International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249 – 8958 (Online), Volume-9 Issue-4, April 2020

Measurement and Analysis of the Dynamic Load Modeling for Smart Grid Environment

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Abstract: *This paper mainly focuses the dynamic modeling to overcome the severe challenges of dynamic characteristics of loads of Smart Grid System in Kuching and Samalaju, where facility loads have significant consequences to the power system stability. Appearances of conventional types of loads, which are power-electronic, based or interfaced and it requires operating with increasing non-conventional and intermittent types of generation. These lead to an interest in dynamic modeling. In Sarawak Energy Berhad (SEB) power grid, the instability of the voltage, frequency deviations of the power system can damage the bulk load and important data as well. Dynamic modeling is a technique used to model the system to study the power system stability, including system voltage, frequency, and oscillation of the generation. This paper proposes dynamic modeling that will be done based on the data at the Kuching Bulk Load of SEB. Moreover, this study also assesses the time-domain dynamic simulation by comparing the recorded and simulated response as well as assess the parametric study using the parameter estimation method (Least Square Error). The selected model of the bulk load can be optimized by converging on the data of the Least Square Error Method in this study.*

Keywords: *Dynamic Load Modeling; Least Square Error Method.*

I. INTRODUCTION

This paper is based on the study of utility real problems at the Sarawak Energy (SEB) system. It is focused on the dynamic load model considering bulk load in Kuching for the reasons that SEB have typically studied on assuming static load models in time-domain dynamic simulations. This study is necessary as SEB had studied recently with assumed on arbitrary static load models and its parameter in contemplation of matching records data and simulated load response but however, fewer ideas regarding on dynamic characteristics of the loads in the Sarawak Grid System, specifically in Kuching and Samalaju in Bintulu. Basically, most of the models on the transformer, generators and transmission lines can be done exactly and perfectly compared to load models as loads are time-varying, do not constant and somehow depends on the types of load class either it is residential or industrial and etc. In addition, most of the researchers interested in assess static and dynamic loading profile due to the appearances of new-conventional types of loads which are power-electronic based or interfaced and its requirements to operate with increasing on non-conventional and intermittent types of generation [1] and raising usage of devices connected to the switching power supplies and energy-saving lighting. With the high penetration on power electronic-based, most of the load models used by customers today are not updated therefore correct analysis on load modeling should be done by considering the exact and accurate representation of static and dynamic on the system loads. The importance of conducting this study is for the system reliability due to the numerous of blackout events occurred such as in Swedish in 1983 due to the inappropriate representation of system loads. Currently, the amount of production of electricity in Malaysia in 2014 is about 139 billion kWh and its consumption is only 131 billion kWh mentioned in [2] which is consists of numerous types of bulk load either small or large motors. Hence, this paper is beneficial to assess and perceive the power system stability in the industrial facility loads in the consequences of some events (power tripped) that happened in the system. Load modeling is a technique that used to model the system by using an appropriate load model of the complex load in the PSSE software which is CLODBL types and has some features as shown in Fig. 1.

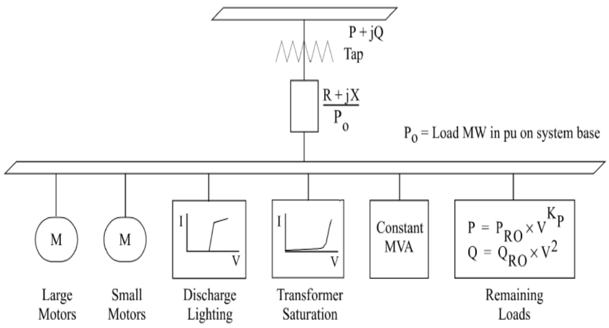

Fig.1. Complex load model features [3]

The complex load is a load that is consists of the static and dynamic load. The dynamic load is known as loads that have large voltage, varies in current, power, and voltage (e.g. induction motors) and can be modeled as large and small motors. Static load means load consumed statically with constant impedance

Revised Manuscript Received on April 25, 2020.
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(*Z*), constant current (*I*), constant power (*P*) and also being known as ZIP model where it is load depending on the voltage and can be demonstrated using polynomial and exponential (e.g. incandescent light) and can be modeled as constant MVA or remaining loads. Behaviors of these static and dynamic loads have a significant impact on the power system stability in concern of some parameters such as voltage, current, frequency or rotor angle of the generator that leads to under/over frequency, over/under voltage and stalling motors. However, the main aim of these papers is to propose a new dynamic model that is based on the data profiles of the bulk load of SEB.

The rest of the paper is organized as Section II discusses the related study of dynamic load modeling and the summary of the existing model's pros and cons, section III discusses the design and its considerations of dynamic load modeling, Section IV discusses the results and analyses the performance. Finally, section V concludes the paper.

II. LITERATURE REVIEW

There are some related works on the dynamic load modeling and being highlighted in this section by mentioning the author’s contributions, pros, and cons for the selected papers.

A. Dynamic Load Modeling Using Real-Time Estimated States

The load model is a mathematical representation of the real and reactive power with having inputs of frequency and voltage that can be accessed via the Phasor Measurement Units (PMU) that is installed on the selected bus [4]. During dynamic load modeling, it is crucial to have a precise result of monitoring and controlling power system during some events (e.g. disturbances) in order to know about the behavior and characteristics of the load on the system where usage of the inappropriate or incorrect parameter and model for the load models lead to the error. Hence, in [5] the authors proposed on load modeling by using Exponential Dynamic Load Model (EDLM) for inputs in calculating changes of the active and reactive power at the selected bus by having multiple load parameters and active power can be expressed as follows:

$$T_p \frac{\delta P_r}{\delta t} + P_r = P_o[\frac{V}{V_o}]^{a_s} - P_o\left[\frac{V}{V_o}\right]^{a_t} \quad (1)$$

$$P_1 = P_r + P_o\left[\frac{V}{V_o}\right]^{a_t} \quad (2)$$

Where, T_p is the active load recovery time constant (in seconds), P_r states as active power recovery, P_o for reactive power before voltage change, measured voltage represents by V, V_o, shows the voltage before disturbance, and a_s and a_t is dimensionless.

A case study was done to investigate the EDLM influence such as sensitivity analysis of the parameters for the load model by presenting on how does the result when inaccurate load models were used. According to the authors, PMU measurement might have some error, hence EDLM is able to reduce 5% errors from it and finally, a study on the sensitivity of inaccurate line parameters can be done where it is comparable to the calculation of the active and reactive power injection. In conclusion, this proposed method is more secure by combining the modeling with the conventional power injection measurement and estimated states can be used for obtaining EDLM parameters, however, the accuracy is dependent on the parameters.

B. *Power Flow Modeling Approach Considering On-Load Tap Changer*

Authors in [6] presented on the simplified load modeling by considering the on-load tap changer (OLTC) where this method reduced the number of variables and hence reduce the time for computation. This simplified power flow modeling has

Define transformer bus type: $T.\ Bus_i$,

TABLE I. i = 1 for tap bus

TABLE II. i = 2 for non-tap bus

1. where tap bus is the receiving-end bus of a transformer branch and non-tap bus is for any bus that is at the sending-end of transformer/ uncontrollable branch.

Define transformer branch type: T. $Branch_{i,j}$ ij = 1 if no voltage regulator (VR) or OLTC ij = 2 if the branch has VR or OLTC Define tap variable for each of the buses: T_i, T_i is transformer tap-ratio Calculate Ybus matrix and line admittance by assuming no taps.

2. Define power flow formulation by using simplified nodal power injections as well as line power flow.

few steps need to be taken as follows:

Modeling for the power flow being proposed by making on consideration for the transformer tap ratios as control variables and letting Ybus admittance matrix as constant parameters. However, this proposed model cannot be used for the cases having multiple tap changing transformers linked to one bus as indicates in Fig. 2 below:

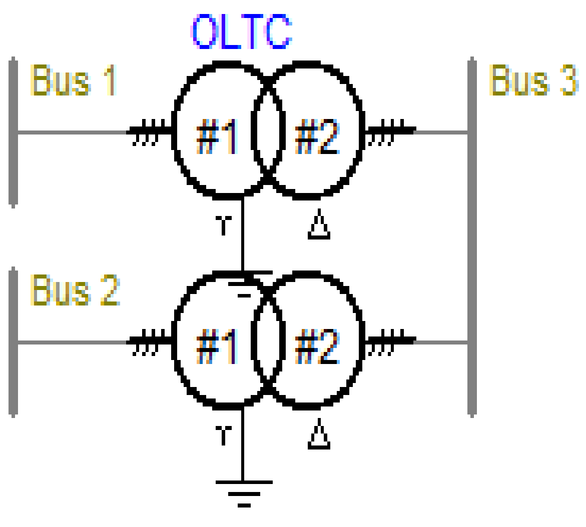

Fig.2. One bus connected to secondary sides of OLTC

C. Model Reduction of Dynamic Loads

Load modeling has been gaining a lot of attention to be studied as it is important for the power system stability and it is tough to be done due to frequent changes of the load composition contingent on the weather, economic conditions, timescale, and typical bus load is consist of numerous diverse components. In order to carry out a load modeling, some parameters need to be declared based on the load itself. Thus, authors in [7]

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introduce the new approach for load modeling to simplify the load models and estimate the parameters involved. Composite load referred to both static and dynamic load connected to each other as revealed in Fig. 3 below:

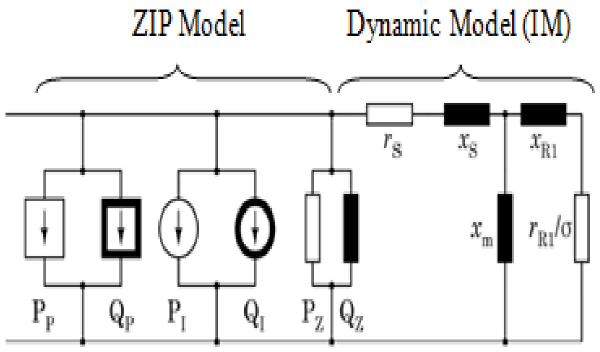

Fig.3. Equivalent circuit of composite model [6]

A simplified method using simulation in MATLAB involving IEEE 14 bus test system was done by performed two different situations of faults on the chosen bus. Based on that, the paper indicates that two parameters of x_{R1} and r_s from the five parameters on the induction machine can be reduced while for the ZIP model, two parameters of p_i and q_i can be reduced from all the parameters shown in the equivalent circuit without changing on the original characteristics. In addition, the effects of model mismatch also can be seen through the simulation. However, this method is limited where if there is a small variation in parameter, it will lead to the dramatic changes in the measurement of data whereas other variations in parameter also lead to a non-detectable change in the model behavior.

D. Identification and Derivation of Dynamic Load Model

Authors in [8] proposed the method on the online identifying exponential recovery of the dynamic load model by using synchrophasor data. The proposed method has a few steps as follows:

- Event Detection

The algorithm is started when an event (e.g. sudden voltage disturbance) is sensed by monitored on the voltage changes and signal recording is activated for further action.

- Data Acquisition and Post-Processing

Data on phase voltage and power were collected for all buses until the system reached the steady-state. All the data gained then will be improved on the quality by undergoing filtering such as Robust Local Regression (RLR), FIR, Savitzky-Golay (SG) and Moving Average (MA) filters where FIR is better as it preserves on the sharp and smooth of the original data.

- Parameter Identification

The initial estimation of each model of the parameter was done by using the formula and using a multi-start (MS) algorithm of MATLAB Global Optimization Toolbox. Next, the removal of outliers is done by analyzing the result of R^2 for both real P and Q responses and to ensure the validity of the proposed method.

- Generic Modeling

A generic model is proposed to investigate the consequence of dynamic load penetration and spread applicability of the procedure to a wide range of conditions. It is derived by using two data classification approaches which are using all available training data and classifying data into four groups according to dynamic load penetration. Next, the cross-validation method is applied to evaluate the accuracy of the generic load model in order to simulate P and Q for an extensive range of disturbance.

E. Load Modeling

Load modeling was studied by evaluating voltage stability so that the practice of solution can be made with consideration on economics, reliability, and security as mentioned in [9]. This paper was referred regardless of the year due to its scope which is load modeling based on the actual field data. Some consideration should be made during modeling such as:

- Classification of Reactive Power

Real power (P) at the substation = P consumed by load, Reactive power (Q) at the substation ≠ Q consumed by the load. Both expressions above are due to the shunt capacitance that was installed in the substation for balancing Q consumed by the load and also to improve the power factor.

- The proportion of Dynamic Loads

It is important to know the quantity of modeling and power system analysis because the dynamic load does not have a constant voltage, current, and power in a mountain. Basically, the exact quantity and load demand on this dynamic load are important as the expansion in inverter technology especially in air conditioning is growing.

- Load Tripped Over Faults

Voltage sags happened due to overload on the transmission system and triggered some of the load that was designed to be tripped if faults happened to avoid and protect it from damage and malfunction. Some of the load tripped might recover after the system is normal and some might not depend on the design itself. Load drop is important for consideration on voltage stability.

- Dynamic Load Time Constant

After the system back to normal, dynamic load will recover and have different P and Q proportionally to time as severe faults take a long time for the dynamic load to recover and vice versa.

The total dynamic load and the characteristic are essential to computing for modeling and following power system analysis as stated by the researcher. One major load used by customers for the dynamic load is air-conditioned with the usage of inverter technology as it is growing rapidly. However, in handling this method, load characteristics are serious and have to be simulated and assessed by making a consideration of the dynamics of load and load tap changers of the transformer. Based on the research and journal that have been explained in the previous section, there are some highlighted points and ideas with consideration of the author's contribution, merits and research gap as indicated in the table below:

Table I: Summary of Related Works

Methods	Pros	Cons

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An approach of the load modeling by using EDLM by doing some analysis based on a few case studies [5].	EDLM with the combination of the real and reactive power injection is better to be used as it is more accurate than (PMU).	Estimated states can be used for obtaining EDLM parameters, but the accuracy is dependent on the parameters.
A simplified power flow modeling by considering the on-load tap changer (OLTC) and Ybus admittance matrix is taken as constant parameters [6].	This model is capable to reduce the total number of variables and hence reduce the time taken for computation to solve the models.	Simplified models cannot be used for the cases which have multiple OLTC that are connected to one bus.
A simplified model of load modeling by reduction on some parameters based on information geometry [7].	The simplified method produced useful, practical results that match and extend the local analysis for composite load models as well as reduce the time for load modeling. This method was available for other forms of the model (Exponential recovery) and benefits the PMUs.	If there is a small variation in parameter, it will lead to the dramatic changes in the measurement of data, whereas other variations in parameter also lead to a non-detectable change in the model behavior.
Online identification and modeling procedure for the exponential recovery load model by having fewer steps on event detection, data acquisition, parameter estimation and generic modeling of real and reactive power [8].	Accurate presentation of dynamic characteristic load enables on power system planning, reliable estimation of procedure and strategies of system control can be done. This paper also verified the proposed load modeling for real-time applications.	This method has to undergo many steps in order to identify online parameters and derive generic modeling of a dynamic load model in distribution grids.
This paper was chosen regardless of the year due to the load modeling constructed was on the real field data. It's explained on parameters need to be taken care of during load modeling throughout and after the system faults based on the actual field data [9].	This model provides consideration need to be made during load modeling by using the actual network data.	Actual load characteristics were used as it is critical and hence the actual load needs to be computed and evaluated with consideration of the dynamic of the load as well as load tap changer transformer.

III. PARAMETER SETUP AND CONFIGURATION OF THE LOAD MODEL

Network data on system outage happened in the selected bus was collected from the SEB and assessed with consideration on their behavior and influences towards power system such as under/over frequency and over/under voltage. Load at the Entinggan bus was chosen as Kuching bulk load and the influences on the load due to the bus tripping at Mambong were considered by referring to the PMU data. A review on the network bus can be seen in the reduced network of Kuching Power System. Steps and techniques took in this study being listed in the flowchart as shown in Fig. 4.

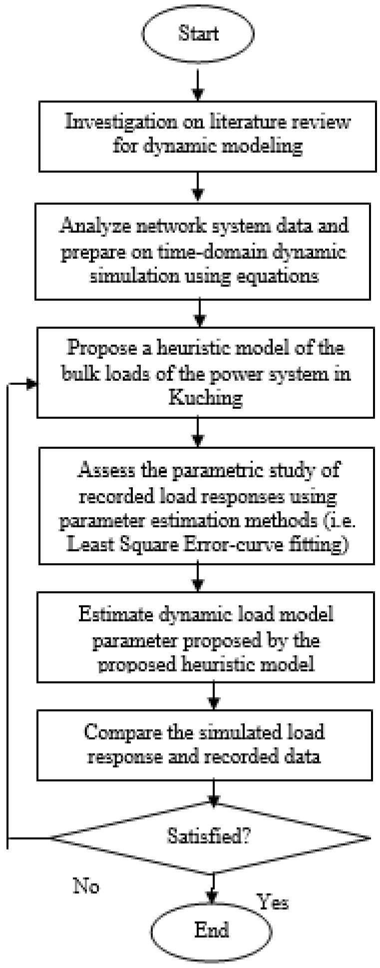

Fig.4. Proposed procedure of the parametric study of load model

This paper used model parameter estimation during analysis by using typical values for large and small induction motor in the CLODBL load model.

$$E(X) = \sqrt{\sum_{k=1}^{N} \{X_{meas}(t_k) - X_{sim}(t_k, X)\}^2} \qquad (3)$$

Table II: Symbol Definition

Symbol	Definition	Values
N	Total number of sampling	n
k	Number of sampling	1, 2, 3, n.
Xmeas	Parameter	Follows to recorded PMU value
Xsimu	Parameter simulated	Follows to CLODBL load model

Fig. 5 reveals the procedure of the estimation parameters used in this paper. Fig. 5 describes the parameter estimation procedure with a comparison of the simulated and recorded data. Simulated data is the values after undergoes a simulation of the complex load equations using MATLAB and recorded data is the data that is collected from PMU for selected buses owns by the SEB.

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Least square error is presented in the following Equation and the explanation with parameters is given in in Table 2 [10].

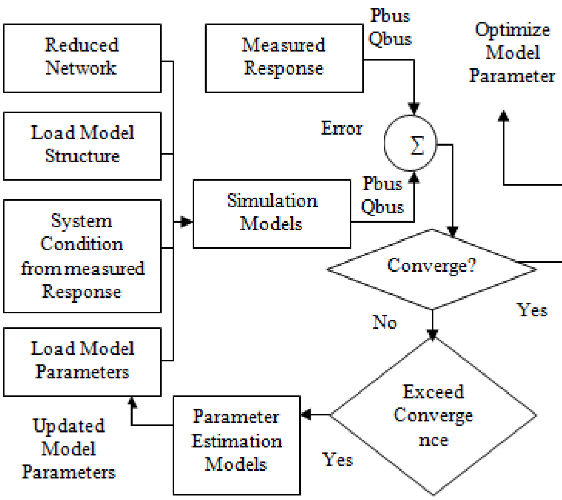

Fig.5. Parameter estimation procedure

IV. RESULT AND DISCUSSION

Modeling the real-time data that was collected from SEB for the voltage and angle for each bus of 11kV and 33kV was assess by presenting it in the graph, as shown in Figure 6 for 11kV and Figure 7 for 33kV. Each of the values for the angles and voltage was different in every bus since it is depending on the rotation of the magnetic field in the generator for each bus.

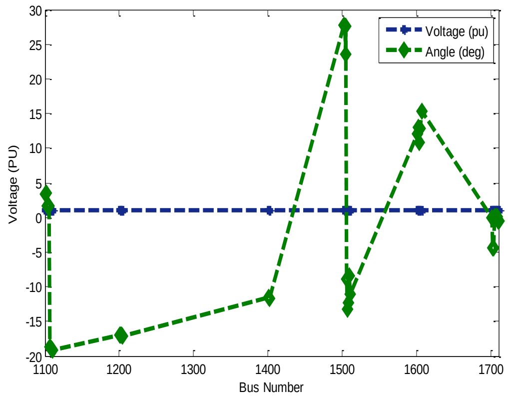

Fig.6. Voltage (pu) monitoring over bus number for 11kV bus

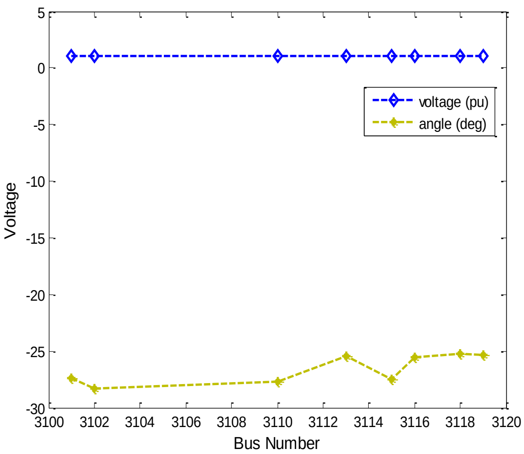

Fig.7. Voltage (pu) monitoring over bus number for 33kV bus

Reduced network bus of the Kuching power system was carried out in this paper and parameters for each of the buses were simulated in the MATLAB[11]. There are some elements and parameter need to be considered before plotting the graph as in Fig. 8. Few parameters (X) on the CLODBL need to estimate such as % large and small motor, % transformer exciting current, and % constant power. However, typical values of the large and small motor such as rotor and stator resistance can be used as in the load model of the PSSE. An excellent style manual for science writers is [7].

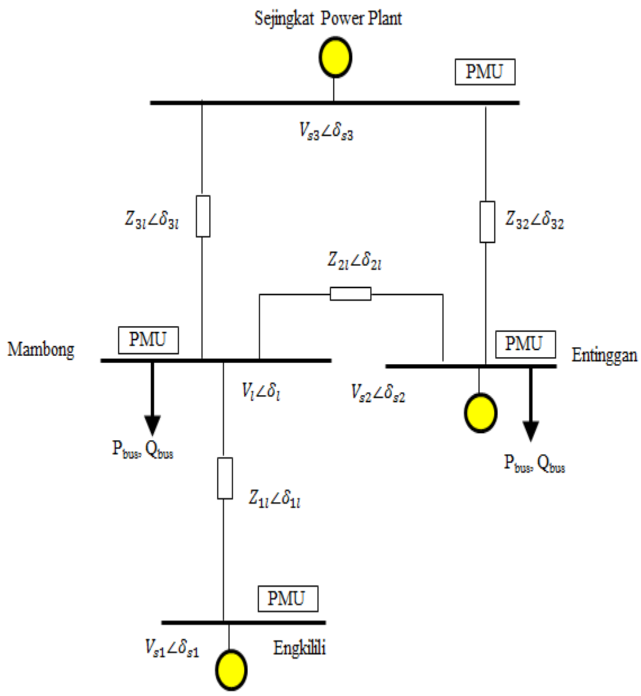

Fig.8. The reduced network of Kuching power system

Solving all the parameters for the buses, compare both simulated and measured values to get the error by using Least Square Error Method and literally, the graph for the error can be plotted (Fig.9). The optimization technique needs to be done in order to minimize the error by using the gradient-based method.

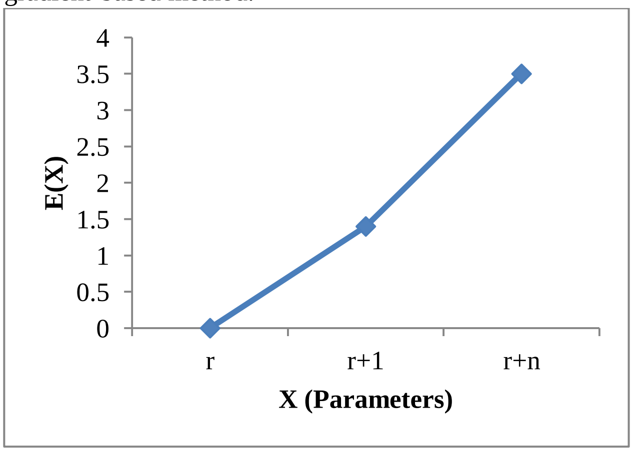

Fig.9. Representation of the error using the gradient-based method

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V. CONCLUSION

This paper investigates and discusses several existing methods in order to highlight the challenges as well as key factors. Finally, this paper proposes a method for the dynamic load modeling to obtain optimized load model parameters by using Least Square Error Method. Values for the simulated data and measured data were compared by using the method and being plotted in a graph by doing some convergence of the parameter until the error becomes zero and hence optimized load model is obtained.

ACKNOWLEDGMENT

This research was supported and sponsored by the Research Management and Innovation Centre (RMIC), Universiti Malaysia Sarawak (UNIMAS) under the Grant F02/DPD/1639/2018. The author would like to thank Sarawak Energy Berhad (SEB) for their technical support and real-time data.

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