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Nonlinear state space model identification of synchronous generators

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Abstract

A method for identification of a synchronous generator is suggested in this paper. The method uses the theoretical relations of machine parameters and the Prony method to find the state space model of the system. Such models are useful for controller design and stability tests. The proposed identification method is applied to a third order model of a synchronous generator. In this study, the field voltage is considered as the input and the active output power and the rotor angle are considered as the outputs of the synchronous generator. Simulation results show good accuracy of the identified model.

Keywords: Identification; Synchronous generators; Nonlinear model; State space model; Prony method; Regression equation

1. Introduction

The increasing complexity of modern power systems highlights the need for advanced identification techniques. The identified model is used to design an effective controller. Obviously, more accurate model leads to more accurate controller design and satisfactory results are obtained [1].

Among the power system elements, synchronous generators play an important role in the stability of the power systems. A proper model for synchronous generators is essential for a valid analysis of stability and dynamic performance.

There are three approaches for modeling the synchronous generators [2]: white-box modeling [3,4], grey-box modeling [5–7] and black-box modeling [8–13]. The first method is based on off-line tests and the second and the third methods are based on on-line measurements.

The white-box modeling refers to some methods such as the traditional methods of modeling the synchronous generators [3,4]. These methods assume a known structure for the synchronous machine. They address the problem of finding the parameters of the assumed structure. Usually the procedures involve difficult and time-consuming tests, such as short-circuit tests, stand-still frequency response (SSFR) and open circuit frequency response (OCFR) tests. These tests can be carried out when the machine is not in service. This is the main disadvantage of these methods.

To overcome this disadvantage, identification methods based on on-line measurements have gained attention during recent years [5–13].

In the grey-box modeling, one assumes a known structure for the synchronous machine, as the traditional methods, and then the physical parameters are estimated from on-line measurements. In black-box modeling, the structure of the model is not assumed to be known a priori. The only concern is to map the input data set to the output data set.

In the last two decades, there have been significant advances in modern control theory. Techniques that can take in to consideration the plant uncertainties such as LMI, H_∞ and μ-synthesis have gained attention [14,15]. Due to the complexities of these approaches, a low order model which consideres the most important dynamics of the system, is very useful for controller design. Some papers

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refer to the system order reduction to make it more useful for practical purposes [16], but the order reduction method decreases the controller performance in some aspects.

In this paper, the aim is to identify a grey-box model for a synchronous generator. Such a model can be used for system analysis and controller design. The model is based on the theoretical relations between the synchronous machine parameters, so it consideres the physical meaning of each parameter.

To avoid complexity, the known nonlinear model of order three is assumed for the system. The model is quite accurate for studying low-frequency oscillations and stability of power systems. It has also been successfully used for designing classical power system stabilizers (PSSs), too [7].

There are some obvious nonlinear terms in the state space synchronous generator model of order three. In this paper, these nonlinearities are considered and the unknown related parameters are identified.

Most of the previous works done on the topic of synchronous generator parameter estimation [5–7], can only be applied to the linear system model parameter estimation. In ref. [2] a method is suggested for the synchronous machine parameter estimation, which results in some nonlinear set of equations. In each test, the nonlinear set should be solved numerically. Furthermore, the algorithm does not discuss the conditions in which the system of equations can be solved. In some situations, the algorithm may result in a singular set of equations and no solution can be found.

The algorithm derived here to extract nonlinear state space model of a synchronous generator, is a straight forward algorithm for implementation. It requires online measurement of signals with the generator in service. It uses the theoretical background of the state space model and directly finds the nonlinear model. Furthermore, a parametric solution for each parameter is derived. At last, three regression equations, based on online measurements, are needed to find the model, so it is a simple method for implementation.

The paper is organized as follows: the study system used in this paper and the identification method are described in Sections 2 and 3, respectively. The method is applied to a simulated model of a synchronous generator in Section 4. Section 5 concludes the paper.

2. The synchronous generator model

A synchronous generator connected to an infinite bus through a transmission line (Fig. 1), is considered as the study system.

It is assumed that the field voltage, rotor angle and the electrical power can be measured. The procedure for rotor angle measurement can be found in ref. [17].

Applying a small perturbation to the field voltage, the above mentioned signals are measured and used in an algorithm to identify the third order model parameters.

The third order nonlinear model derived in refs. [18,19] is used in this paper. All the parameters are assumed to be defined in per unit values. The model is described by the following nonlinear equations:

$$\begin{aligned} \dot{\delta} &= \omega \\ \dot{\omega} &= \frac{1}{J}(T_{\mathrm{m}} - T_{\mathrm{e}} - D\omega) \\ \dot{e}'_{\mathrm{q}} &= \frac{1}{T'_{\mathrm{do}}}(E_{\mathrm{FD}} - e'_{\mathrm{q}} - (x_{\mathrm{d}} - x'_{\mathrm{d}})i_{\mathrm{d}}) \end{aligned} \tag{1}$$

where

$$i_{\mathrm{d}} = \frac{e'_{\mathrm{q}} - V\cos\delta}{x'_{\mathrm{d}}} \tag{2}$$

$$i_{\mathrm{q}} = \frac{V\sin\delta}{x_{\mathrm{q}}} \tag{3}$$

$$T_{\mathrm{e}} = P_{\mathrm{e}} \cong \frac{V}{x'_{\mathrm{d}}}e'_{\mathrm{q}}\sin(\delta) + \frac{V^2}{2}\left(\frac{1}{x_{\mathrm{q}}} - \frac{1}{x'_{\mathrm{d}}}\right)\sin(2\delta) \tag{4}$$

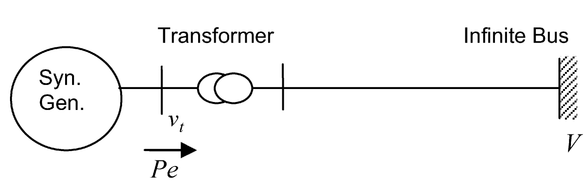

Fig. 1. Structure of the study system.