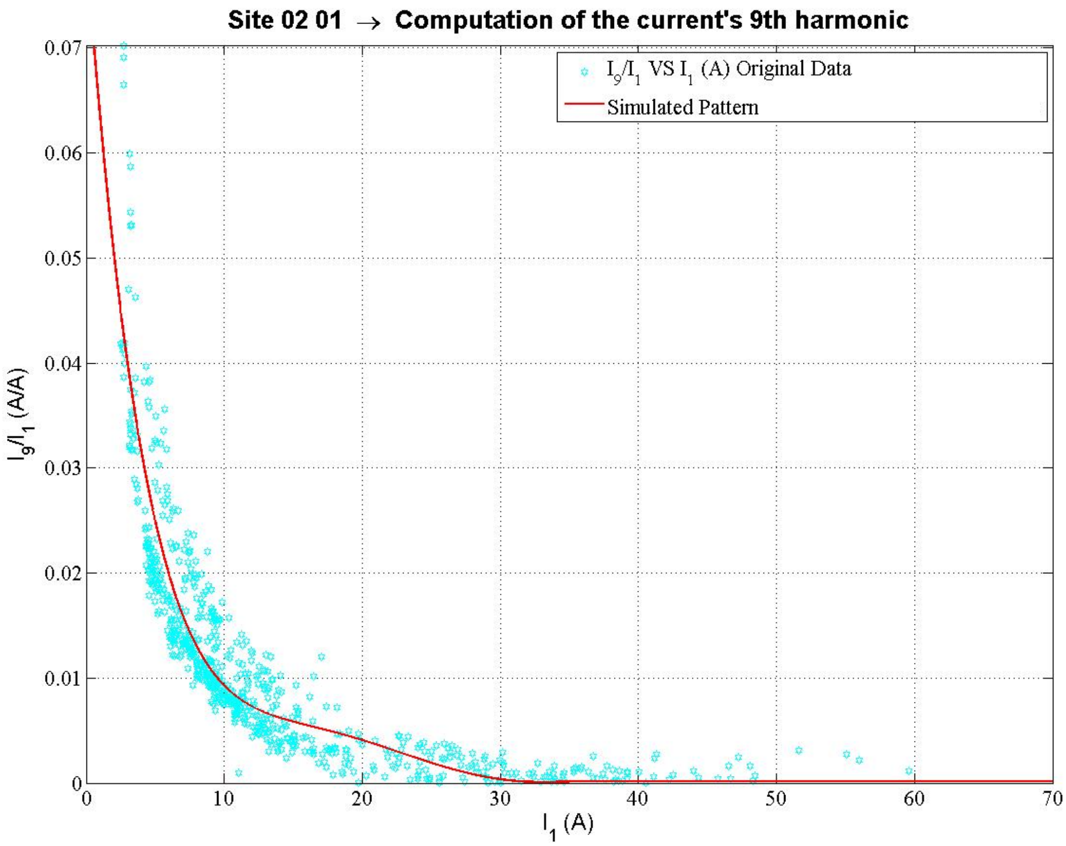

Figure 7: House Harmonics Data Processing for the 9th harmonic – Site 02-01

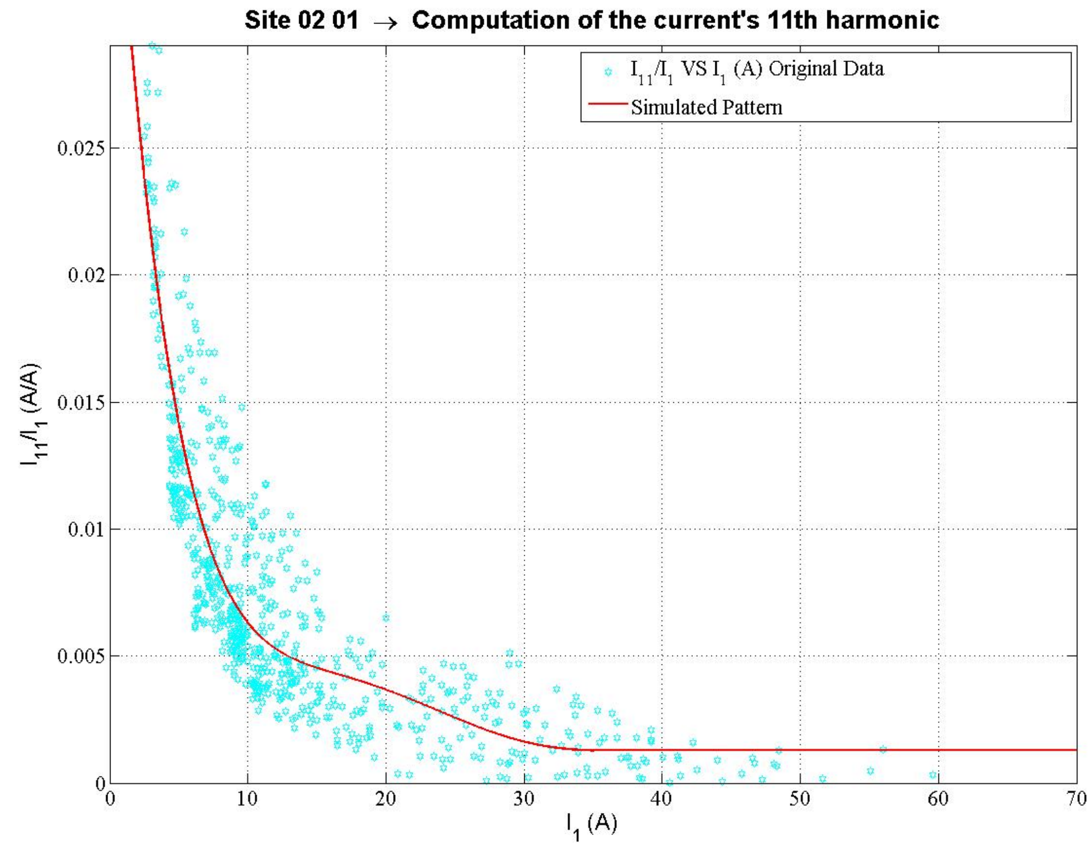

Figure 8: House Harmonics Data Processing for the 11th harmonic – Site 02-01

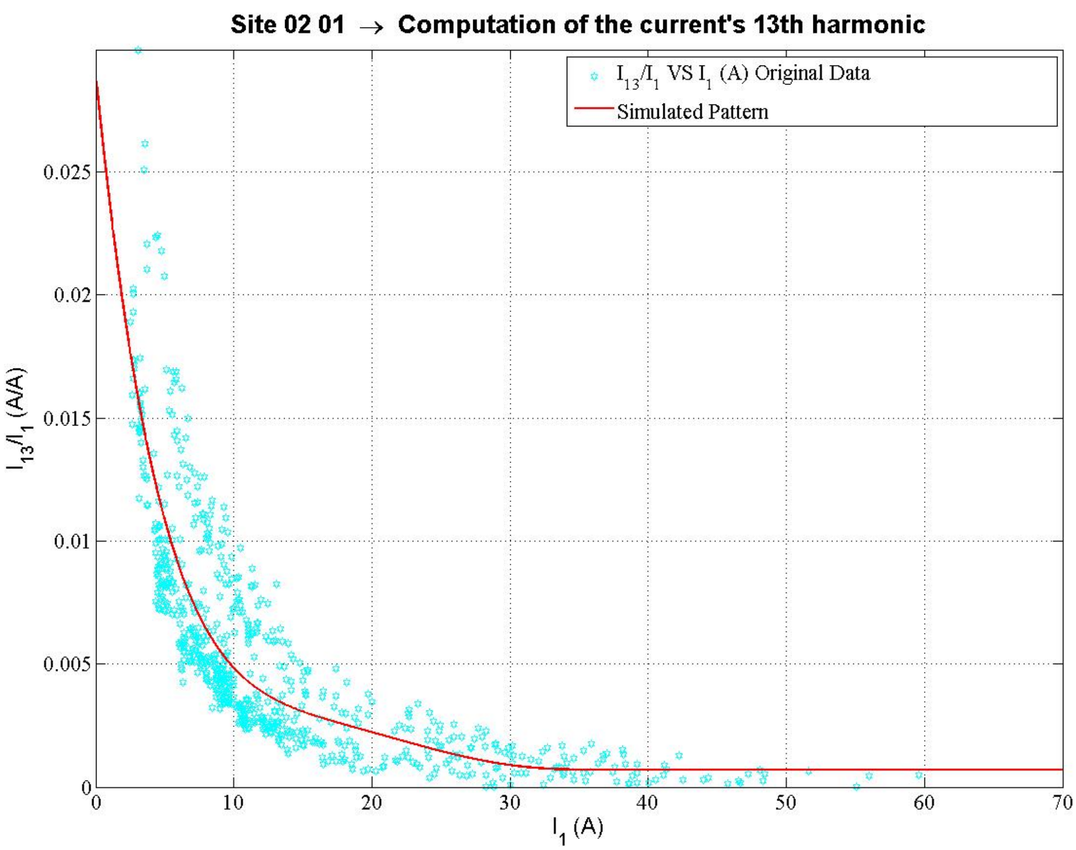

Figure 9: House Harmonics Data Processing for the 13th harmonic – Site 02-01

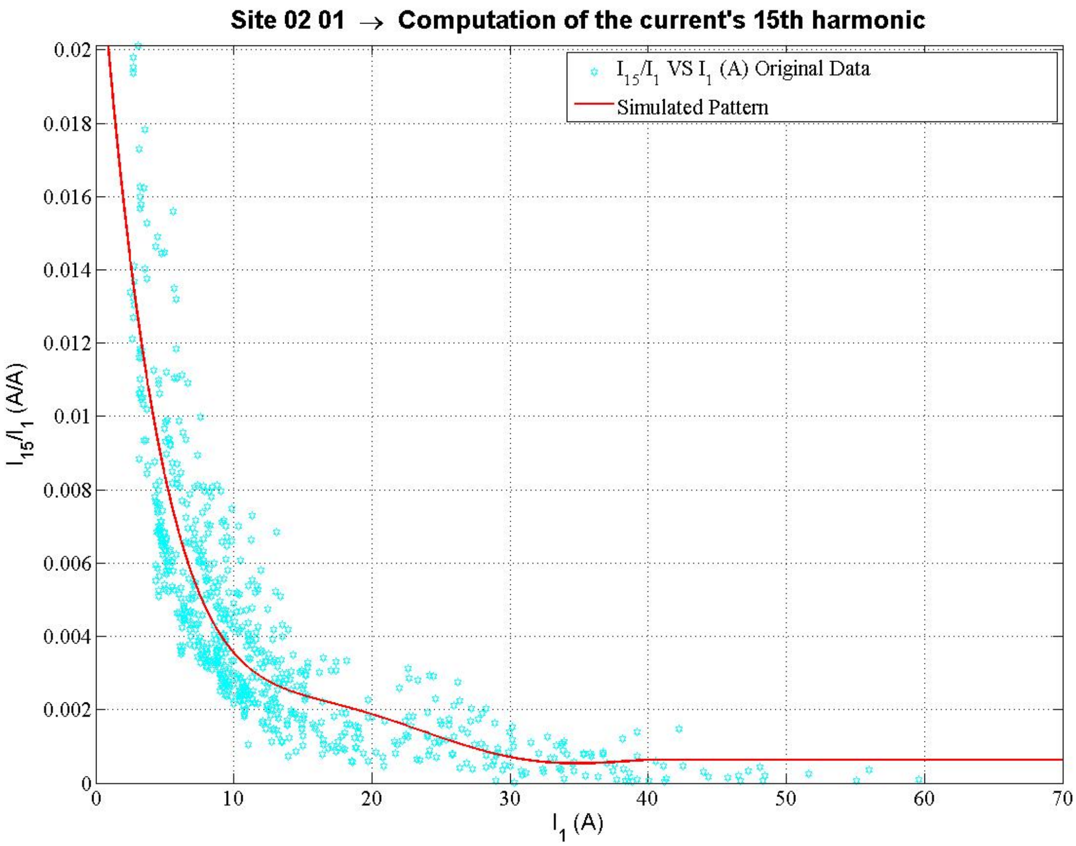

Figure 10: House Harmonics Data Processing for the 15th harmonic – Site 02-01

For site 02-23, unexpected lumps are seen on the fitted curves (e.g. on Figure 11). The polynomial curve follows a trajectory dictated by the concentration and distance of a majority of points, which creates these oscillations. It is hard to explain why the data is dispersed as it is for this site. The polynomial technique therefore gives good, but debatable accuracy. Other techniques and more research could be done in future work to validate the model accuracy.

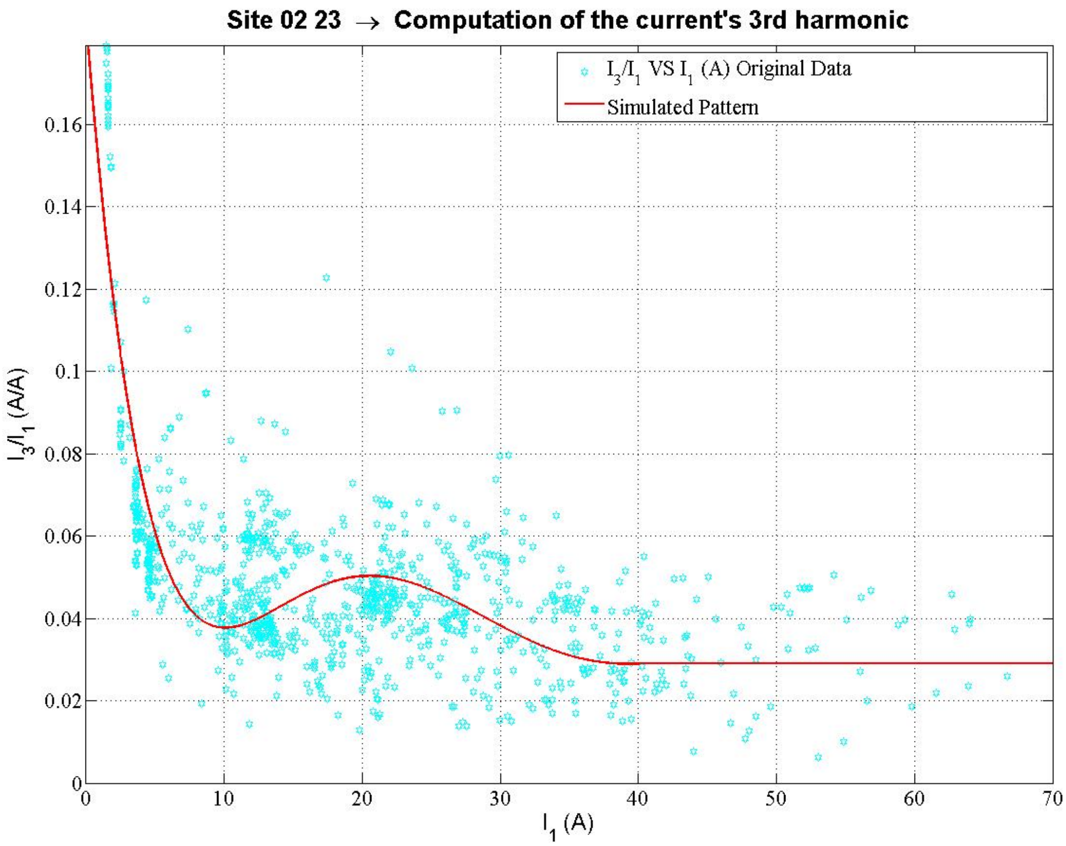

Figure 11: House Harmonics Data Processing for the 3rd harmonic – Site 02-23

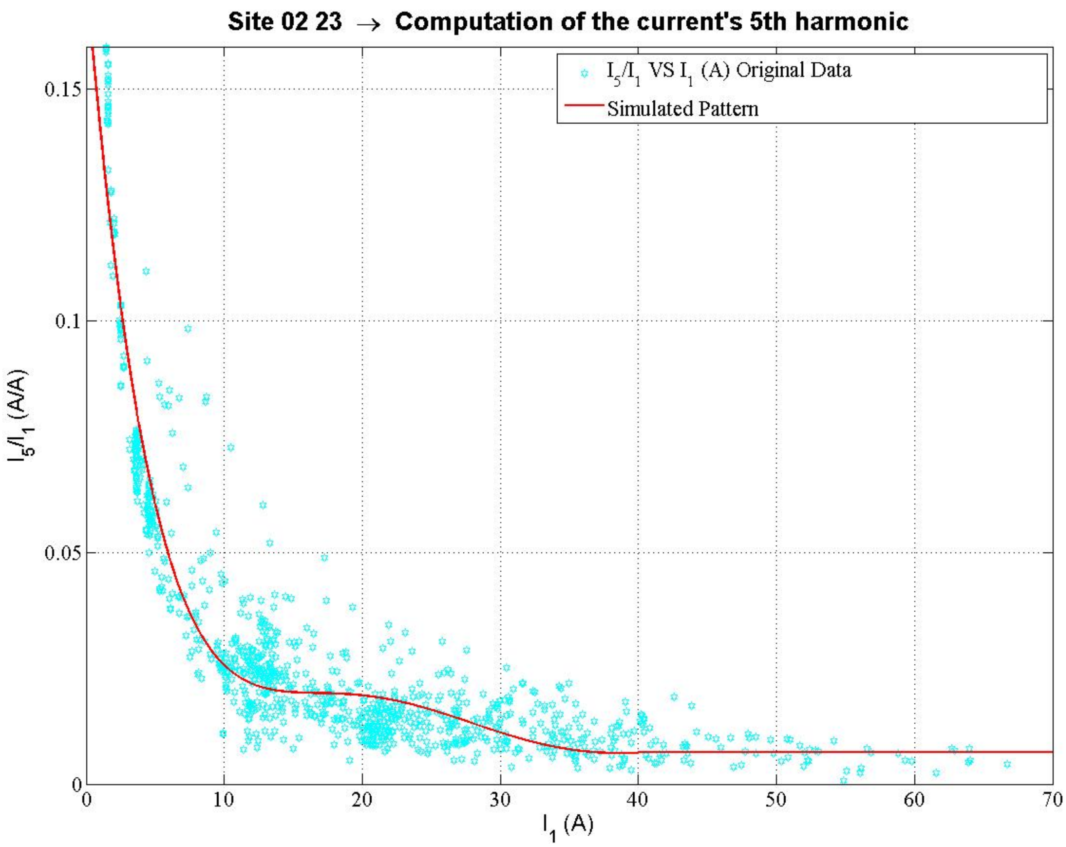

Figure 12: House Harmonics Data Processing for the 5th harmonic – Site 02-23

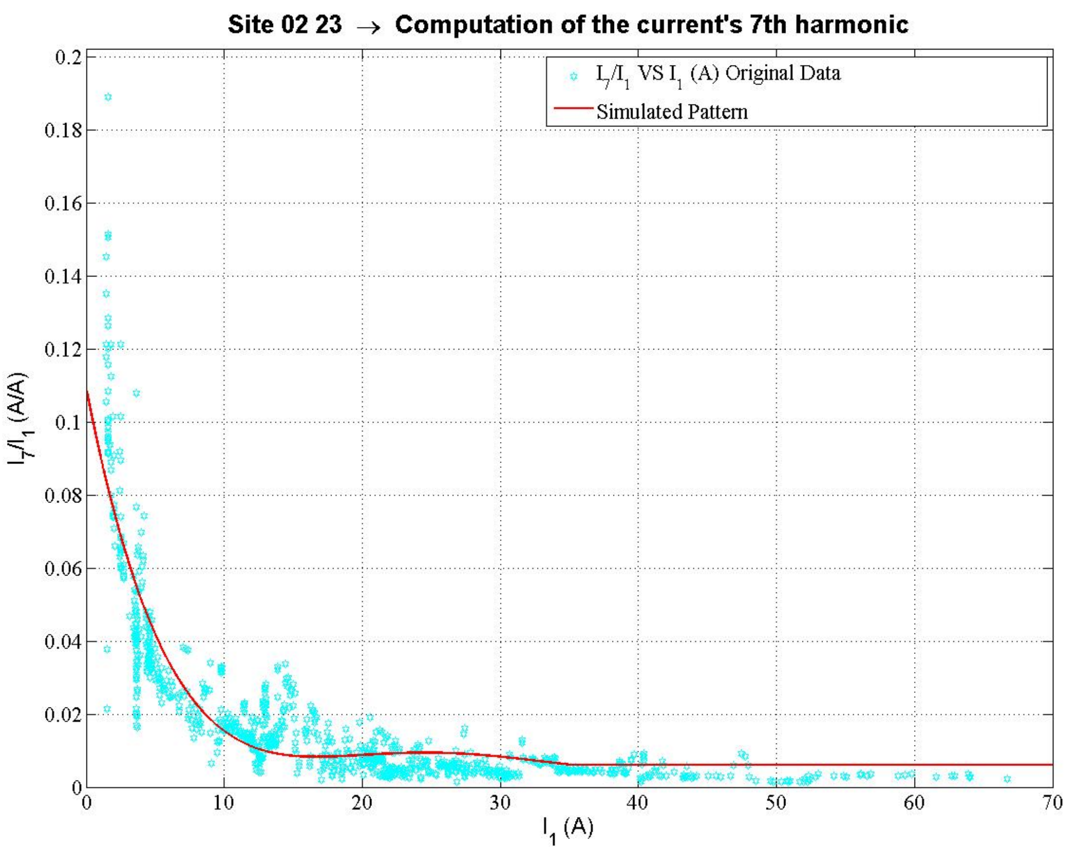

Figure 13: House Harmonics Data Processing for the 7th harmonic – Site 02-23

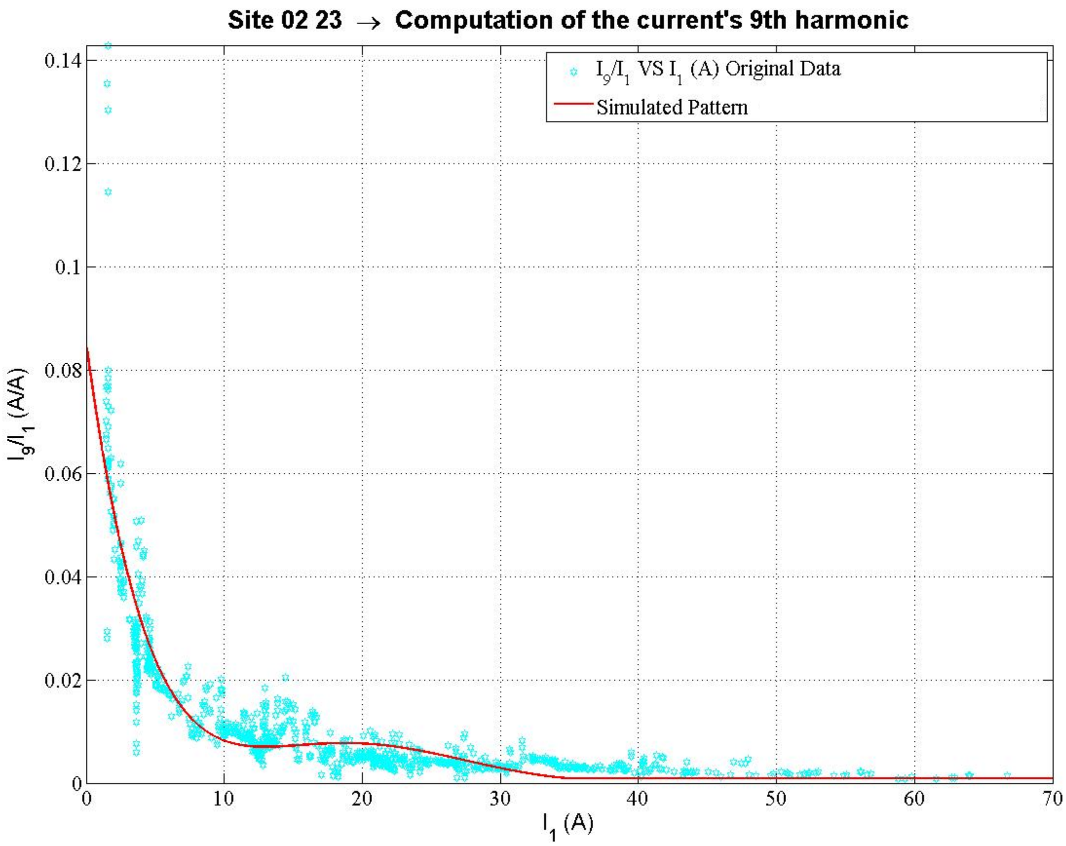

Figure 14: House Harmonics Data Processing for the 9th harmonic – Site 02-23

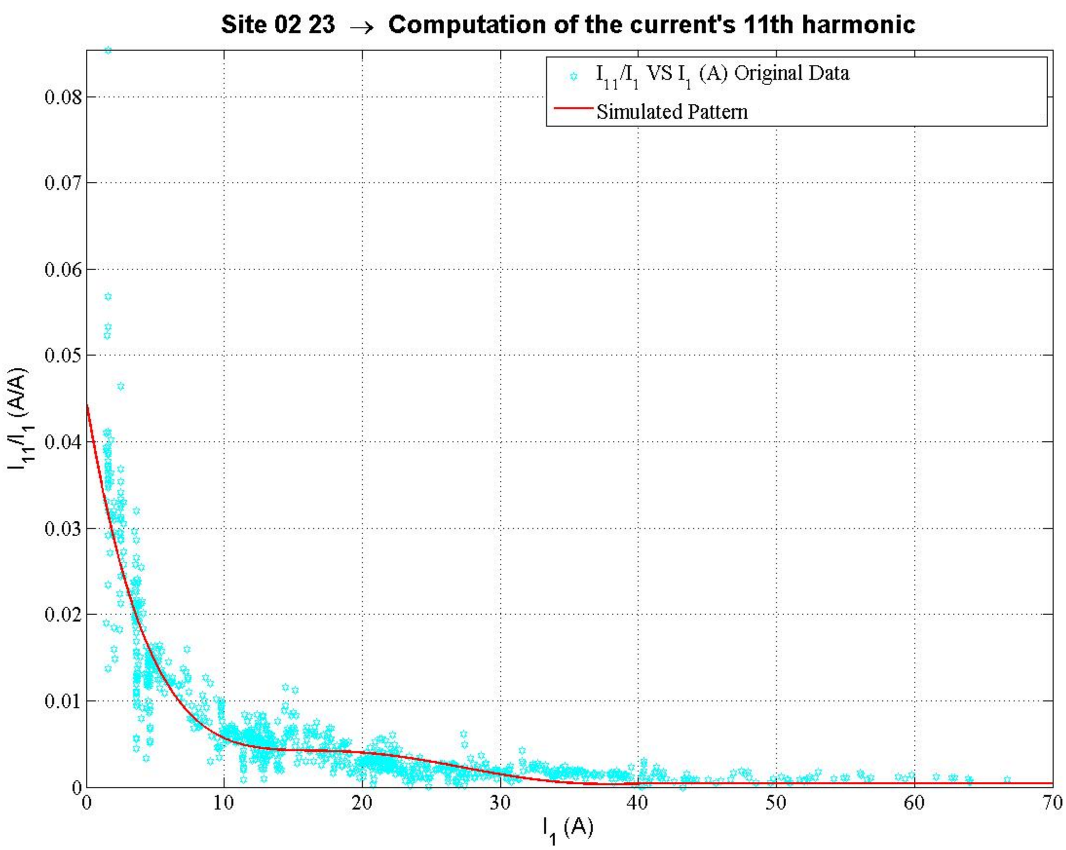

Figure 15: House Harmonics Data Processing for the 11th harmonic – Site 02-23

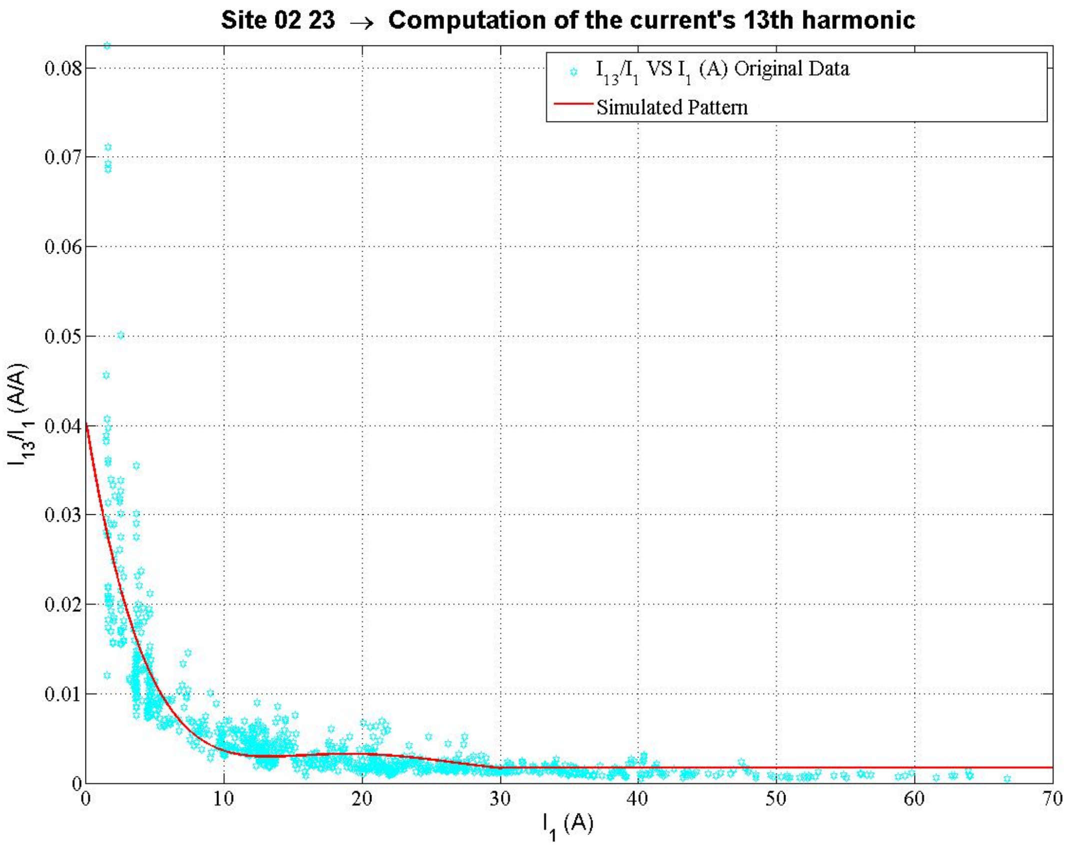

Figure 16: House Harmonics Data Processing for the 13th harmonic – Site 02-23

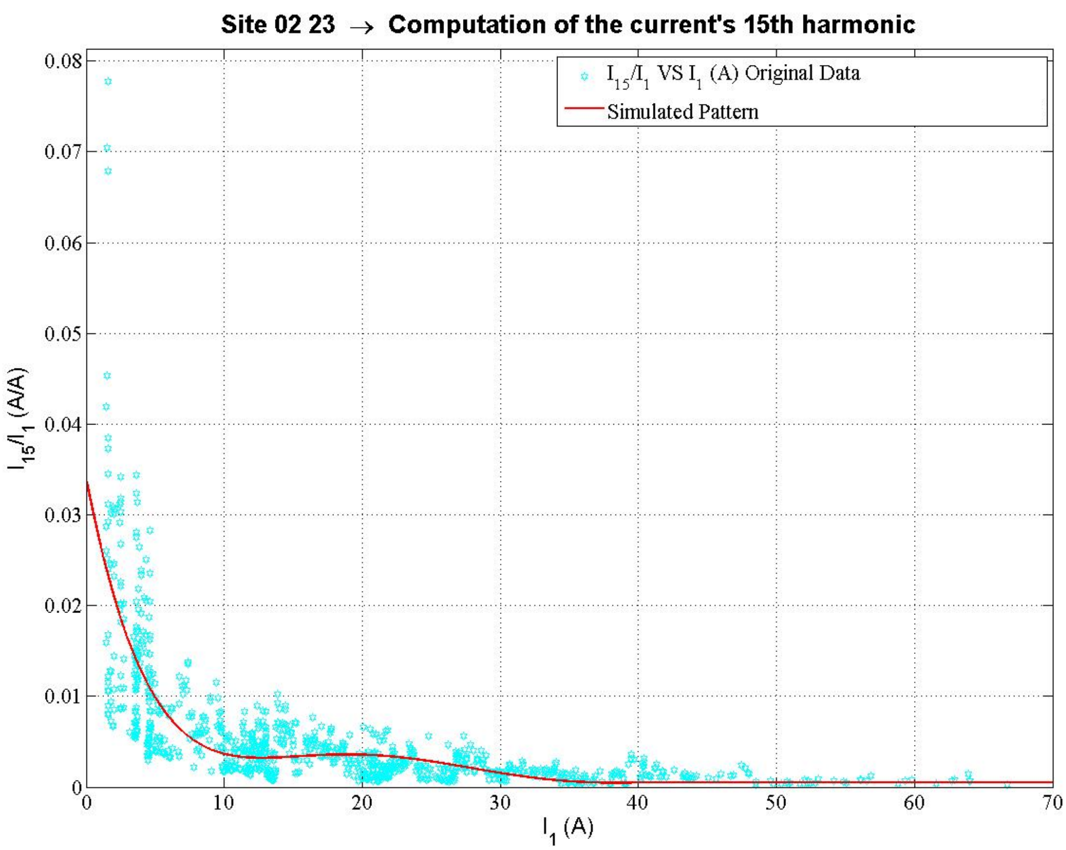

Figure 17: House Harmonics Data Processing for the 15th harmonic – Site 02-23