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Measurement-based modelling of composite load using genetic algorithm

Mansour Eshragh-Niay Jahromi [a,*], Mohammad Taghi Ameli [b]

[a] Iran Grid Management Company (IGMC), Tehran, Iran
[b] Shahid Beheshti University, Tehran, Iran

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ABSTRACT

One of the major issues in simulation and control of power system dynamics is load modelling. More accurate load models in power system stability analysis increases the accuracy of simulation results. If inappropriate model is used for the load, the obtained results may contain a high degree of error. In majority of analysis, the loads are usually considered as a constant impedance element. Whereas, such a model is not only accountable for the stability analysis of power system but also may sometimes lead to opposite results. Due to the variation of the load and also the variation of the composition of the load components, it would be difficult to provide a fixed model for electrical loads similar to those of other elements of the power system. A method for modelling the power system loads via genetic algorithm is presented in this paper. This methodology is performed based on the composite load model. In order to get an accurate load model, several scenarios are considered. The particular method of this paper is that after obtaining the load model parameters corresponding to each of the scenarios, various values obtained for the parameters are averaged. Finally, the validity of the obtained parameters is testified with some other scenarios. The results reported in this paper indicate that the existing load models satisfactorily describe the actual behaviour of the physical load and can be reliably estimated using the identification techniques presented herein.

1. Introduction

In most researches which are conducted on power systems, the dynamic load model is not used, because the researchers consider the dynamic effect of the load on the power system to be insignificant in these studies. In the short circuit calculations which are used to select the circuit breakers or to set the relays, the loads are ignored, therefore, the load modelling is not substantial. However in studies like the load flow, long-term stability and low-frequency inter-area oscillation and alike, if the load modelling does not accompany with sufficient accuracy, the results may contain considerable errors. In the transient stability analysis performed on the power system of China, the output power and the cost of some power units have been found greatly dependent to the model of the load. It should be also noted that the load model used for the dynamic analysis of a power grid, may not be necessarily used for another power grid [1].

Ref. [2] is focused on the issue of parameter identifiability in the complex load model with a large number of parameters. It is proposed analysis used the trajectory sensitivity as the feature characterizing each parameter, and employed K-medoids and multidimensional scaling technique to provide quantitative characterization and intuitive visualization of the WECC CMPLDW parameters' interdependency, respectively. Ref. [3] proposed the parameter sensitivity and linear dependency analyses to improve the efficiency of optimization for the measurement-based composite load modelling with the L–M algorithm. Twelve effective field measurement set was obtained from the digital fault recorder (DFR) established in a practical substation. The sensitivities of parameters in composite load modelling were evaluated by the eigenvalues of Hessian matrix formed by Jacobian matrix, which was defined with the partial derivatives of output responses with respect to parameters. Also, the linear dependences between selected two parameters were analyzed by calculating the condition number of matrix, which was formed with two selected columns of Jacobian matrix corresponding to two parameters. Ref. [4] has presented a new algorithm for estimating the composite load model parameters based on the analytical similarity of model parameter sensitivity and demonstrated its computational efficiency and unharmed

* Corresponding author.
E-mail addresses: eshragh@igmc.ir (M.E.-N. Jahromi), m_ameli@sbu.ac.ir (M.T. Ameli).

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accuracy for ten field measurements: the proposed algorithm effectively reduces the number of the parameters to be identified without compromising the desired complexity of the model, providing comparable accuracy with less than three quarters of computation time in the same computing environment (MATLAB running in Intel Quad-Core, 3.6 GHz) with reference to a conventional method through theoretical investigation and extensive validation studies using real measurements. Analysis performed in Ref. [5] showed that using the standard model of the load for simulating the behaviour of a power system during the occurrence of a fault leads to unacceptable results. The static load model known as ZIP (constant impedance, constant current and constant power) is often traditionally used in power system simulations. However the ZIP simulations containing deviation in the results are inefficient in comparison to the results of the field test.

Ref. [6] has better confirmed the necessity and importance of load modelling and concluded that using the composite load model for dynamic instability analysis is more accurate than the other models. To obtain non-linear load characteristic during recovery of the voltage, a non-linear structure for the model was proposed by Hill [7]. Later the model of the load was proposed according to nonlinear dynamic equations by Karlsson and Hill.

It's not possible to simulate the unstable behaviour of power system during a fault by using of standard load model [8]. In Ref. [9] expressed two dynamic structures of the measurement based load model, as first-order and second-order transfer function, and specified that the load model with the second-order transfer function represents the load characteristic better than the first order one. Lesieutre compared various dynamic load models in Ref. [9] and obtained a PQ model from the third order model of induction motor. It has recently been attempted to combine the dynamic model with the static model. Ref. [10] presents a modelling approach for capturing closed-loop load behaviour in distribution networks using bottom-up time-variant load models and incorporating load-flow feedback for thermal loads. The methodology uses high-resolution bottom-up load models, with time-variant composite load models based on appliance level ZIP load surveys. Physical based models of residential loads, such as heating and cooling appliances, have been modelled for demand response studies in Ref. [11]. Ref. [12] presents a measurement-based methodology for modelling the loads under unbalanced disturbances. Ref. [13] presents an experimental study on modelling the loads in a university environment by using measurements obtained from the PMUs. Both static and dynamic load models are considered and the load model parameters are found by minimizing the sum of square of errors between the measurement and the model output by using suitable optimization algorithm. In Ref. [14] the bottom-up, Time-Use Survey (TUS) based, Monte Carlo demand model found in Ref. [15] is further developed by creating Markov Chain Monte Carlo activity dependency and a library of electrical appliance characteristics is added to create a time-varying composite load model.

One of the most important conditions that the load modelling should be carefully considered, is after voltage disturbances in power systems. So in this article, the process of load modelling is performed with obtaining the values of V, P and Q of the load after a voltage disturbance, and then the parameters of the load model calibrated via genetic algorithm so that the sum of squared error between the simulated and measured values of P and Q becomes minimal. Also, the another contribution of this paper is that, after obtaining the load model parameters corresponding to each of the scenarios, various values obtained for the parameters are averaged. Finally, the validity of the obtained parameters is testified with some other scenarios. According to the obtained results, the efficiency of the proposed method has been approved. Detailed modelling techniques and mathematical representation of loads and their voltage response is presented in voltage disturbance condition. A set of comprehensive case studies are conducted on a 39-bus test system and the obtained numerical evidences are thoroughly discussed.

The rest of the paper is outlined as follows. Section 2 demonstrates the modelling technique of the load. Section 3 reveals the load modelling stages. In Section 4 simulation results and numerical evidences are presented and the paper is concluded in Section 5.

2. Modelling techniques of the load

Two methods are commonly used for the load modelling: Component-based method and measurement-based method. Component-based approach begins from individual load components to obtain an integrated response from the load at a higher voltage level. This method has an obvious physical meaning because it makes the concentrated load using each components of the load model. However, it is difficult to obtaining the data of combined load, especially for large power systems.

The theoretical basis of measurement-based method is the system identification. This method measures the dynamic responses of the electric load under a perturbation in the measurement system, and obtains a set of parameters through the optimization of an objective function. Optimization is done to minimize the differences between the simulated and measured dynamic responses. Measurement based method is easier in practice. However this is only a model of the input–output that may take any mathematical form and does not include any physical concept for power system [2–5].

Fig. 1a–c show the real measurements at Hushitai substation in Liaoning Province of china. The voltage disturbance is shown in Fig. 1(a), and the variations of the active load as well as the reactive load are shown in Fig. 1(b) and (c), respectively. From the figures it can be seen clearly that during the steady states, i.e., when there is no voltage disturbance, the active load and the reactive load keep their constant values. That is why the load is modelled as the PQ node in the power flow analysis. However, when the voltage varies due to the disturbance, the load changes with respect to the voltage variation.

Traditionally, the load is modelled as the combination of the constant impedance, the constant current and the constant power, which is called the static load model. With the increased complexity of the power system dynamics, it is required to model the load in more accuracy. Consequently, the dynamic load model is developed. Currently, the composite load model consisting of the static part and the dynamic part is widely used in the power system analysis and control. Two methods have been suggested to derive the composite load model parameters [2–4]. One is the component-based approach while the other is the measurement-based approach. To derive a component-based load model, one has to know the details of the load mixture and the load composition, which is, however, hard to be accurately estimated. It is also very difficult to derive the equivalent of the load in total even the dynamic characteristics of each individual load component are well known. Compared to the component-based load modelling method, the measurement-based load model is much easier to be implemented in power engineering. Since the load model describes the functional relationships of the consumed load active power and reactive power with respect to the voltage and the frequency variations, the bus voltage, frequency and the bus load are recorded in the power substation. Then the load model parameters are identified to fit the model outputs to the recorded measurements. However, no matter which approach is applied for building the load model, there always exist a basic but very tough question, i.e. is the load model valid if the operation scenarios when the load model is