Research Article

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Field-circuit analysis and measurements of a single-phase self-excited induction generator

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Abstract: The paper deals with a single-phase induction machine operating as a stand-alone self-excited single-phase induction generator for generation of electrical energy from renewable energy sources. By changing number of turns and size of wires in the auxiliary stator winding, an improvement of performance characteristics of the generator were obtained as regards no-load and load voltage of the stator windings as well as stator winding currents of the generator. Field-circuit simulation models of the generator were developed using Flux2D software package for the generator with shunt capacitor in the main stator winding. The obtained results have been validated experimentally at the laboratory setup using the single-phase capacitor induction motor of 1.1 kW rated power and 230 V voltage as a base model of the generator.

Keywords: induction generator, single-phase, field-circuit modeling, performance characteristics, simulation

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1 Introduction

Performance characteristics of single-phase induction generators usually have been improved by introducing power electronics to vary capacitance of an excitation capacitor without changing design of the generator itself. To investigate steady-state performance characteristics of the single-phase induction generators, circuit models based on field revolving theory are commonly used with taking saturation into account [1–3]. To study transients phenomena in the generators, two axis dq model with saturation included may be used [4]. A comprehensive simulation model valid both for steady-state and transients may be obtained only by field-circuit modeling of the induction generators. Such field-circuit models can be found in recent papers [5–9]. They allow to analyze all relevant electromagnetic phenomena in induction machines and usually yield more accurate results but are more expensive in terms of computing time. A study of the phenomena occurring in the single-phase induction generators by field-circuit models have cognitive importance since not enough space is devoted so far to voltage self-regulation and self-excitation requirements from design point of view of the single-phase induction generators.

2 A field-circuit model of the generator

The single-phase capacitor induction motor of 1.1 kW, 230 V, employed for stand-alone generating operation has 4 poles and 30 skewed rotor bars. The ratings of the induction machine are listed in Table 1.

<table>
<thead>
<tr>
<th>Table 1: Ratings of the single phase induction machine</th>
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<tr>
<td>Rated power</td>
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<td>Rated voltage</td>
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<td>Rated current</td>
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<td>Rated speed</td>
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<td>Run capacitor</td>
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<td>Frequency</td>
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Taking into consideration geometrical symmetry and electromagnetic periodicity of the machine, two-dimensional magnetic field computation of the generator was reduced to two pole pitches of the cross-section. The FE model of the generator accounts for nonlinear magnetizing characteristic of the magnetic core (Figure 1) and skin-effect in the rotor bars. The finite element mesh of
3 Self-excitation transients of the generator

The single-phase four poles induction machine operating as a single-phase self-excited induction generator (SPSEIG) was modeled applying 2D vector potential formulations of magnetic field in cross-section of the induction generator. The field-circuit model of the generator was described in detail in [5]. Self-excitation transients of voltages and currents of stator windings obtained by measurements at no-load and speed \( n = 1620 \) rpm for \( N_A = 444 \) and 424 turns, and excitation capacitor \( C_{ex} = 40 \) \( \mu \text{F} \) with capacitor \( C_{sh} = 20 \) \( \mu \text{F} \) connected in parallel to terminals, are presented in Figures 3-6.

From the above magnified transients it is clear seen distortion of the stator winding currents due to saturation of magnetic core of the generator at no-load conditions, especially in the main stator winding.

In order to ensure nominal voltage at terminals of the main stator winding for \( N_A = 424 \) turns, it is necessary to apply larger excitation capacitor, e.g. \( C_{ex} = 40 \) \( \mu \text{F} \) and

\[
\text{curl} (\mathbf{\nu} \cdot \text{curl} \mathbf{A}) = \begin{cases} J_S & \text{in stator windings} \\ J_b - \sigma \cdot \frac{\partial \mathbf{A}}{\partial t} & \text{in rotor bars} \\ 0 & \text{in air, iron core and shaft} \end{cases}
\]
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Figure 4: Self-excitation: a) no-load voltage and b) current of excitation stator winding, for $N_A = 444$, $C_{ex} = 40 \ \mu F$, $C_{sh} = 20 \ \mu F$

Figure 5: Self-excitation: a) no-load voltage and b) current of main stator winding, for $N_A = 424$, $C_{ex} = 40 \ \mu F$, $C_{sh} = 25 \ \mu F$

Figure 6: Self-excitation: a) no-load voltage, and b) current of excitation stator winding, for $N_A = 424$, $C_{ex} = 40 \ \mu F$, $C_{sh} = 25 \ \mu F$
4 Steady-state performance characteristics of the generator

For validation of the simulation field-circuit model of the generator, computed load characteristics of the tested single-phase self-excited induction generator for reduced number of turns in the excitation stator winding \( N_A \) and suitable capacitor connected to the load stator winding, are compared with experimental results in Figures 7-10. Operating characteristics of the base model of the generator \( N_A = 528, C_{ex} = 30 \, \mu F, C_{sh} = 15 \, \mu F \) and the models with reduced number of turns in the excitation winding were measured using the test setup shown in Figure 11.

Load characteristics of base model of the generator with shunt capacitor in the main stator winding, obtained by simulations and measurements were presented in Figures 12 and 13.
5 Conclusions

For the sake of inconvenience caused by necessity of applying two different circuit models, separate for transients and steady-states performance of the generator, and owing to comprehensiveness of field-circuit analysis, the two-dimensional field-circuit model of the single-phase induction generator was implemented for computation of performance characteristics for transients and steady-state operation. The reduction of number of turns of the excitation winding of the base model causes profitable reduction of voltage magnitude to about 300 V, which for the original excitation stator winding reaches above 400 V. Limitation in reduction of induced voltage in the auxiliary stator winding results from restriction of increase of current in the stator winding. Some discrepancy between the simulation and experimental characteristics, noticeable outside the range of stable operation of the generator, are caused mainly by difference between real and calculated magnetization characteristic of the magnetic core and also due to omitting iron losses in magnetic core of the generator in calculation of performance characteristics.

References