ABSTRACT

In the recent days, the increased emphasis is being given on the harnessing of the renewable/non-conventional sources of the energy due to the tremendous increase in the fuel cost and the depletion of the fossil fuel at a faster rate. As a result of it, the Self Excited Induction Generators (SEIGs) are receiving greater attention from the utilities for the cost effective power generation from such sources. The use of these generators could contribute to an overall cost reduction of the generating systems, as their use would avoid the necessity of the sophisticated controls such as the AVRs, governors and the emergency shut down devices. Moreover, the induction generators could be used to generate the power from a constant as well as a variable speed prime mover.

The main problems associated with the use of the SEIGs have been their poor voltage and frequency regulations. The use of such generators can only be made viable, if they are able to generate the supply with the constant voltage and the frequency under the varying loads. The other related problems in the use of the SEIGs are the loss of the excitation, the occurrence of the over voltages due to the loss of load or the switching of the capacitors. However, the squirrel cage construction in the induction machine leads to lower cost and maintenance free operation. This has motivated to facilitate the u e of an induction generator in the isolated mode with a suitable low cost control which could ensure a reliable supply of a good quality.

Such systems for the power generation could also be made efficient and cost effective to compete with the other conventional sources of the energy. In order to increase the potential applications of the SEIGs, an attempt has been made to carry out its steady state and dynamic analysis and to improve its design using a suitable optimization technique.

The steady state analysis of the SEIGs has been carried out in the different modes of the operation, to design the control system to ensure the good quality of the supply and the reliable operation of the machine. The performance characteristics of the SEIGs have been studied in terms of the terminal voltage, the output power, the stator and the rotor currents etc., for the given values of capacitance, load and speed. The excitation requirements have also been estimated in terms of the capacitances and the reactive VARs to maintain the terminal voltage within specified limits under the varying operating conditions.

The steady state analysis of the SEIG in the following modes of operation, has been carried out for the purpose of the design of a suitable control system.

1. Self Excited Induction Generator in an Isolated Mode.
2. Self Excited Induction Generator with an ac-dc-ac Link.
3. Pole Changing SEIG in an Isolated Mode.
4. Pole Changing SEIG with an ac-dc-ac Link.

The switched step capacitors have been considered to regulate the terminal voltage of the SEIG within the specified limits. The steady state performance of the SEIG in an isolated mode has been analyzed to estimate the number and size of the step capacitors needed to load the machine up to its rated capacity while maintaining the terminal voltage within the specified limits. Such a system can feed power to the frequency insensitive isolated loads. The performance characteristics of the different small rating induction machines and a specially designed line excited induction generator operating as a SEIG, have been compared in terms of their voltage regulating capabilities and the capacity utilisation. From these results, it has been observed that this specially designed generator has better voltage regulating capability because of its lower blocked rotor impedance and higher level of saturation in the machine. It has also been observed that the voltage regulating capability could be improved with the increased rating of the machine.

A SEIG with an ac-dc link has been considered to convert the variable voltage and frequency supply of the SEIG to a constant voltage and a constant frequency supply. The performance of such a system with the different configurations of the converters (such as the full wave, the half wave and the uncontrolled converters) in an ac-dc link has been analyzed to estimate the size and the number of capacitor steps, to regulate the terminal voltage of the SEIG under varying loads. These systems can feed the generated power to the isolated loads or interconnected grid.

The pole changing cage machine has been considered to increase the operating speed range of the prime movers. The steady state analysis of the pole changing SEIG has been carried out to estimate the operating speed range, the number and the size of the step capacitors in the different pole settings. Also, with the use of this method the speed range of the machine could be increased without increasing its excitation requirements.

To achieve a constant voltage and frequency supply from the SEIG driven by the variable speed prime mover, a pole changing induction generator with an ac-dc link has been considered. The steady state analysis of such systems has been carried out to estimate the number and the size of step capacitors required for a controlled and an uncontrolled converter in an ac-dc link. The step capacitors obtained in one pole setting could be used for other pole setting by connecting them in the star/delta configuration.

The dynamic analysis of an induction machine in a SEIG mode is also desirable as the steady state analysis alone is not enough to design the system for its safe and reliable operation. The loss of the self excitation due to a sudden application of a heavy load or sudden rise in the terminal voltage due to the loss of a large load at the machine terminals could only be estimated by carrying out the dynamic analysis of the machine. The knowledge of the value of transient currents is required in assessing the suitability of the machine windings. The study of the voltage profile due to the load or the capacitance

perturbations is necessary for the design of the insulation and to decide voltage ratings of the regulator components, the windings and the terminal capacitors.

For this purpose, a generalized dynamic model of the SEIG in a stationary reference frame using a d-q variable approach has been developed to analyze the dynamic performance of the SEIG. The saturation due to the main flux has been considered in the model. The currents have been used as state variables because of impedance matrix approach. With the use of this approach, the effect of the cross saturation on the impedance matrix can directly be observed. The dynamic equations have been solved using fourth order Runge-Kutta method to simulate the transient performance of a generator during the initial voltage build up, load and capacitance perturbations. The dynamic model has also been modified to include the effect of the cross saturation in addition to the saturation due to the main flux to study the accuracy of analytical results. The dynamic performance of a 3.7 kW SEIG has been simulated for the voltage buildup and the load and the capacitance perturbations. The validity of simulated results has been established by comparing the simulated results with the experimentally measured values. The dynamic performance of a specially designed line excited 6 kW induction generator as a SEIG, has also been analyzed under the normal and the abnormal operating conditions.

The parameters of a machine required to operate as an induction generator could be different than the one to operate as

an induction motor for its optimum performance. For example, a cage rotor with a low resistance is desirable for an induction generator, whereas for a motor it adversely affect its starting performance. Similarly other parameters like leakage reactance and magnetizing reactance etc. have to be carefully designed to obtain optimum performance from the induction generators. The effect of variation of the parameters of the machine on its performance in the generator mode is available in the literature. However, there is no single attempt to improve the design of the SEIG. Therefore, an optimal design of the SEIG has been achieved using the sequential unconstrained minimization technique (SUMT). The Rosenbrock's method of rotating coordinates has been employed for unconstrained minimization in SUMT. In case of the induction machines there are large number of variables from physical considerations. Out of these variables some of them are assigned to fixed values as they do not influence significantly either the objective function or the specified constraints. A set of nine basic variables has been considered and nine constraints have been imposed on the design to achieve a feasible and practically acceptable machine. The eight different objective functions consisting of the cost and the performance indices have been considered to achieve a most appropriate design of the SEIG. The comparative design data for a 3.7 kW and 11 kW machine with the performance indices for the different objective functions have been presented and discussed in detail. From the design results, it has been concluded that it is possible to obtain an induction generator with a better voltage and frequency regulation along

with the improved efficiency and a higher maximum output power. The optimally designed machine could have a better steady state and dynamic performance in addition to its higher efficiency. Such characteristic could be improved to a better extent in a higher rating machines because of its larger size and it could also be possible to regulate the terminal voltage within the specified limits using only a single capacitor. The design based on the optimum voltage regulation also has a higher efficiency, an overload capacity and a better frequency regulation. It could also be concluded that a higher rating machine have improved voltage regulation, but it will require substantially higher initial cost. However, the increase in the cost could be off set on account of the increased energy generation due to its higher efficiency over the life cycle of the machine and the minimal maintenance due to the absence of a voltage regulator. Finally, on the basis of experience with different objective functions and the design data of the two machines, the design based on the optimization of voltage regulation has been recommended for the development of the SEIG.