Load Modeling based on Real Data applying PSO Algorithm

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ABSTRACT:
Load modeling is one of the most important features in power system operation and stability studies. So far, various methods have been applied based on measuring the relevant load data, and obtaining the load models through the mathematical models. This paper presents a method for load modeling based on processing the recorded data by the measurement equipment with PSO algorithm, which is located in substations. In the proposed method, for improving the accuracy of the load model, some constraints are applied for eliminating the undesirable measured data. These constraints are applicable for any time periods, such as; hourly, daily, seasonally, and annually. Furthermore, a combination of the static and dynamic models is utilized. The performance of the proposed method is tested on two industrial power grids from the west regional electric company (WREC) network, and the results are thoroughly analyzed. The results have shown that the proposed method has an acceptable accuracy for load modeling in comparison with real model of the case study systems.

KEYWORDS: Load Modeling, Static Load Model, Dynamic Load Model, Load Model Parameters.

1. INTRODUCTION

Load modeling is one of the most important features in power system operation, stability, and control studies, as well as it is important for power systems planning, voltage stability analysis, power system reliability, and improving the power quality. However, the most importance of load modeling is the analysis of power system stability and maintaining the balance between the electrical generation and load demand. Formerly, the focus of researches was on modeling the generation and transmission part of the power system, and various models have been formulated in this regard [1-6].

Load models can have significant effects on the stability analysis, power flow, and etc. Regarding the complexities of load modeling, presenting an accurate model is a challenging task requiring complex calculations and procedures. The main reasons of complexity of load modeling are as follows:

- Excisting of some large industrial loads in the power systems at any time.
- Connecting various load types to the power system at any time.
- Countinuoes load changes, in hourly, daily, and seasonally time horizones.

Therefore, a general and constant load model cannot be applied in a power system for all the time and the dynamic or static characteristics of loads are required. The static loads are generally determined by ZIP and exponential models. The ZIP model includes constant impedance (Z), constant current (I) and constant power (P). Around 60-70% of the energy generated by the different sources is consumed by the dynamic loads which generally occur in the induction motor [7]. However, the cumulative load model as a combination of static and dynamic models can be applied [8]. On the other hand, the load modeling methods can be classified into two main groups of measurement-based and constituent-based methods. In the measurement-based method, the data extracted from a certain substation or a feeder is used to define a load model matched with the observed behaviors of loads [9-10]. The constituent-based method consists of all constituents of loads [11-12]. In all of the measurement-based and constituent-based methods; data collection and load characteristics for modeling are extremely difficult and time-consuming.

So far, various methods have been proposed for load modeling by researchers [13]. According to the results provided by the CIGRE committee for achieving the load modeling which are used in different power electric companies, about 84% of the load model is constant power (PQ) which is used for static studies of the power systems, nearly 23% of the load model is constant impedance, and about 19% of the load model is constant current which is used in power system dynamic studies. Furthermore, 50% of the load model parameters are identified by measurement-based methods [14].

This paper presents a novel method for load modeling based on extracting the required data from the measurement equipment located in each feeder at substations, and their processing by PSO algorithm. However, there is undesirable value in recorded data that can affect the load modeling. Hence, some constraints have been applied to remove the undesirable data. The considered model is a combination of static (ZIP) and dynamic models (differential equation). The simulation results on two sample industrial grids show that, obtained values of the active and reactive powers from the proposed model have high accuracy and acceptable accordance with the real values.

The reminder of the present work is as follows: section 2 presents the theoretical fundamentals of load modeling, section 3 describes the proposed method and its implementation, section 4 introduces the simulation results. Finally, the conclusion of the paper is explained.

2. THE THEORETICAL FOUNDATIONS OF LOAD MODELING

2.1. The Load Models

The load model is a mathematical representation of the relationship between magnitude and frequency of voltage with active and reactive powers of load or with the load current. In other words, a load model refers to its equations or equations with the given values of the related parameters, which can calculate the power or current of the load [15].The presented models for load modeling generally falls into two categories of static and dynamic models. The static model is mostly used for load flow studies, power loss calculations, and etc. While the dynamic model deals with dynamic studies, power system stability, relay settings, and etc. In the following sub-sections, each of the static and dynamic models is discussed in detail.

2.1.1. Static model

The static load model represents the active and reactive powers at any time in the functions of voltage frequency and magnitude. This model is used for the constituents of the static loads such as lighting and resistance loads and approximately for the constituents of the dynamic loads such as motor loads. The most basic static load model is the ZIP model which is represented by (1) and (2).

$$P = P_0\{P_1(\frac{V}{V_0})^2 + P_2(\frac{V}{V_0}) + P_3\}(1 + K_{pf}\Delta f) \qquad (1)$$

$$Q = Q_0\{q_1(\frac{V}{V_0})^2 + q_2(\frac{V}{V_0}) + q_3\}(1 + K_{qf}\Delta f) \qquad (2)$$

Where: P_1-P_3, q_1-q_3 are the coefficients of the load power, V_0 is the nominal voltage, P_0 and Q_0 are the initial values of active and reactive powers, K_{pf} is a coefficient between zero and three, and K_{qf} is a coefficient between -0.2 and zero.

Various parts of formulas in (1) and (2) represent the constant impedance, constant current and constant power model. The first sentence is related to the constant impedance model, which expresses changes of active and reactive powers, in terms of the squared changes of the voltage. The second sentence represents the constant current model, which shows the changes of active and reactive powers in terms of changes in voltage. The third sentence represents the constant power model, which expressed that, the active and reactive powers are not changes with the changes in voltage. The constraints of (1) and (2) are $P_1+P_2+P_3=1$ and $q_1+q_2+q_3=1$[16].

2.1.2. Dynamic model

The dynamic load model is the active and reactive powers as the time functions of the voltage frequency and magnitude, which are expressed in (3) and (4). The dynamic load model can be expressed by an equation which shows the relationship between the active and reactive power of loads in terms of voltage and frequency at any point of time or during several intervals. In general, two models are used for dynamic modeling including the induction motor model and general load model. The general load model is defined based on the dynamic response of the load to the changes in voltage [17].

$$P(t) = \{P_0(\frac{V}{V_0})^{\alpha s} - P_0(\frac{V}{V_0})^{\alpha t}\}(1 - e^{-t/T_p}) \qquad (3)$$

$$Q(t) = \{Q_0(\frac{V}{V_0})^{\beta s} - Q_0(\frac{V}{V_0})^{\beta t}\}(1 - e^{-t/T_q}) \qquad (4)$$

Where:

α_s: Load voltage dependence on the active power in steady state.

α_t: Load voltage dependence on the active power load in transient state.

T_p: The time constant of active power return.

β_s: Load voltage dependence on the reactive power in steady state.

β_t: Load voltage dependence on the reactive power in transient state.

T_q: The time constant of reactive power return.

2.2. Methods of Determining the Parameters of the Load Models

There are two general methods for determining the characteristics of the loads, including; the constituent-based method and the measurement–based method. In the following, each of these methods is discussed in detail.

2.2.1. The constituent-based method

In this method, load modeling is based on data of the load constituents. At a major point of consumption, the loads are categorized into residential, commercial, industrial, agricultural, etc. In addition, loads are expressed based on their components such as lighting, air conditioning, heating, water heating, and cooling. Then, the characteristics of these loads are studied and some methods are introduced to find out the combined model of the loads through the constituent models. A suitable load model is provided for load flow and stability studies, by the introduced program from the EPRI institution. In the EPRI program, the load is modeled by combining the different types of loads and their constituents. [18-20].

The constituent-based modeling is a part-to-whole method. In other words, the constituents of a load are identified and modeled one by one. Each of the load constituents are examined with the aim of determining the relationship between the voltage and frequency with active and reactive powers. Then, the load models are determined in the form of exponential or multi-sentence equations. The major drawbacks of this method include; lack of adequate and complete data to precise analysis and presentation of the model, and lack of easy access to the general characteristics for special loads due to diversity of their characteristics.

2.2.2. The measurement-based method

The measurement-based method is a direct method, i.e. it is directly depended on the sensitivity of the active and reactive powers to the voltage and frequency of power plants and substations. In this method, the characteristics of loads are measured in the certain substations and feeders at certain times of the days, seasons and so on, which are used for extrapolation the load parameters. In this method, the parameters of the load model are obtained through adaptation of the measured data to the assumed data in the model [21-22].

The measurement-based modeling is a whole-to-part method, due to the results of the loads measurement are directly used in this method. The load model is based on the effects of voltage changes on the measured active and reactive powers of consumption. This method is most commonly used in modeling.

In the measurement-based modeling, several sensors are installed in different buses to determine the structures and models of loads. The main feature of this method is the direct measurement of the actual behaviors of loads. Moreover, the drawbacks of this method include some items such as the impossibility of determining the characteristics of loads in a wide range of voltage and frequency variations, challenges of re-measurement of loads, during the time and changes climate for updating the load model, and high costs of equipment for data monitoring and recording.

3. THE PROPOSED METHOD

As mentioned earlier, in the measurement-based method for measuring the required data, various equipments are installed at substations. Installing the needed equipments is very costly and time-consuming and its executive operation is difficult. Hence, this paper presents a method to improve the measurement-based method, based on processing the measured data from a real power system with PSO algorithm. As regards, the loads data, including the active and reactive powers, current, voltage, phase difference and frequency are measured by existing measurement equipments at substations and recorded in the WREC for long years, the use of these data is suggested. However, these data cannot be used directly; due to some existed undesirable data. Therefore, to remove the undesirable data, some constraints are applied to the measured data and finally they processed with PSO algorithm. In the following subsections, the proposed method is completely analyzed.

3.1. The Flowchart of the Proposed Method

The flowchart of the proposed method is illustrated in Fig. 1. As it is depicted that, the data of the consumed loads which is recorded in the WREC are sieved, and undesirable values are removed by PSO algorithm in MATLAB software. Then, the ZIP and dynamic models are implemented, and the parameters of the mentioned models are obtained with PSO algorithm. Since the proposed model is a combination of static and dynamic models, the impact coefficients of each model are recalculated through PSO algorithm. Finally, by comparing the different data sets with real values, the best data sets with the lowest errors are identified and the model parameters which is matched with these data sets are selected as the optimal parameters.

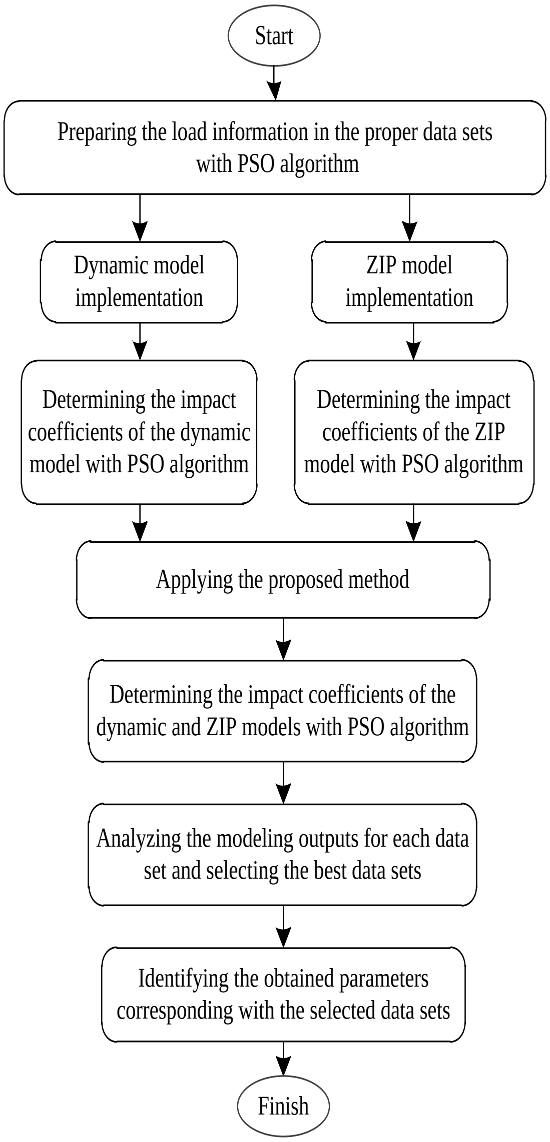

Fig. 1. The proposed process of load modeling.

3.2. The Proposed Load Model

The industrial loads are generally included in motor and some fixed loads; such as lighting and general consumption. Therefore, the intended model is a combination of the static and dynamic loads. The proposed model is expressed as (5) and (6).

$$P_{rel} = K_1(P_{ZIP}) + K_2(P_{DYN}) \tag{5}$$

$$Q_{rel} = K_1(Q_{ZIP}) + K_2(Q_{DYN}) \tag{6}$$

Where, P_{ZIP}, Q_{ZIP}, P_{DYN}, and Q_{DYN} are explained in (1) - (4), and K_1 and K_2 are the impact coefficients of the static and dynamic models in the proposed combined model. It is clear that, the sum of the K_1 and K_2 is equal to unit.

The reason of using the combined load model is achieving the best matched load model with each of the static and dynamic models.

3.3. Data Generation and Processing

In the WREC, all data of the consumed energy by the industrial loads, such as active and reactive powers, voltage, frequency, current, and phase difference are measured by measuring equipments of substations and recorded with a constant interval of 15 minute. The recorded data are transferred to the central database in the WREC and then registered in excel files [23]. Fig. 2 shows the monitoring and recording process in the WREC for energy consumption by a sample consumer.

As mentioned earlier, the recorded data cannot be directly used in the modeling process based on the following reasons:

- For conditions that, the telecommunications is disconnected, the zero values are recorded.
- The purpose of the modeling is realizing the normal values of the loads consumption. However, at some periods of time, the consumed loads are significantly reduced because of maintenance, trriping the some generation units, and etc.
- Since for determining the parameters of the load models, the effects of the voltage and frequency variations on the consumed active and reactive powers are considered; the voltage and frequency changes could not be observed at some periods of time.

Therefore, to reduce the adverse effects of the mentioned problems in the modeling, data sieving is done based on the proposed algorithm in Fig. 3. It can be seen from Fig. 3, after calling the required data, the minimum and maximum length of the chosen data sets, the primary basic voltage, acceptable changes value of the voltage and power, the values of the active and reactive powers, voltage, current, frequency, phase difference, etc. are selected. Then, the undesirable data are removed based on the defined constraints, and the adequate data are extracted. Finally, the errors of each of the sieved data sets are calculated and the data sets with the lowest errors are chosen as the optimal data.

In the flowchart shown in Fig. 3, V_0 is the voltage value which has the lowest errors in the selected data sets than the nominal voltage value for the consumed loads. Also, P_0 and Q_0 are determined by considering the value of V_0, and determined by the proposed algorithm.

It should be noted that, the proposed algorithm can be utilized for modeling at various intervals of time such as hourly, daily, monthly, seasonally or any other periods. Furthermore, the length of each data set is variable and can be defined.

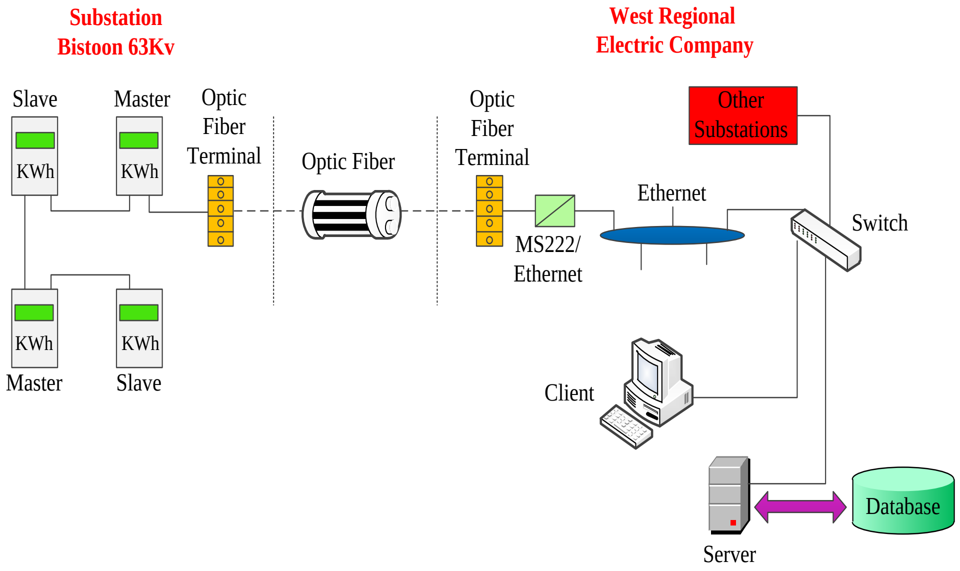

Fig. 2. The process of monitoring and registering the data of the consumed energy in the WREC.

3.4. Implementation of the PSO Algorithm

The flowchart in Fig. 4 shows the various steps of implementation of the PSO algorithm to determine the optimal coefficients of the load models which are defined in (1) to (6). As it is depicted, at first the initial values of the particles are selected in random. Then, the cost functions and new positions are determined based on the cost functions in the prior step and its defined speed. The cost functions are calculated for new positions of the particles, and this algorithm is continued for defined maximum repetition. At the end of the repetition cycles (e.g. 200 times), the related data of the best particle parameters is introduced as the output of the optimization function. The intended parameters for the PSO algorithm are shown in Table 1.

3.4.1. The objective function

The parameter of root mean squared error (RMSD) is used as the objective function, which is the difference between the predicted value by the model and the real value.

$$RMSD = \sqrt{\frac{\sum_{i=1}^{n} (P_{real} - P_{model})^2}{n}} \tag{7}$$

Where, n, P_{real}, and $P_{modeled}$ are the number of data included in the data sets, the recorded real value of active power, and the calculated value of active power in the load models, respectively.

In fact, the goal is minimizing the RMSD value in each of the functions. The intended objective functions for the static and dynamic sections are as follows:

$$RMSD(P_{ZIP}) = \sqrt{\frac{\sum_{i=1}^{n} (P_{real} - P_{model})^2}{n}} \tag{8}$$

Constraint: $p_1+p_2+p_3=1$

$$RMSD(Q_{ZIP}) = \sqrt{\frac{\sum_{i=1}^{n} (Q_{real} - Q_{model})^2}{n}} \tag{9}$$

Constraint: $q_1+q_2+q_3=1$

$$RMSD(P_{DYN}) = \sqrt{\frac{\sum_{i=1}^{n} (P_{real_i} - P_{DYN_i})^2}{n}} \tag{10}$$

$$RMSD(Q_{DYN}) = \sqrt{\frac{\sum_{i=1}^{n} (Q_{real_i} - Q_{DYN_i})^2}{n}} \tag{11}$$

The objective functions of the general model (in which the impact coefficients of the static and dynamic models are determined in load modeling) are as follows:

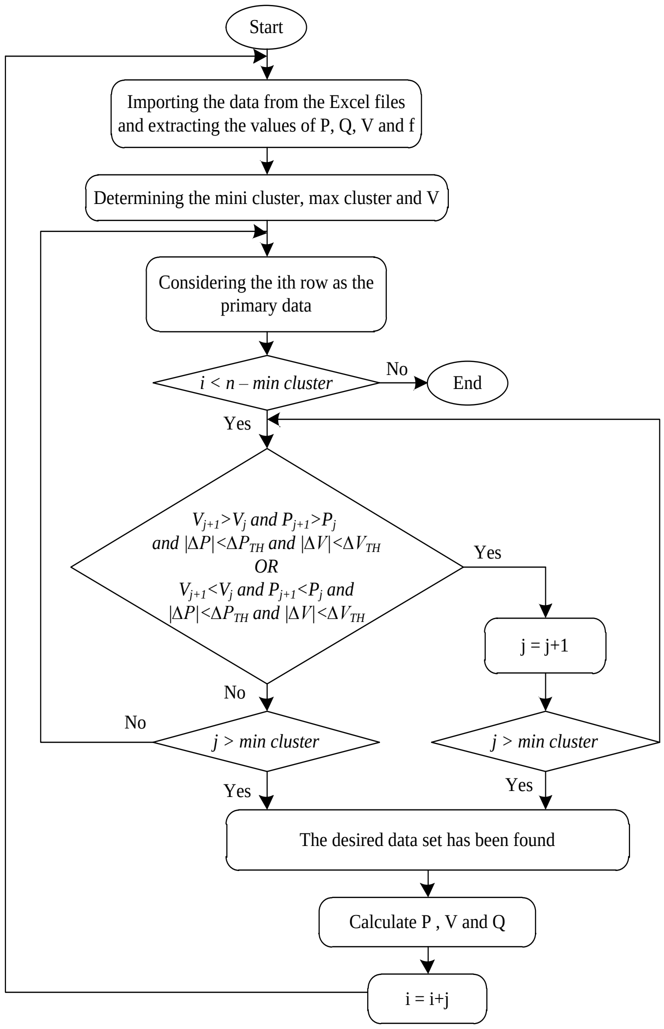

Fig. 3. The algorithm for producing optimum data.

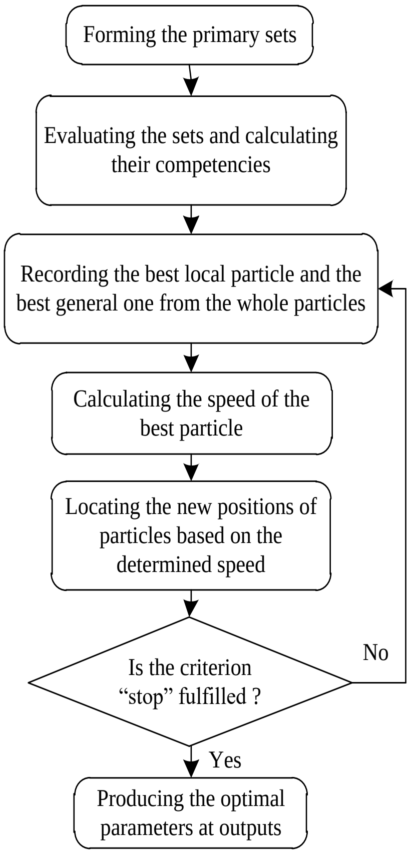

Fig. 4. The flowchart of PSO algorithm.

Table 1. The parameters of PSO Algorithm.

Parameter	Define	Value
n_{pop}	The intended set for determining the coefficients of Q_{ZIP}, P_{DYN}, Q_{DYN}, and P_{ZIP}	30
n_{pop}	The intended set for determining the coefficients of $K_1$and K_2	10
n_{var}	The number of dimensions of each particle for determining the coefficients of P_{ZIP} and Q_{ZIP}	4
n_{var}	The number of dimensions of each particle for determining the coefficients of P_{DYN} and Q_{DYN}	6
n_{var}	The number of dimensions of each particle for determining the coefficients of K_1 and K_2	2
W	Damping ratio (Inertia)	1
C_1 and C_2	The personal and general learning coefficients	2,2
Maxit	The number of repetitions	200

$$RMSD(P_{rel}) = \sqrt{\frac{\sum_{i=1}^{n} (P_{real_i} - P_{rel_i})^2}{n}} \qquad (12)$$

$$RMSD(Q_{rel}) = \sqrt{\frac{\sum_{i=1}^{n} (Q_{real_i} - Q_{rel_i})^2}{n}} \qquad (13)$$

Constraint: $K_1+K_2=1$

4. SIMULATION RESULTS AND DISCUSSIONS

In this part, the proposed method is implemented on two sample industrial loads for different periods of time and the results are completely analyzed. The case studies are radial feeders which operate at 63 kV voltage level from the WREC network.

4.1. The First Case Study

The selected period of time for the first industrial load is from 05:30 on 15-October-2013 to 11:30 on 15-November-2013. The parameters of the extracted load model from the proposed method are presented in Table 2. These parameters are the required coefficients in the main load modeling equations (1 to 6). The obtained values of the active and reactive powers from the modeling with real data over the selected period of time are presented in Table 3. Figs. 5 and 6 show the modeled powers with real data over the selected period and the real powers, respectively.

Table 2. The obtained parameters for the first case study.

P_1	P_2	P_3	K_{pf}	q_1	q_2	q_3	K_{qf}
0.035412	0.000238	0.964564	0.029937	0.0000	0.0000	1.0000	0.0000
K_1	K_2	α_s	α_t	t_p	b_s	b_t	t_q
0.281861	0.723648	0.436821	0.49044	3.590172	3.22225	2.489757	10.000

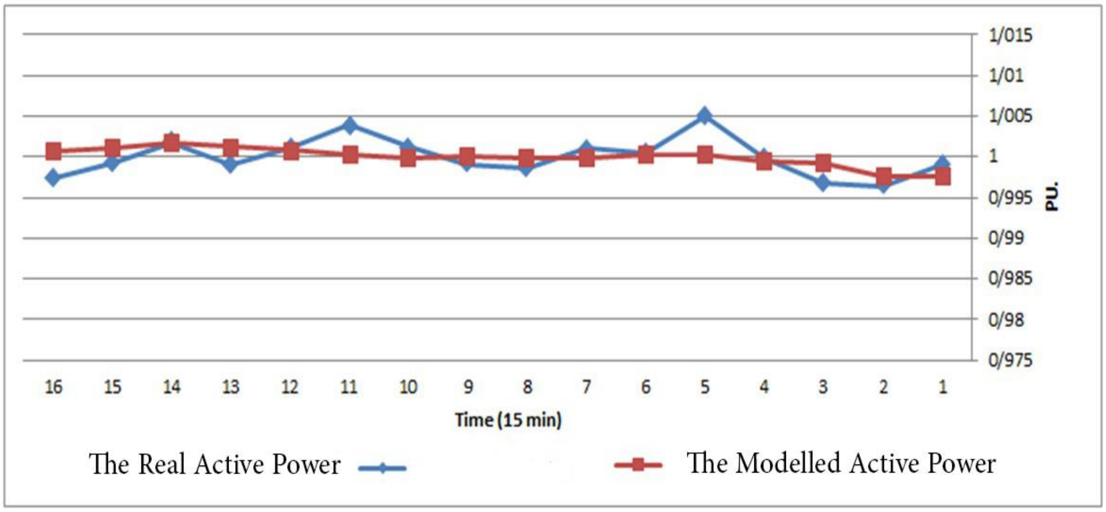

Fig. 5. The modeled and real active power for the first case study.

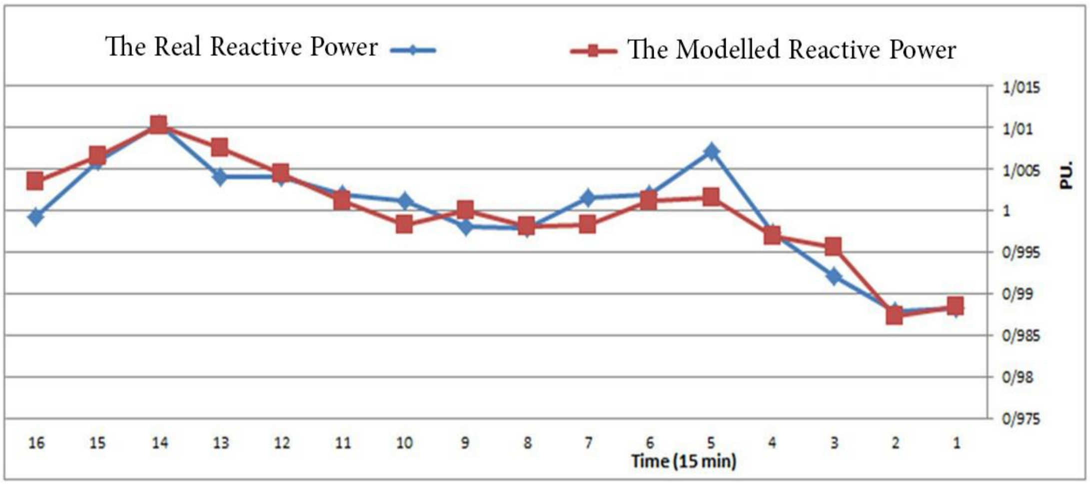

Fig. 6. The modeled and real reactive power for the first case study.

Table 3. The values of real and modeled powers for the first case study.

	Real Voltage (Per Unit)	Real Active Power (Per Unit)	Real Reactive Power (Per Unit)	Changes in Frequency	Modeled Active Power (Per Unit)	Modeled Reactive Power (Per Unit)
03:30	0.99520997	0.998958567	0.988296346	0.050	0.997623964	988600295
03:45	0.994933320	0.996463763	0.988028818	0.015	0.997577844	0.987352248
04:00	0.998207340	0.996769917	0.992166941	0.000	0.999152189	0.995582773
04:15	0.998852922	0.999912526	0.997456464	0.010	0.999476746	0.997059899
04:30	1.000559101	1.005049590	1.007118945	0.040	1.000265740	1.001571195
04:45	1.000512988	1.000404200	1.001962536	0.015	1.000255106	1.001308593
05:00	0.999544616	1.001037709	1.001614742	-0.010	0.999832487	0.998420003
05:15	0.999498503	0.998635089	0.997990549	-0.040	0.999819756	0.998143598
05:30	1.000190198	0.999080985	0.998164908	0.005	1.000130848	1.000033407
05:45	0.999636842	1.001234288	1.001140648	-0.010	0.999890993	0.998301886
06:00	1.000651327	1.003886874	1.002013756	0.040	1.000339927	1.001219942
06:15	1.0002772524	0.998979921	1.004167411	0.010	1.000807008	1.004474298
06:30	1.0002772524	0.998979921	1.004106651	0.010	1.001271964	1.007511127
06:45	1.0003694783	1.001803479	1.010523432	-0.040	1.001675440	1.010314485
07:00	1.0002495846	0.999250411	1.005978970	-0.070	1.001151613	1.006627606
07:15	1.0001481361	0.997412577	0.999268886	-0.050	1.000708542	1.003480654

4.2. The Second Case Study

The selected period of time for the second case study is from 05:30 on 15-October-2013 to 11:30 on 15-November-2013. The parameters of the extracted load model from the proposed method are presented in Table 4. The values of the active and reactive powers obtained from modeling with real data over the selected period of time are presented in Table 5. The powers obtained from the modeling with real data over the selected period of time, and the real powers values are presented in Figs. 7 and 8.

4.3. Analysis of the Simulation Results

In the first case study, from the 2880 called records, 141 data sets with the length of 12-16, and 10% changes magnitude for the voltage and powers are selected. For the second case study, with the same conditions, 82 data sets are provided. In the following, the most important results of the simulations are reported.

- In the first case study, for the worst case, there is 0.47 and 0.55 error between the modeled active and reactive powers with the real active and reactive powers, respectively.
- In the second case study, for the worst case, there is 0.30 and 0.76 error between the modeled active and reactive powers with the real active and reactive powers, respectively.
- In the first case study which is conducted for one-month period, about 72% of the resulted model is oriented to the dynamic model and the remaining 28% is oriented to the static model.
- In the second case study which is conducted for a similar period with first case study, the resulted model is completely oriented to the dynamic model.
- The results show that, selecting the small period of time for voltage and power changes leads to small errors, and the model is closer to the reality. Also, the small data set leads to small errors than large data set.

5. CONCLUSION

This paper presents a method for load modeling based on processing the extracted data from a real power system (WREC network) applying PSO algorithm. The proposed method is a combined static and dynamic model. It is tested on two real industrial power grids from the WREC network. Therefore, one of the advantages of the proposed load modeling is the application of recorded parameters from the measurement apparatus of substation instead of direct field measurements which are costly and time-consuming. The results demonstrate that, data sieving is precisely carried out and the undesirable data are removed. Hence, the desired data sets are provided by the proposed method regarding the defined intervals and constraints. The obtained values of the active and reactive powers from the proposed model have acceptable match with real values. Therefore, the proposed method can be used in modeling the various types of loads considering some items such as recording the measured parameters from the measurement equipments of substation with small intervals without limitation for any periods of time.

Table 4. The obtained parameters for the second case study.

P_1	P_2	P_3	K_{pf}	q_1	q_2	q_3	K_{qf}
0.166214	0.000	0.833786	0.016203	1.0000	0.0000	0.0000	0.0000
K_1	K_2	α_s	α_t	t_p	b_s	b_t	t_q
0.0000	1.0000	0.00	6.264929	3.555288	2.223426	10.000	3.265417

Table 5. The values of real and modeled powers for the second case study.

Date and Time August 11th, 2013 (from 21:15 to 23:45)	Real Voltage (Per Unit)	Real Active Power (Per Unit)	Real Reactive Power (Per Unit)	Changes in Frequency	Modeled Active Power (Per Unit)	Modeled Reactive Power (Per Unit)
21:15	0.996736460	0.994830958	0.993132113	0.060	0.997389960	0.990090716
21:30	0.997821589	1.002791413	0.999623763	0.070	1.000911822	0.996587263
21:45	0.997369452	0.999268158	1.000257773	-0.010	0.998456131	0.992623492
22:00	1.000805695	1.005125277	1.009368808	0.070	1.004911529	1.007463785
22:15	1.001664756	1.004848578	1.006497385	0.080	1.004052305	1.008194338
22:30	1.001031764	0.998299047	1.002288308	0.060	1.001299408	1.003594625
22:45	1.001574328	1.001064990	1.005291871	0.080	1.000460509	1.003782934
23:00	1.001800397	1.001564297	1.009204958	0.040	0.999493991	1.003179189
23:15	1.002749885	0.997657127	0.996927088	0.020	0.999098801	1.004809926
23:30	1.002026465	0.998452712	0.996221488	0.025	0.998032106	1.002077855
23:45	0.996419964	0.996097910	0.986588350	0.040	0.995892817	0.987593954

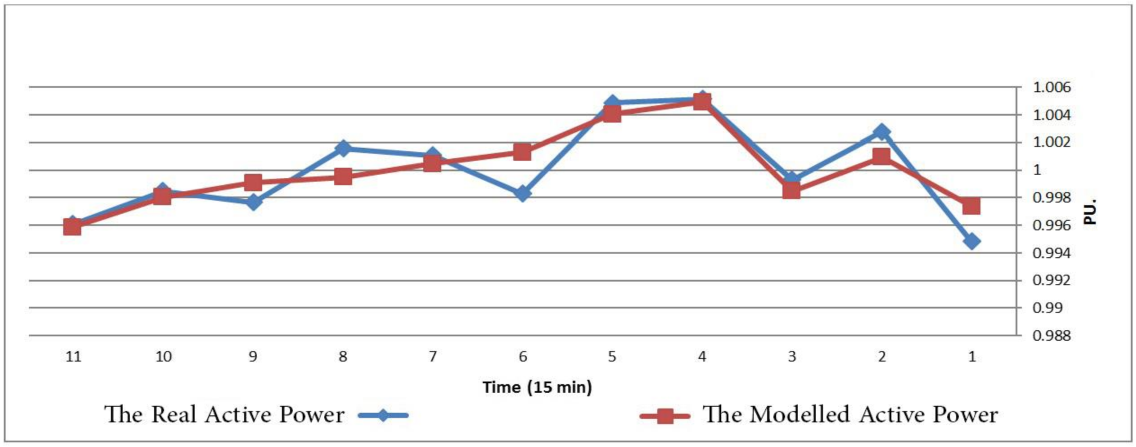

Fig. 7. The modeled and real active power for the second case study.

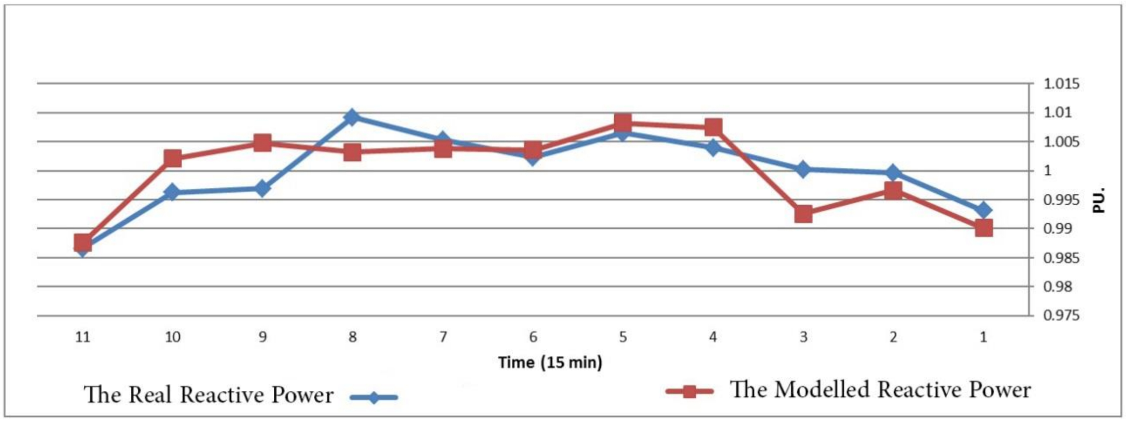

Fig. 8. The modeled and real reactive power for the second case study.

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