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Development of synchronous generator saturation model from steady-state operating data

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ABSTRACT

A new method to estimate and model the saturated synchronous reactances of hydroturbine generators from operating data is presented. For the estimation process, measurements of only the generator steady-state variables are required. First, using a specific procedure, the field to armature turns ratio is estimated from measured steady-state variables at constant power generation and various excitation conditions. Subsequently, for each set of steady-state operating data, saturated synchronous reactances are identified. Fitting surfaces, defined as polynomial functions in two variables, are later used to model these saturated reactances. It is shown that the simpler polynomial functions may be used to model saturation at the steady-state than at the dynamic conditions. The developed steady-state model is validated with measurements performed on the 34 MVA hydroturbine generator.

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1. Introduction

Many papers have been published on determination of the saturated synchronous reactances of the synchronous machines [1–12]. In earlier studies, investigators have used one saturation factor or two different saturation factors obtained from the open-circuit characteristic for modifying the *d*- and *q*-axis reactances [1–3]. In these approaches, the effect of cross-magnetizing phenomenon is totally ignored and because of that the accuracy of the machine saturated reactances is found to be poor. In [4], a model has been presented for the *d*- and *q*-axis synchronous reactances in which the effect of both the *d*- and *q*-axis saturation factors and the cross-magnetizing are included separately, and the accuracy of the machine reactances is found to be good. In this paper, a specially designed salient-pole synchronous machine has been under the test. Subsequently, in [5] analytical approaches are proposed to determine parameters, that represent the cross-magnetizing effect from the *d*- and *q*-axis saturation curves of conventional synchronous machines. Thus, the problem of determination of the synchronous reactances is solved if the *d*- and *q*-axis saturation curves are known. A method for determination of saturated synchronous reactances by considering cross-magnetizing phenomenon using finite element technique has been presented in [6].

Another approach to determine the saturated synchronous reactances, which includes cross-magnetizing phenomenon, is based on the synchronous machine operating data [7–11]. In these references, an approach has been proposed, which uses the time domain on-line small disturbance data for estimating the saturated synchronous reactances. The unsaturated reactances are estimated first using the light load and underexcited conditions. The saturated synchronous reactances are then identified based on a wide range of operating conditions. In [10] and [11], an artificial neural network based estimator is used to model these saturated reactances. However, in some cases, it is not possible to achieve linearity with the machine operating at light load and underexcited conditions, and estimation procedure does not work when linearity is not satisfied.

In this paper a new approach for identification and modelling of the saturated synchronous reactances of synchronous machines is proposed. This approach is based on a specific procedure, which is used to estimate the field to armature turns ratio from collected steady-state operating data. Thus, the measurements of steady-state variables are needed only. From steady-state operating data at a wide range of operating conditions, the saturated synchronous reactances are estimated and modelled using fitting surfaces defined as polynomial functions in two variables. To verify the developed steady-state saturation model the simulation studies have been conducted.

2. Description of measurements

The measurement configuration that has been used for the tests is shown in Fig. 1. This measurement configuration, designed as a system for recording large disturbances and testing methods for on-line parameter identification of the synchronous machines, is installed on the 34 MVA generator of Peruca hydroelectric power

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