Improving performance of a single-phase self-excited induction generator by modification of an excitation winding

Abstract. The paper deals with single-phase induction machine operating as a self-excited induction generator which may be used to generate electrical energy from non-conventional energy sources. Performance characteristics of the self-excited generator with capacitor connected to the both stator windings under load operating conditions are computed by field-circuit method. By changing number of turns and size of wires of the auxiliary stator winding, considerable improvement of performance characteristics of the generator were obtained with respect to no-load voltage and under load condition. Furthermore, an influence of corresponding changes in the excitation stator winding on voltage magnitude induced in excitation winding, winding currents and output power of the generator for two capacitor topology in the main stator winding have been presented. The obtained simulation results may be useful in designing the self-excited induction generator on the base of single phase capacitor induction motors.

Keywords: induction generator, single-phase, field-circuit modelling, performance characteristics, excitation winding

Stowia kluczowe: generator indukcyjny, jednofazowy, modelowanie polowo-obwodowe, charakterystyki pracy, uzwojenie wzbudzenia

Introduction

Small power self-excited single-phase induction generators (SPSEIGs), driven by wind turbine may be employed as an extra source of electrical energy at household. The self-excited induction generators compare favourably with synchronous, permanent magnet or DC generators as regards simplicity, durability, and low costs of manufacturing and maintenance. Their main disadvantages are unpredictable residual magnetism and weak voltage self-regulation [1, 2, 5, 7]. Field-circuit models of the induction generators can be found in recent papers [3,4,6]. No-load and load characteristics of the SPSEIGs may be inherently improved by a proper change of the magnetic circuit, windings and capacitor topology used in stator windings. The voltage regulation can also be improved with use of power electronics-based scheme [2].

The improvement of performance characteristics of the base model of induction generator (N_a=528, d=0.45mm, C_e=30μF, C_w=15μF, C_{se}=200μF) constructed on the base of single-phase induction motor (Tab. 1) has been presented for two capacitor topology in the load stator winding (Fig. 2).

Field-circuit model of the generator

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

Due to geometrical symmetry and electromagnetic periodicity, two-dimensional magnetic field computation of the generator was reduced to one pole pitch of the cross-section shown in Fig. 1. The finite element mesh of the generator comprises 25752 nodes forming 11244 second-order triangular and quadrangular elements. The time step for the FEM computation was 0.4 μs. The developed model of the generator accounted for nonlinear magnetizing characteristic of the magnetic core and skin-effect in the rotor bars [3, 8].

\[ \mathbf{A}(0,0,A(x,y,t)) \] is the magnetic vector potential, \( \mathbf{J}_S \) – the current density in the stator slots, \( \mathbf{J}_0 \) – the current density in the rotor bars, \( \sigma \) – electric conductivity.

Figure 1. FE mesh of 2D field-circuit model of the SPSEIG

The 2D magnetic field in the induction generator is determined by the equations:

\[ \text{curl}(\nabla \cdot \mathbf{A}) = \mathbf{J}_S - \sigma \frac{\partial \mathbf{A}}{\partial t} \quad \text{in stator windings} \]

\[ \mathbf{J}_0 \quad \text{in rotor bars} \]

\[ 0 \quad \text{in air, iron core and shaft} \]

where \( \mathbf{A}(0,0,A(x,y,t)) \) is the magnetic vector potential, \( \mathbf{J}_S \) – the current density in the stator slots, \( \mathbf{J}_0 \) – the current density in the rotor bars. The above field equations coupled with voltage equations of stator and rotor windings were solved simultaneously to

Table 1. Ratings of the single phase induction machine

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated power</td>
<td>1.1 kW</td>
</tr>
<tr>
<td>Rated voltage</td>
<td>230 V</td>
</tr>
<tr>
<td>Rated current</td>
<td>7.5 A</td>
</tr>
<tr>
<td>Rated speed</td>
<td>1380 rpm</td>
</tr>
<tr>
<td>Run capacitor</td>
<td>30 μF</td>
</tr>
<tr>
<td>Frequency</td>
<td>50 Hz</td>
</tr>
</tbody>
</table>
obtain voltages and currents induced in the stator and rotor. Having the variables $A$ and $J$ computed, the other quantities of electromagnetic field as magnetic flux, magnetic induction (flux density), etc. may be determined taking into account the magnetization characteristic of iron sheets of magnetic core of the generator.

**Performance characteristics**

Steady-state performance characteristics of the SPSEIG were computed for two topology of the load stator winding: with parallel connected capacitor to the terminals (the shunt capacitor $C_{sh}$) and short-shunt connection (the shunt capacitor $C_{sh}$ and series capacitor $C_{se}$), as shown in Fig. 2.

a) ![Fig. 2 Capacitor topology in the load stator winding: a) shunt connection, b) short-shunt connection](image)

b) ![Fig. 2 Capacitor topology in the load stator winding: a) shunt connection, b) short-shunt connection](image)

For comparison of performance characteristics it was assumed that for the both analyzed capacitor configuration, the terminal voltage is nominal (230V) for synchronous rotor speed at no-load operation. It obviously needed selection of adequate capacitors connected (in series or parallel) to the stator windings.

Load characteristics of the single-phase self-excited induction generator for decreased number of turns in the excitation stator winding ($N_A$), different diameters of the wires (d) and capacitors connected to the load stator winding are presented in Figures 3-6.

![Fig. 3. Terminal voltage ($U_L$) versus output power of the SPSEIG with shunt capacitor in load stator winding](image)

![Fig. 4. Voltage of excitation stator winding ($U_A$) versus output power of the SESPIG with shunt capacitor in load stator winding](image)

![Fig. 5. Terminal voltage ($U_L$) versus output power of the SPSEIG with short-shunt capacitors in load stator winding](image)

![Fig. 6 Voltage of excitation stator winding ($U_A$) versus output power of the SESPIG with short-shunt capacitors in load stator winding](image)

**Validation of the simulation method**

For experimental validation of the field-circuit model used for performance simulation of the single-phase self-excited induction generator, operating characteristics of the base model were measured using the test setup described in [3]. Load characteristics of the generator with shunt capacitor in the main stator winding presented in Figs. 7, 8 show that the generator operates stably for resistive load up to the about 50% of the machine rated power.
Table 2. Parameters of the generator at no-load and n = 1620 rpm for different numbers and sizes of excitation stator winding

<table>
<thead>
<tr>
<th>C_{ex} (μF)</th>
<th>C_{sh} (μF)</th>
<th>N_{s}</th>
<th>a</th>
<th>(d) [mm]</th>
<th>(U_{m}) [V]</th>
<th>(I_{m}) [A]</th>
<th>(J_{t}) [A/mm²]</th>
<th>(k_{0}) [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>15</td>
<td>528</td>
<td>1.44</td>
<td>2 x 0.45mm</td>
<td>227</td>
<td>1.16</td>
<td>3.82</td>
<td>12.01</td>
</tr>
<tr>
<td>40</td>
<td>15</td>
<td>424</td>
<td>1.15</td>
<td>2 x 0.5mm</td>
<td>233</td>
<td>1.14</td>
<td>4.25</td>
<td>10.82</td>
</tr>
<tr>
<td>35</td>
<td>20</td>
<td>444</td>
<td>1.21</td>
<td>2 x 0.45mm</td>
<td>237</td>
<td>1.55</td>
<td>3.78</td>
<td>9.63</td>
</tr>
<tr>
<td>40</td>
<td>20</td>
<td>444</td>
<td>1.21</td>
<td>2 x 0.5mm</td>
<td>234</td>
<td>1.61</td>
<td>4.43</td>
<td>11.29</td>
</tr>
</tbody>
</table>

Load range of the SPSEIG may be extended by applying the short-shunt capacitor topology, e.g. the capacitor 200 μF connected in series with the main stator winding and then the generator may be loaded up to the rated power when load is purely resistive (Figs. 9, 10).

Fig. 7. Voltages versus output power of the SPSEIG with shunt capacitor in load stator winding

Fig. 8. Currents versus output power of the SPSEIG with shunt capacitor in load stator winding

It should be noticed very good agreement of the simulation characteristics with experimental ones in the range of stable operation of the generator.

Conclusions

The calculation of performance characteristics of the single-phase self-excited induction generator were carried out by applying the 2D field-circuit modeling. To expand output power of the generator up to the nominal power of the machine, the short-shunt capacitors should be employed. The decrease of number of turns of the excitation winding causes profitable reduction of voltage magnitude in the auxiliary stator winding. The increase in size of wires of the excitation winding, brings about decrease of current density and working temperature of the excitation winding.

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REFERENCES


