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Simulation of a Self-excited Three-phase Induction Generator Using the EMTP/ATP

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Abstract

Three-phase self-excited induction generators (SEIGs) are often used as energy conversion devices in micro-grids for renewable energy sources such as wind, pico-hydro, bio-gas, etc. A three-phase SEIG is modeled in this paper using the Alternative Transients Program (ATP), which is a version of the Electro-Magnetic Transients Program (EMTP) commonly used in universities and private/governmental power companies. The generator's performance at different excitation, rotating speeds and loading conditions is to be studied. Although modeling of SEIG has been well documented in literature, few have reported the use of ATP to model the SEIG, leaving several important functions of this powerful tool untapped for renewable energy applications. To bridge this gap, examples of how to model and simulate an SEIG with balanced and unbalanced loading conditions are presented. Results obtained by the analytical model, experiments and ATP simulation will be compared.

Keywords: EMTP/ATP; Induction Generators; Modeling; Micro-grids, Unbalanced Loading

1. Introduction

Induction generators (IGs) have been largely used in the areas of wind, pico-hydro and bio-gas power generation because of IGs' low costs and high flexibility to operate at variable speeds. The voltage and frequency of a self-

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excited induction generator (SEIG) are influenced by three factors: rotational speed, excitation capacitance and load, making analysis of an SEIG more complicated than that of a grid-connected IG. Several studies [1-5] have analyzed the SEIG in the steady-state, which include the cases of single-phase excitation capacitor and/or single-phase load. The problem of single-phase load supplied by a three-phase SEIG was also studied by Alolah and Alkanhal [6], and by Wang and Cheng [7]. It merits mentioning a two-port network model proposed by Wang and Huang [8] that applies to general unbalanced loading of a three-phase SEIG. To balance a three-phase SEIG supplying a single-phase load, Wang and Lee [9] proposed a method to rectify the load unbalance.

It is noted that most studies in [1-9] modeled the SEIG in the steady-state. The dynamic characteristics of the SEIG were simulated using the state variable models, among which Kumar and Kishore [10] modeled an SEIG in the state space, and Jayalakshmi and Gaonkar [11] gave state-equations of a wind-driven SEIG. Both [10] and [11] were modeled on Matlab/Simulink.

Modeling induction motors using the Alternative Transients Program (ATP) is well documented in the literature but ATP is rarely used for modeling the SEIG because of lack of experience. Rusnok et al. [12] has reported their experience of using ATP to simulate an SEIG. In their work, an initially charged capacitor was used to excite an SEIG to successfully build up voltage. The work of Rusnok et al. did not consider the magnetic saturation of the generator and modeled the SEIG using one of the universal machine (UM) modules of the ATP with a fixed value of magnetizing inductance. In this paper, the UM module with nonlinear saturable magnetizing reactance is considered by approximating the magnetization curve with two straight lines featured by the remanence, the unsaturated and saturated inductances, and the knee point at which magnetic saturation starts. A 1/2 Hp cage induction motor working as an SEIG is taken as an example. The results obtained from the ATP SEIG model, the analytical model, and the experiments are compared.

2. Modeling of SEIG in ATP

The basic principle of the SEIG can be explained by the single-phase equivalent circuit shown in Fig. 1(a) in which V_g is the air-gap voltage, I_m the magnetizing current, F and v the per-unit frequency and per-unit speed, X_r and R_r the rotor reactance and resistance, X_s and R_s the stator reactance and resistance, X_C the excitation capacitive reactance, Z_L the load impedance, and X_m the magnetizing reactance. X_m is saturable, which causes the magnetizing curve to intersect the load line at the working point of the generator, as shown in Fig. 1(b). The generator performance can be analyzed by solving the circuit of Fig. 1(a) if the three-phase load is balanced. For the case of unbalanced loading, ref. [8] provides an analytical method based on a two-port network model. Another method of analyzing an SEIG is to resort to a simulation tool. In this paper, the SEIG is modeled in the ATP environment.

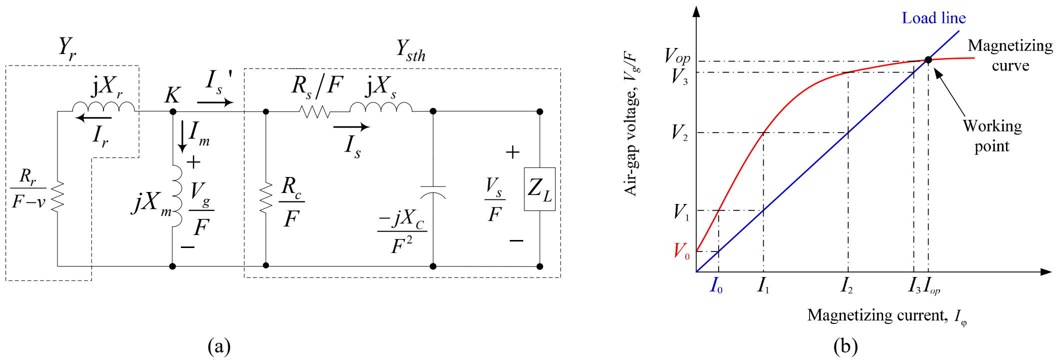

Fig. 1. (a) Single-phase equivalent circuit of an SEIG; (b) voltage building-up of the SEIG.

ATP has three modules available for simulating the induction machine: the type-56 induction machine, the UMIND (universal induction machine with manufacturer's data input) and the UM (universal machines), among which the UM module is perhaps the most widely used for its ease of learning and preparing data.

The SEIG differs from an ordinary induction motor mainly in its working condition that the generator's iron core goes more deeply into saturation than a motor. This explains why saturation of the magnetizing reactance of the