Establishing a Load Model for System Dynamic Simulations using Real and Historical Data

Kah Kin Cheong

Tyrone Fernando, Herbert Iu
School of Electrical, Electronic & Computer Engineering

Huuson Nguyen, Reza Bank Tavakoli
CEED Client: Western Power

Abstract

In power system planning, the use of an appropriate load model is a critical factor to the accuracy of results. By increasing the accuracy of the model used for loads, uncertainty is reduced, leading to cost savings from lowered safety margins. This allows for more effective and economical decision making.

This project utilises the measurement-based approach to load modelling, with data collected from sources such as SCADA, PMUs, and transient recorders. A number of model structures were selected to be tested in order to select the most suitable structure and corresponding parameters. Least squares optimisation was then used to determine suitable values for the parameters by minimising the error between the data values and modelled values. As Least squares optimisation had a tendency to choose local optima, the use of Particle Swarm Optimisation to determine parameters is underway.

1. Introduction

Power system modelling is a powerful and essential tool for the planning, control, and analysis of power networks and its stability. However, accurately modelling a power system is a challenging task due to the complex nature of a load. The process requires a load model: a mathematical representation of an aggregation of thousands of load components differing in quantities and characteristics. Additionally, this load varies by time-of-day, season, weather, and location. Due to the uncertainty of a load, the chosen load model has a substantial effect on power system analysis, even to the extent of possibly obtaining conflicting conclusions about stability (Renmu, Jin & Hill 2006). It is therefore crucial to obtain a suitable load model in order to effectively plan electricity networks.

Obtaining a load model of increased accuracy will permit for more precise decision-making in order to reduce its costs. Production loss from the application of excessive safety and design margins from inaccurate models affects the efficiency of operations involving delivery of service. It is anticipated that the new model will reduce the large safety margins in current planning procedures.

1.1 Project Objectives

The objective of this project is to establish and validate load models for individual zone substations in the South West Interconnected System (SWIS) for dynamic simulations using MATLAB. Data supplied by Western Power, taken from SCADA, transient recorders, and phasor measurement units were used to determine a model structure and find its most suitable parameters.

Models can be designed for either static applications or dynamic applications. Static load models represent the real and reactive power of the load at an instant. Dynamic load models provide a time-domain solution from the electromechanical behaviour, as well as a steady-state power flow solution based off phasors. Static models are still considered, as they are still sufficiently accurate to be common in practice (Chung 2014). However, as the load model is to perform transient stability and dynamic stability analysis, a dynamic load model would be more appropriate.

In measurement-based load modelling, data for voltage, frequency and power consumption is taken from a Phasor Measurement Unit (PMU) or another source. Various methods are then used to derive the load model structure and parameters. The advantage to this is direct measurement of actual load behaviours, compared to the aggregation of loads based on surveys under the component-based approach.

2. Process

The procedure for identifying a load model is shown in Figure 1. The project is here broken down into sub-tasks.

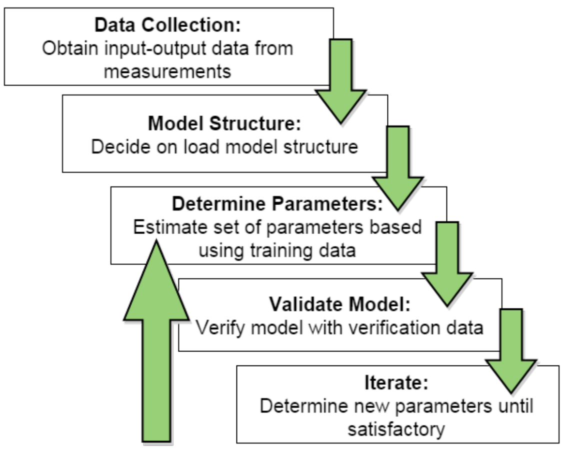

Figure 1 Algorithm for determining load models

2.1 Data Collection

Data supplied by Western Power was used in one of two sets. One set of the data was labelled as *training data*, which was used to determine the parameters. Another set of data was then labelled as *verification data*, which was used to test the accuracy of the parameters obtained.

2.2 Model Structure

Literature details many of different load structures to choose from. In order to determine the model that most correctly fits the data, multiple models were simulated and compared. A selection of common structures that have been tested or proposed is outlined below.

2.2.1 Polynomial Models

Also known as the ZIP model due to a combination of constant impedance, constant current, and constant power terms; this model represents power as a polynomial equation. The parameters to be solved for in this model are a_1, a_2, a_3, a_4, a_5, a_6. The equations for this model structure are shown below, with P, P_o, Q, Q_o and V representing real power, initial real power, reactive power, initial reactive power and voltage respectively.

$$P = P_0 \, [a_1 V^2 + a_2 V + a_3] \quad (1)$$
$$Q = Q_0 \, [a_4 V^2 + a_5 V + a_6] \quad (2)$$

Instead of modelling the load using voltage as the main variable, a variation of this model determines the load based on current.

$$P = P_0 \, [a_1 I^2 + a_2 I + a_3] \quad (3)$$
$$Q = Q_0 \, [a_4 I^2 + a_5 I + a_6] \quad (4)$$

Similarly, this model determines the load based on the phase angle of the data, that is, the difference in phase angle between voltage and current.

$$P = P_0 \, [a_1 \theta^2 + a_2 \theta + a_3] \quad (5)$$
$$Q = Q_0 \, [a_4 \theta^2 + a_5 \theta + a_6] \quad (6)$$

2.2.2 Exponential Load Model

In this model, the parameters are now exponents of the power equation. The parameters to be solved for in this model are α and β.

$$P = P_0 \left(\frac{V}{V_0}\right)^{\alpha} \quad (7)$$
$$Q = Q_0 \left(\frac{V}{V_0}\right)^{\beta} \quad (8)$$

2.2.3 Induction Motor Load Model

A popular model used today is based on the induction motor. The large presence of induction motors in networks is reason behind its popular use. The parameters to be solved for in this model are R_s, X_s, X_m, R_r, X_r, H, A and B.

2.2.4 Composite Load Model

This model features the ZIP load model in parallel with a dynamic induction motor, as shown in Figure 2. The parameters to be solved for in this model are R_s, X_s, X_m, R_r, X_r, H, A, B, K_{pm}, $M_{lf,}$ $P_z*_,$ P_P*, Q_z* and Q_P*.

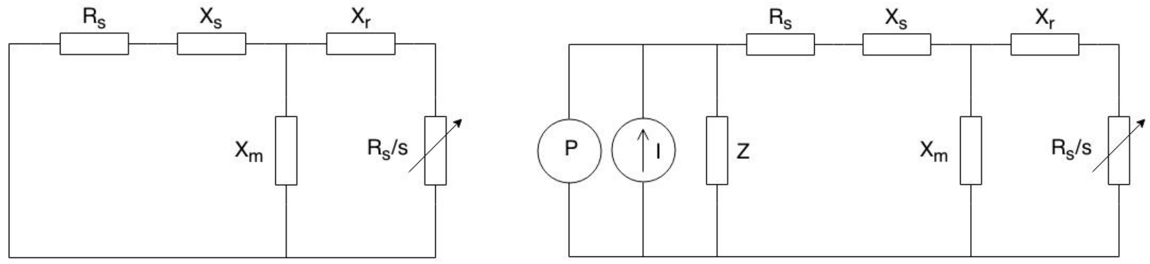

Figure 2 Equivalent circuit of induction motor model (left)
Equivalent circuit of composite load model (right)

2.3 Parameter Determination

After a suitable model had been chosen, the next step was to determine the parameters of that particular model. Figure 3 below outlines the process used to determine these parameters.

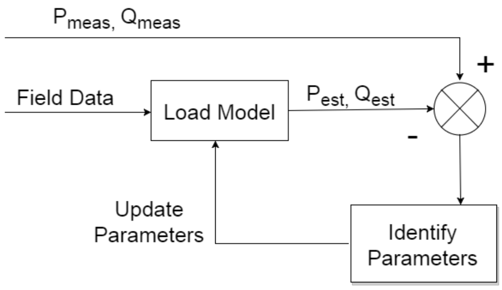

Figure 3 Algorithm for parameter determination process

In this step, different methods of iteration and optimisation were considered to determine the parameters and validate the models. Measured data was input into the load model to output an estimate for real and reactive power, P_{est} and Q_{est}. These estimated values were then compared to the actual measured values for real and reactive power, P_{meas} and Q_{meas}. The error function, ε, was calculated based on the difference between the measured and estimated figures.

A popular approach to determine parameters is least squares optimsation, which aims to minimise the error function as follows:

$$\varepsilon_P = min[\frac{1}{N}\sum_{k=1}^{N}(P_{meas}(k) - P_{est}(k))^2] \quad (9)$$

$$\varepsilon_Q = min[\frac{1}{N}\sum_{n=1}^{N}(Q_{meas}(k) - Q_{est}(k))^2] \quad (10)$$

Another, more advanced way of searching for solutions is Particle Swarm Optimisation (PSO). PSO is a technique developed based on the social behaviour of a flock of birds in search for food (Kennedy & Eberhart 1995). It uses an analogy of a swarm of particles in a field of all possible solutions, in an attempt to obtain the optimal solution. The experience of both the particle and the best found by the swarm is together used to calculate the trajectory of the next iteration.

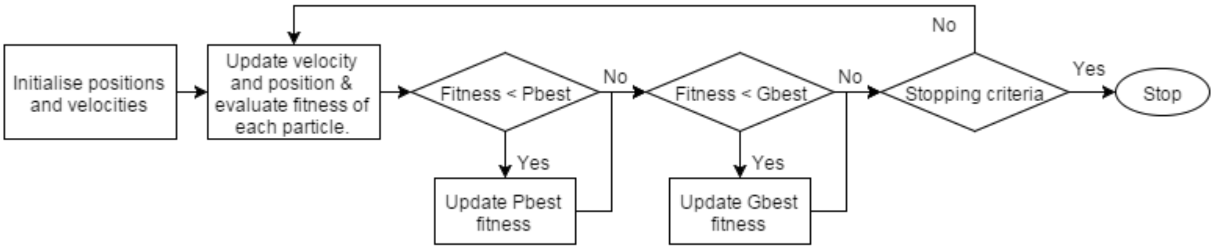

Figure 4 Particle Swarm Optimisation flowchart

2.4 Model Validation

The load model generated by the procedure will consist of the model structure used and the final parameters determined. The parameters will be satisfactory if the error function is within the specified limit of 5%. If the parameters fail to converge to a value that falls within limits, the model will be deemed unsatisfactory for use. One possible cause is the model structure chosen may not be a good representation of the data. Alternatively, it could be that the data chosen was poor, contained outliers, contained noise, or was unsuitable for use. Another reason for failure may arise from issues with the parameter optimisation procedure.

3. Preliminary Results

A selection of preliminary results is shown here. The results in Figure 5 below show the model determined by the polynomial current model structure. In this case, the fit for real power is fairly accurate. However, the reactive power model is poor. Using phase angle as a base, the results can be seen in Figure 6. In this case, the real power results are quite poor, while the reactive power model was better, but still unacceptable.

These results were derived from scripts utilising least squares optimisation. The tendency for this method to arrive at local optima instead of global optima can be seen from the inaccurate fittings. It is hoped that the use of particle swarm optimisation, when finished, will lead to more accurate results. Additionally, these results have used static load model structures as a base. These models are generally not as accurate as dynamic model structures (Hou, Xu & Dong 2011). Finally, the data used for these preliminary results had not yet been properly filtered. More appropriate data will be required for future results.

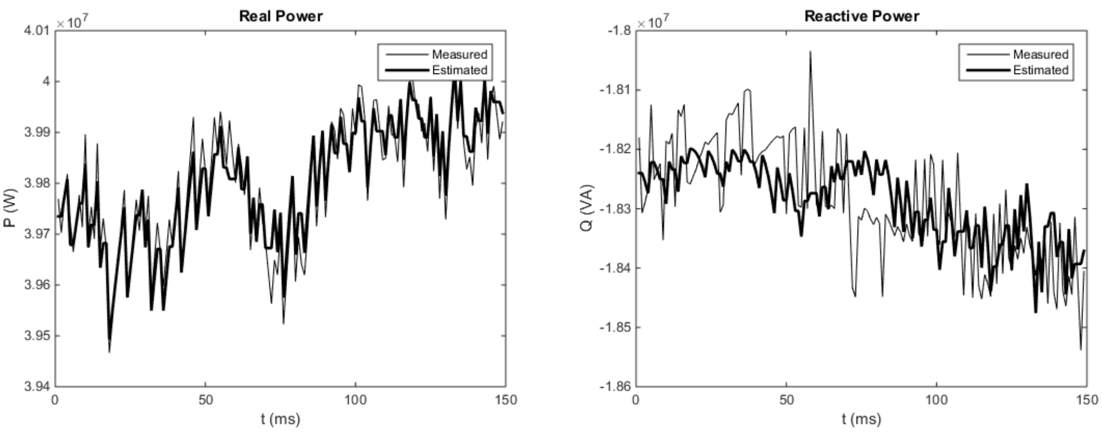

Figure 5 Polynomial Current Model Results

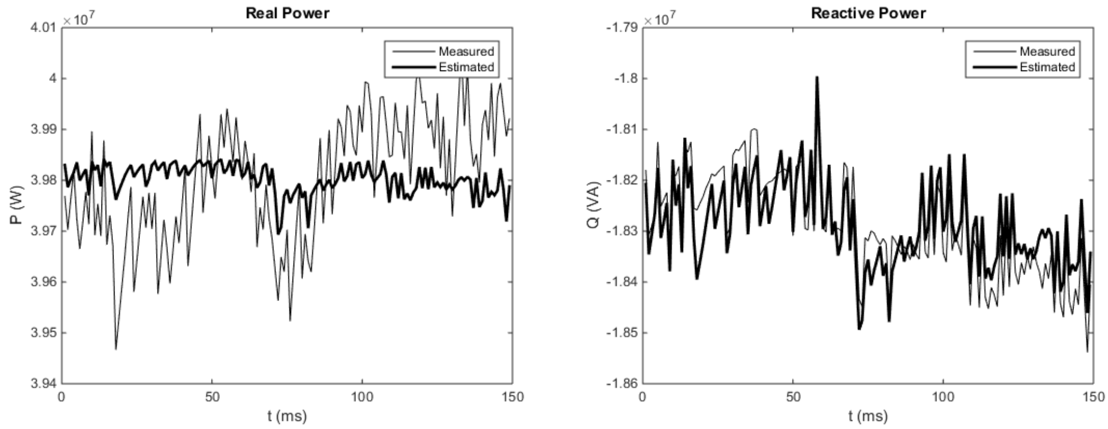

Figure 6 Polynomial Phase Angle Model Results

4. Conclusions and Future Work

Work needs to be done on the data, in order to determine the most useful and appropriate data to be used for modelling and verification. Present results are based on small samples.

At the time of writing, dynamic load models such as the induction machine model and composite load model have not yet been finalised. As dynamic load models are usually more accurate than their static counterparts, more accurate results should be produced once this is completed.

Additionally, the tendency for least squares optimisation to arrive at local optima has spurred the need to search for solutions using intelligent methods. As a result, parameter determination using particle swarm optimisation is currently in progress.

5. References

Chung, D 2014, 'A Study on the Measurement Based Approach Techniques for Static Load Modelling', *International Journal of Computer an Information Technology*, Vol. 3, no. 2, pp. 199-204.

Hou, J, Xu, Z & Dong, Z 2011, 'Load Modelling Practice in a Smart Grid Environment', *Electricity Utility Deregulation and Restructuring and Power Technologies,* pp. 7-13.

Kennedy, J & Eberhart, R 1995, 'Particle Swarm Optimization', *Proceedings of IEEE International Conference on Neural Networks,* Vol 4, pp. 1942-1948.

Renmu, H, Jin, M & Hill, D 2006, 'Composite Load Modelling via Measurement Approach', *IEEE Transactions on Power Systems*, Vol. 21, no. 2, pp. 663-672.