General study of self excited induction generator used in isolated renewable energy conversion source


Abstract—In this paper we have present a general study of self excited induction generator used in isolated renewable energy conversion source, the behavior of generated voltage under variable load, rotor speed and excitation capacitance is presented, and we have proposed a robust controller suitable in order to control the terminal DC voltage under different speed and AC load conditions for supplied an isolated DC load, the experimental characteristic curve of the generator and simulation result of proposed control scheme are presented.

Keywords—Renewable energy, Self-excited induction Generator, DC link control.

I. INTRODUCTION

The energy demand around the world increases the great opposition facing the nuclear energy in some countries have spur researchers attentions for renewable energy. The self excited induction generator is a very popular machine used in isolated areas to generate electrical energy because of its low price, mechanical simplicity, robust structure. When capacitors are connected across the stator terminals of an induction machine, and driven at a given speed, the voltage will be induced from a remnant magnetic flux in the core.

The induced emf and current in the stator windings will continue to rise until steady state is attained. This behavior is influenced by the Magnetic saturation of the machine. At this operating point the voltage and current will continue to oscillate at a given peak value and frequency[6], However, its major disadvantage is the inability to control the terminal voltage under variable load and speed conditions.

The objective of this work is divided into two parts: in the first part we present the experimental curve of variation speed and capacitance with the SIEG connected to load and no load in order to show the behavior of our machine, The relationship between magnetizing inductance (Lm) and phase voltage for induction machine was obtained experimentally, and in the second part we are more interested in the control of the DC bus voltage in order to provide an essentially constant terminal DC voltage in spite of the presence of disturbances such as step change in rotor speed and application of sudden AC load for supplied an isolated DC load, the simulation results are given to demonstrate the effectiveness of the proposed method.

II. SYSTEM CONFIGURATION WITHOUT CONTROL SCHEME

The proposed system starts excitation process from capacitors bank which are connected across the stator terminals of an induction machine driven by unregulated prime mover (DC motor in laboratory test) and supplying AC load.

When the induction machine when used for motoring application, it is important to determine the magnetizing inductance at rated voltage. In the SEIG, the variation of
magnetizing inductance $L_m$ is the main factor in the dynamics of voltage build up and stabilization[3].

The relationship between magnetizing inductance ($L_m$) and phase voltage for induction machine was obtained experimentally as shown in Fig 3:

the magnetizing inductance is calculated by driving the induction machine at synchronous speed and taking measurements when the applied voltage was varied from zero to 100% of the rated voltage.

![Fig.2: Variation of magnetizing inductance with phase voltage](image)

The variation of magnetizing inductance, increases until it reaches a peak value and decreases until it attains saturated value as shown in Fig.2.

**A. Self Excited induction Generator**

The state-space form of the induction generator in the q-d synchronously rotating reference frame is given by[3]:

$$A = \frac{1}{L} \begin{bmatrix} L_m K_q - L_m V_{eq} & L_m R_q - L_m W_r & L_m R_r - L_m W_r & L_m R_r \\ L_m K_d - L_m V_{eq} & L_m W_q - L_m W_r & L_m W_r & L_m R_r \\ L_m V_{eq} - L_m K_q & L_m V_{eq} - L_m K_d & L_m W_r & L_m R_r \\ L_m V_{cd} - L_m K_d & L_m V_{cd} - L_m K_d & L_m R_r & L_m R_r \end{bmatrix}$$

$$B = \begin{bmatrix} -L_r R_q - L_m^2 W_r & L_m R_q - L_m W_r & L_m R_r - L_m W_r & L_m R_r \\ -L_r R_q & L_m W_q - L_m W_r & L_m W_r & L_m R_r \\ -L_r R_q & -L_r R_q & L_m W_r & L_m R_r \\ -L_r R_q & -L_r R_q & -L_r R_q & L_m R_r \end{bmatrix}$$

$$I = \begin{bmatrix} i_{qs} \\ i_{sd} \\ i_{qr} \\ i_{dr} \end{bmatrix}$$

Where:

$$L = L_q, L_s - L_m^2$$

**Where $i_{d}, i_{r}, q$ are input currents of three-phase diode bridge rectifier and $i_{rlq}, i_{rld}$ are the AC load current.**

The instantaneous amplitude of the magnetizing current of the SEIG, which is computed as:

$$i_m = \sqrt{(i_{qs} + i_{qr})^2 + (i_{ds} + i_{dr})^2}$$

**B. Experimental results of variation speed and capacitance while the SIEG is connected to load and no load**

In the laboratory test rig, a three phase squirrel cage induction machine was coupled to a DC motor operating as the prime mover.

The experimental setup includes the variation of rotor speed with capacitance bank respectively with no load and load, in this investigation for have a fixed generated voltage of 400V and 250 V as show in Fig.4 and Fig.5 respectively.

![Fig.3: d-q model of SEIG at no load](image)

$$P_l = AI + B$$
must provide a control system capable of controlling the output voltage for a good functioning.

Recently the application of semiconductor devices, controlled converter circuits, and control algorithms has resulted in suitable and good regulating schemes for SIEG. In literature many researchers have proposed numerous control for regulating the terminal voltage[2 4 5 7 10 15 17]. Since this paper present a simple and uncomplicated control scheme.

The motivation of this work is to study the feasibility of this system by providing a detailed transient and steady-state analysis in order to keep the DC bus voltage at a constant value even the rotor speed change and application of sudden AC load. Detailed Matlab/Simulink-based simulation studies are carried out to demonstrate the effectiveness of the scheme.

**III. PROPOSED CONTROL SCHEME OF SIEG**

For proper operation of the use for this machine in standalone renewable energy Source, cases (Wind-, micro hydro) we
B. Buck Converter
The DC-DC converter inputs are generally unregulated DC voltage input and the required outputs should be a constant or fixed voltage. Application of a voltage regulator is that it should maintains a constant or fixed output voltage under variation of input voltage.

\[
\frac{dI_L}{dt} = \frac{V_d}{L} (d) - \frac{V_c}{L} \quad (6)
\]

\[
\frac{dV_c}{dt} = \frac{i_L}{C} - \frac{V_c}{R+C} \quad (7)
\]

Where \( R \) = resistive load

C. Control scheme

Current-mode control is a dual loop control method, including current and voltage control loops[8]. In this method, the error signal between output voltage \( V_{dc} \) and reference voltage \( V_{dc \_ref} \) is used to generate reference current \( i_{ref} \). Then, this reference current is compared with sensed inductor current \( i_L \) to control the duty cycle As show in Figure 9

IV. SIMULATION RESULTS AND DISCUSSION

MATLAB/Simulink® modelling is used to observe the proposed control. The residual magnetism in the machine is taken into account in simulation process without which it is not possible for the generator to self excite.

The induction generator is rated at 3 kw and the system parameters approximation are given in Table I.

The SIEG is tested during 7 s, when the system is subjected to step change in the rotor speed and sudden application AC load. The proposed system starts excitation process from AC capacitors bank of 100\( \mu \)F and variation rotor speed between 1500rpm, 1096rpm to 1296rpm, respectively at 0s,3s,4s, as shown in Fig.3 in this section, for investigate the response of the system with sudden application of AC load the generator is initially excited at no-load and suddenly a AC load of \( R_{ac} = 80 \) \( \Omega \) applied at \( t = 6 \) sec
Any variation in rotor speed of the SEIG is directly indicated by the variation in the terminal voltage and current of the generator as shown in Fig.11, Fig.12.

After connecting the AC load at $t = 6s$, we see the generated current increases during this time and then decreases to its initial value then the terminal voltage dropped, the load current is created as shown in Fig.12, Fig.11, Fig.813 respectively.
The value of the DC bus voltage is maintained at constant value of 300 V even if the rotor speed changes at 3s, 4s and application of AC load at 6s. The controller provides a rapid and accurate response for the reference as shown in Fig.16 it has been demonstrated that the system is able to feed an isolated DC loads with a robust regulated voltage.

V. CONCLUSION

This paper presents a general studies of SIEG include dynamic behavior, the variation of magnetizing inductance are considered, also we propose a simple and uncomplicated control scheme in order to provide a regulated DC voltage. The controller has been tested for different transient conditions such as, sudden application for both three-phase loads, and variable rotor speed. The simulated results show a good performance and efficiency of the global SEIG conversion system.

APPENDIX

Table I: Generator and buck converter Parameters

<table>
<thead>
<tr>
<th>designation</th>
<th>value</th>
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<tbody>
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<td>$R_s$</td>
<td>2.2 $\Omega$</td>
</tr>
<tr>
<td>$R_r$</td>
<td>2.68 $\Omega$</td>
</tr>
<tr>
<td>$L_a, L_r$</td>
<td>12 mH</td>
</tr>
<tr>
<td>$C$</td>
<td>600 mF</td>
</tr>
<tr>
<td>$L$</td>
<td>50 mH</td>
</tr>
<tr>
<td>$R_{dc}$</td>
<td>120 $\Omega$</td>
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</table>

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