ABSTRACT

This World is facing the challenge of Energy crisis. At present, the conventional energy sources are estimated to be a very small fraction of the total inexhaustible renewable energy sources available all over the globe. Moreover, increasing industrialization and growing energy needs are further pressurizing the situation. Besides, the fossil fuel based energy supply is deteriorating the environment, resulting in serious situation like global warming, acid rain etc. The conventional energy resources have limited supplies and after a certain definite time period, these would be exhausted completely if the present rate of consumption continues.

The remote areas, which are away from national grid, are the worst sufferer. As far situated isolated rural areas are rich with renewable energy sources, but national grid supply cannot be extended to them due to high cost of transmission line, heavy transmission, distribution losses and the poor economic conditions of the inhabitants. Such areas have been considered for energisation through decentralized power generation using renewable energy sources like solar, wind, SHP, biomass etc. Such rural population normally requires single-phase power supply to meet their energy needs. Their main demands are for heating, lighting and other loads of daily uses.

These areas therefore need low cost, user friendly, echo friendly, maintenance free technologies for tapping renewable energy sources available in the area. The hydro resources available in remote areas especially, hilly zones have been found to be a suitable option for supplying power in decentralized mode.

The suitability of the use of an induction machine, as stand-alone generator is emerging very fast for such conditions. Traditionally, the synchronous generator is employed for all kind of energy generation starting from a very small to very high range of modern power plants. In contrast, the self-excited induction generator (SEIG) is being preferred for very small to medium size power requirements. A small single-phase induction machine can be used as a single-phase induction generator. But it is having certain limitation such as these single-phase machines are readily available in the market only up to a range of 2 kW. Over and above this range a single-phase induction machine is found uncommon, bigger in size and hence costlier. Moreover, single-phase induction machine is an unsymmetrical machine due to which it results in problems like vibration, noise, torque pulsations etc. during its operation. Therefore, a single-phase SEIG beyond 1kW rating, using a single-phase machine does not appear to be feasible.

In literature, it is reported that a single phase, single winding, induction machine used as SEIG has inferior performance compared to a specially designed single-phase, two winding SEIG. The auxiliary and main winding are excited by shunt and series capacitor across the load respectively. Though, the two winding SEIG has been reported to give good performance, but, few problems still existed such as higher voltage has been observed across its auxiliary winding, which is about 1.5 times more than the rated voltage across the load in the main winding. Another draw back of this single-phase, two winding SEIG is, its operation, at very high speed (3000 rpm), which may require high head or high-speed turbo engine as prime mover. This may

require gearbox, hence increases the cost of overall power generating system.

A three-phase induction machine, which is normally and easily available in the market, has higher efficiency compared to an equivalent single-phase induction machine is symmetrical in nature, inexpensive and can be used as a single phase SEIG covering the range of output power of 1kW and above. However, single-phase operation of a three-phase machine is a case of extreme unbalance, resulting in the problems such as heating, less power output, torque pulsation, stress on insulation, reduction in machine life, vibration of shaft etc. Such shortcomings can be overcome by proper selection of appropriate value capacitor to be placed for differently configured winding arrangement like star or delta connections.

The star and delta connected machine as single-phase SEIG with different configuration of capacitor placement have been analyzed. In order to get the maximum satisfactory permissible output with the constraint that winding currents are within the allowable limits, so as to restrict the temperature rise of the machine.

The objective of the present work is to design and develop a single-phase power source capable of generating power at the appropriate voltage level suitable for home appliances. In order to achieve this objective the steady state and transient performance of three-phase, star and delta connected induction machines, operating as single-phase, self-excited induction generator with safe permissible output and to study its performance

with a suitable induction generator controller as a single-phase isolated power source.

A 3-phase star connected machine as a single-phase SEIG has been taken for studying optimum performance characteristics, such as maximum power output, minimum unbalance etc. A parallel capacitor (C_p) is placed across the load and two capacitors (C_s) are placed in series with the two other phase windings. In order to derive a mathematical model, all phase voltages are expressed as voltage drop across each phase impedance. The phase voltages are transformed to positive and negative sequence components. The same voltage equations are expressed in terms of sequence currents and the machine sequence impedances. Further, above expressions of terminal voltage have been used to derive impedance matrix related to positive and negative sequence of stator current. The impedance matrix is used to derive steady state equivalent circuit in terms of positive and negative sequence impedance. The total impedance, as seen by positive sequence current, is minimized for unknown magnetizing reactance and generated pu frequency for the given load, speed and terminal capacitances. A generalized technique, known as Sequential Unconstrained Minimization Technique (SUMT) along with Rosenbrock's Method of rotating coordinates has been used to evaluate critical parameter like magnetizing reactance and per unit frequency necessary for determination of performance characteristic of the SEIG. The steady state performance characteristics are simulated using this technique. The experimental results are compared with simulated performance under different operating conditions.

The performance characteristics of a typical 2.2 kW, 200 V, three-phase, star connected machine with C_s-C_p capacitor configuration has been investigated. This machine generates single-phase power at phase voltage. Subsequently, delta connected three-phase machine of 3.7 kW and 6 kW, 415 V rating are also analyzed as star connected single-phase SEIG with C_s-C_p capacitor configuration. With a 3.7 kW machine, it has been observed that with series and parallel capacitor, it is not possible to obtain rated phase voltage, particularly suitable for doemstic appliances, at no load for any combination of C_s and C_p. It is also observed that the 3.7 kW machine designed for motor operation has high value of leakage and magnetizing reactance, so as to have low starting current and better power factor. However, due to high leakage reactance, the same machine generates higher voltage as a generator. The 6 kW machine appears to be a saturated machine. The simulated results of 6 kW machine indicates that this machine may be suitable for single-phase power generation at the level of phase voltage (230 V).

3-phase induction machine beyond 3.7 kW (with 6 terminals) power rating, are generally delta connected. The equivalent parameters of such machines are different from the normal (high value of leakage and magnetizing reactances) star connected machines. Therefore, it was felt necessary to carry out the investigations on delta connected machines also for single-phase power generation with the other possible excitation schemes. The, two excitation schemes, for delta-connected machines for single-phase power generation, one as C-2C and other as shunt (C_{sh}) series (C_{se}) scheme, have been explored,

In case of C-2C scheme, the value of C is obtained by optimizing equivalent impedance so as to have phase balance for given load and speed. In order to calculate the value of C, the steady state equivalent circuit of three-phase induction machine with C-2C scheme has been considered to compute equivalent impedance at the machine terminals. This equivalent impedance is derived from the inspection equation for voltage and current. The capacitor current term, in voltage equation, are eliminated by expressing them in terms of phase currents. Subsequently, the method of symmetrical components is applied to express the load voltage and current in terms of positive and negative sequence components. Zero sequence component is also eliminated from the voltage equation. The equivalent impedance is taken as ratio of the positive sequence voltage to positive sequence current. This equivalent impedance is solved for unknown X_m and F for given value of load, speed and capacitor using SUMT. In case of a three-phase machine working as single-phase SEIG with C-2C scheme, it is possible to balance the winding current at a given slip or for particular value of the load. With fixed value of capacitor, phase winding currents are disturbed when machine is under varying load. However, this configuration is suitable with load controller to operate it on a constant output power.

A single-phase induction generator can be made self-regulated by suitable combination of shunt and series capacitor. A capacitor in series with load and shunt capacitor in lagging winding can be connected. The load compensation and phase balancing effects are provided with series and shunt capacitances, which enhances the better utilization capacity of the machine. For the computation of optimum impedance of shunt series (C_{sh}-C_{se}) scheme

from steady state equivalent circuit diagram, the inspection equations are established. The phase voltages are expressed in terms of phase currents and admittances. With the help of symmetrical component theory, positive and negative sequence voltage components are derived. The total generator impedance, across the load terminals as expressed in terms of its (generator's) positive, negative sequence impedances and shunt impedance of capacitor. The closed loop impedance is derived by summation of load, series capacitance and generator impedance. The total closed loop impedance of the equivalent circuit is solved for two unknowns X_m and F using SUMT algorithm as indicated above.

In order to show the effect of direction of rotation, the performance of these two schemes has been investigated in two direction of rotation i.e. in a reference direction and the direction in opposite to reference.

On the basis of survey carried out for harmonics during analysis of SEIG, the harmonic patterns of studied schemes are reported.

Transient analysis is necessary to know the suitability of machine winding, level of insulation, rating of capacitor and design of protection system. The C-2C configuration has been investigated using d-q model in stationary reference frame, including the effect of cross saturation. From the circuit diagram of scheme, first the inspection equations are developed. The phase voltages are represented by integrating the capacitor current terms. Then, the capacitor currents are represented in terms of phase currents and load current. These phase variables are finally transformed to d-q variables. These d-q variables are further represented in terms of state vectors of

current. The state vector along with torque balance equation of mechanical motion of the system are developed. The differential equations derived from dynamic model are solved by fourth order Runga-Kutta method. The same model is modified for reverse direction of rotation of prime mover. The rms values of the variables as computed from the steady peak value obtained from dynamic model are compared with the measured experimental data and the values obtained from the steady state model are used to confirm the validity of the dynamic model for both forward and reverse direction of rotation of prime mover. On the basis of analysis carried out for dynamic behavior of C-2C scheme, it is concluded that similar results can be obtained for shunt series (C_{sh}-C_{se}) scheme.

The suitability of self-excited induction generators for cost effective harnessing of renewable energy resources is well established. But, these unit result in poor voltage regulation while feeding frequency sensitive loads due to the absence of regulated reactive VAR source. A load controller can be used to overcome such problems.

An IGBT (Insulated Gate Bipolar Transistor) based induction generator controller has been developed on the technique of Mark-Space ratio control. With this method, the amount of power to be dissipated in the ballast load is controlled by varying the mark space ratio. The PWM (Pulse Width Modulation) technique realized by analog circuit fabricated and tested using various parts of controller like, voltage sensing circuit, power supply and voltage reference circuits, triangular waveform generator, and IGBT gate-drive circuits. The performance of the SEIG using C-2C scheme with load controller

under varying load conditions is studied. The voltage and current waveform of the machine and load terminals are recorded for THD analysis.

A comprehensive steady state and dynamic analysis on three-phase induction machines of different rating has been carried out to design a suitable excitation scheme as single-phase SEIG supply for optimum power generation. A load controller is developed for single-phase SEIG. The performance of the generator with developed load controller has been investigated for different type of loads such as resistive and dynamic type (fan) load. The effect of direction of rotation of prime mover on SEIG performance is also studied.