# An Investigation on Working Principal of Self-Excited Induction Generator

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**Abstract—** The increasing use of renewable energy sources such as wind energy, bio-gas energy, solar energy, and hydro potential have become essential to adopt a low cost generating system, which are capable of operating in the remote areas, and in conjunction with the variety of prime movers. With wind turbines and mini/micro hydro generators as an alternative energy source, the induction generators are being considered as an alternative choice to well developed synchronous generators because of their lower unit cost, inherent ruggedness, operational and maintenance simplicity, absence of separate DC source, self-protection against overloads and short circuits etc. The research is underway to investigate the various issues related to the use of induction generator as potential alternative to the synchronous generator to utilize the small hydro and wind energy to accomplish the future energy requirement, and feed the power to remote locations and far flung areas, where extension of grid is not economically feasible. This paper presents an exhaustive survey of literature of research on self-excited induction generator (SEIG) over the past 30 years so that further work can be carried out for better results.

*Indexed Terms* — SEIG, Renewable Energy, Wind Energy

## I. INTRODUCTION

The increasing concern for the environment and resources has motivated the world towards rationalizing the use of conventional energy sources and has given emphasis on renewable energy sources such as wind, mini/micro-hydro, solar, geothermal, industrial waste etc. [1]. Since small hydro and wind energy sources are available in plenty, their utilization was felt quite promising to accomplish the future energy requirements. Harnessing mini/micro hydro and wind energy for electric power generation is an area of research interest and at present, the emphasis is being given to the cost-effective utilization of these energy resources for quality and reliable power supply [2]. With their limitations, a renewable energy power plant is installed locally and equipped with a small-size generator, up to only a few MW rating [3]. Traditionally, synchronous generators have been used for power generation but induction generators are increasingly being used these days because of their relative advantageous feature over conventional synchronous generators [4].

The self-excited induction generator (SEIG) has attracted considerable attention due to its applicability as a standalone generator using different conventional and non-conventional energy resources with its advantage over the conventional synchronous generator. Due to the research of renewable energy resources and isolated power systems, the SEIG become one of the most important renewable sources in developing countries [5]. It has its inherent advantages such as brushless construction with squirrel-cage rotor, reduced size, absence of DC power supply for excitation, reduced maintenance cost, and better transient performances. Self-excitation occurs when the capacitive reactive current from the capacitor is greater than the magnetizing current of the induction motor. When this occurs, excessive voltages can result on the terminals of the motor. An induction generator produces electrical power when its rotor is turned faster than the synchronous speed. For a four-pole motor (two pairs of poles on stator) powered by a 60 Hz source, the synchronous speed is 1800 rotations per minute (rpm) and 1500 RPM powered at 50Hz.
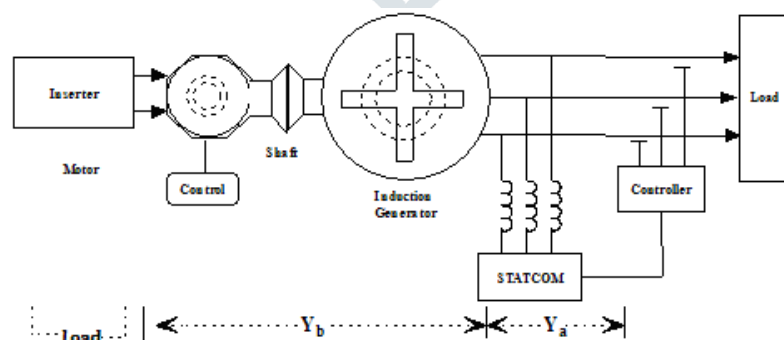


*Figure-1. Self Exited Induction Generator*

Major drawbacks of SEIG are reactive power consumption, its relatively poor voltage and frequency regulation under varying prime mover speed, excitation capacitor and load characteristics [6]. A detailed study of the performance of the SEIG operated in stand-alone and grid connected mode during steady-state and various transient conditions is important for the optimum utilization of its advantageous features. This paper presents a survey of research presented by the researcher recently on self-excited induction generator. This paper also cover the practical aspect of the self exited induction generator and the implementation strategies while penetrating the self exited induction generator in the power grid for industrial application.

## II. CLASSIFICATION OF INDUCTION GENERATORS

The induction generators are simpler than synchronous generators. They are easier to operate, control, and maintain, do not have any synchronization problem and are economical. Depending upon the rotor construction induction generators are two types [7]: (i) the wound rotor induction generator and (ii) the squirrel cage induction generator. On the basis of the prime movers used and their locations, generating schemes can be broadly classified in to two types [8]-[9]: (i) the constant-speed constant-frequency, (ii) the variable-speed constant-frequency, and (iii) the variable-speed variable frequency.

T.S. Jayadev in [9] described that in this scheme, the prime mover speed is held constant by continuously adjusting the blade pitch and/or generator characteristics. An induction generator can operate on an infinite bus bar at a slip of 1% to 5% above the synchronous speed [10].

Dezza et al. [11] presented that variable-speed operation of wind electric system yields higher output for both low and high wind speeds. This results in higher annual energy yields per rated installed capacity. Both horizontal and vertical axis wind turbines exhibit this gain under variable-speed operation. The popular schemes to obtain constant frequency output from variable speed are: (i) AC-DC-AC Link and (ii) Double output induction generator.

The double output induction generator (DOIG) is described in literature [12]-[14]. It consists of a three-phase wound rotor induction machine that is mechanically coupled to either a wind or hydro turbine, whose stator terminals are connected to a constant voltage constant frequency utility grid. One of the outstanding advantages of DOIG in wind energy conversion systems is that it is the only scheme in which the generated power is more than the rating of the machine. However, due to operational disadvantages, the DOIG scheme could not be used extensively.

For variable speed corresponding to the changing derived speed, SEIG can be conveniently used for resistive heating loads, which are essentially frequency insensitive. The application of this scheme for stand-alone wind power is presented in literature [15]-[16].

## III. SELF-EXCITED INDUCTION GENERATOR MODEL

When an induction machine operates as a Self-excited induction generator (SEIG), there is no external power grid that defines voltage and frequency on the stator terminals. Thus, both of them are unknown variables whose values change independently, being affected by rotor speed, capacitance of excitation capacitors and loading conditions. Saturation level of the magnetic circuit is also variable, which means that magnetizing inductance cannot be considered constant [17]. Several different variants of SEIG's equivalent circuit can be found in literature [18]-[20]. For the modeling of the self excited induction generator the main flux path saturation is accounted for while the saturation in the leakage flux path of magnetic core of the machine, the iron and rotational losses are neglected [21]-[22].

**Steady-State Circuit Model:**

Most of the steady state models of SEIG developed by different researchers are based on per phase equivalent circuit. These models use the following two basic methods: (i) Loop impedance method and (ii) Nodal admittance method. The steady state model based on nodal admittance method and used in [17] is presented here in Fig. 1. This model makes assumptions that the load is RL, machine core loss component is neglected and the machine parameters (except for magnetizing reactance) remain constant. T.F. Chan in [23] presented a steady state model of SEIG in which all the circuit parameters are assumed to be constant and unaffected by saturation.

Machine parameter except capacitance and frequency all are known values. Mahendra Lalwani et al. [24] proposed a steady state model of single phase self-excited induction generator with one winding for obtaining constant output voltage. D. Joshi et al. [25] presented conventional equivalent circuit model for steady state analysis of SEIG using artificial neural network. K.S. Sandhu et al. [26] proposed a model for steady state operation of self-excited induction generator with varying wind speeds. Jordan Radosavljevic et al. [27] proposed induction generator model with its positive and negative sequence circuits for steady-state analysis of parallel operated self-excited induction generators supplying an unbalanced load. Eduard Mujadi et al. [28] presented a model of asynchronous machine in terms of admittance using the steady state equivalent circuit.
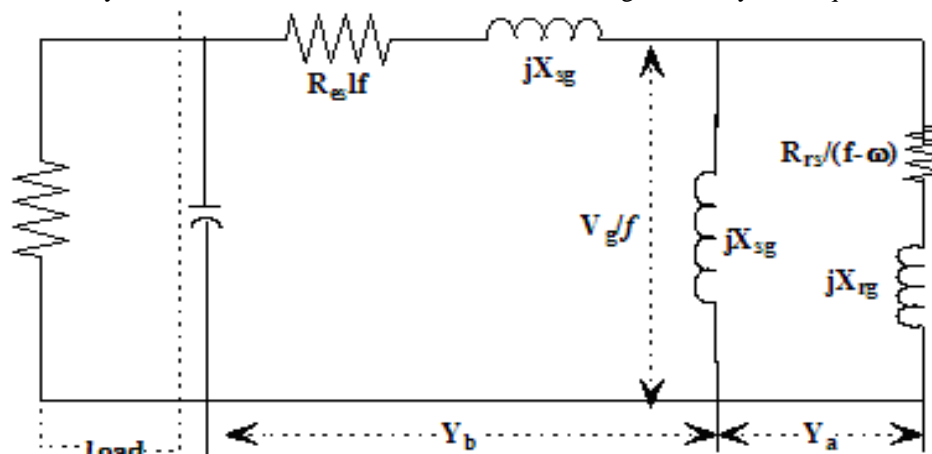


*Figure-2. Equivalent Circuit of Self-Excited Induction Generator*

M.H. Haque in [31] proposed a mathematical model of SEIG for determination of critical speed capacitance requirements in which core losses are modeled by adding resistor in parallel with magnetizing inductance. H.H. Hanafy et al. [32] presented a mathematical model of self-excited short-shunt induction generator driven by unregulated turbine under no load and on load conditions for voltage and frequency control. Analysis was done to choose appropriate set of values of both shunt and series capacitances to control the magnitude and frequency of the load voltage. M.H. Haque in [33] presented a simple method of evaluating the steady state characteristics of a three-phase SEIG with P-Q load model. First the problem of generator is formulated through its equivalent circuit using the basic circuit laws.

The formulated problem is then solved using a numerical based routine. The proposed method is then tested on a 1.5-KW machine. Bhaskara Palle et al. [34] proposed dynamic mathematical model to describe the transient behavior of a system of self-excited induction generators operating in parallel and supplying a common load. Sasikumar et al. [35] presented a simple mathematical model to compute the steady-state performance of six-phase self-excited induction generators. A mathematical model is formed directly from the equivalent circuit of six-phase self-excited induction generator by nodal admittance method. Genetic algorithm is applied to solve the proposed model. The model of induction machine with D-Q axes equivalent circuit has been reported in literature [36]-[39]

## IV. PERFORMANCE ANALYSIS

The performance analysis of self-excited induction generator may be discussed by categorizing in to four important headings viz: (i) steady-state analysis, (ii) the transient analysis, (iii) the voltage control aspects, and (iv) the parallel operation of SEIG.

**Steady- State Analysis**

In an isolated power system, both the terminal voltage and frequency are unknown and have to be computed for a given speed, capacitance and load impedance. Therefore the steady-state analysis of self-excited induction generator is of great interest, both from the design and operational points of view. Harish Kumar et al. [40] presented the steady state performance of SEIG with genetic algorithm, pattern search and quasi-newton optimization techniques. At given load, speed and terminal voltage two unknowns i.e., p.u. capacitive reactance and frequency are determined. The steady state equivalent circuit is used to compute the performance of SEIG after determining the unknowns.

The effects of various system parameters are presented. Wang et al. [41] have presented an eigenvalue-based approach to predict both minimum and maximum values of capacitance required for self-excitation of SEIG. Muthy et al. [42] presented a general steady-state analysis of a three-phase self-excited induction generator feeding a three-phase unbalanced load or single-phase load. Symmetrical component theory is used to obtain relevant performance equations through sequence quantities.

The feasibility of using three-phase machines for unbalanced operations has been critically examined for standalone power generation. B. Singh et al. [43] predicted the steady-state performance of the two-winding single-phase SEIG and verified with experimental results for three different schemes, namely; fixed-shunt capacitor excitation, fixed and variable capacitor excitation, shunt- and series-capacitor excitation. Rajakaruna et al. [44] have used an iterative technique which uses an approximate equivalent circuit and a mathematical model for B-H curve and the solution is reduced to a nonlinear equation.

**Transient Analysis**

The transient studies of induction generators are related to voltage buildup due to self-excitation and load perturbations. The D-Q model can be used to investigate the SEIG transient performance under balanced condition. The literature [45]-[48] have presented transient/dynamic analysis of self-excited induction generator. Hamouda et al. [49] presented a transient model of a stand-alone self-excited induction generator. This model is based on direct phase quantities and is suitable to study the performance of the generator under any condition. It includes a general load as well as general excitation capacitor model. Shridhar et al. [50] presented the transient performance of shortshunt SEIG. It is seen that it can sustain severe switching transients, has good overload capacity, and can re-excite over no load after loss of excitation.

It is also observed that except for the most unusual circumstances, the short-shunt SEIG supplies adequate fault current to enable over-current protective device operation. Wang et al. [51] presented transient performance of a standalone self-excited induction generator under unbalanced excitation capacitors. An approach based on three-phase induction machine model is employed to derive dynamic equations of an isolated SEIG under unbalanced conditions. The neutral points of both Y-connected excitation capacitor bank and Y-connected stator windings of the SEIG are connected together through a neutral line.

Wang et al. [52] have presented a comparative study of long-shunt and short-shunt configurations on dynamic performance of an isolated SEIG feeding an induction motor load. Results show that the long shunt configurations may lead to unwanted oscillations while the short shunt provides the better voltage regulation. In [53], the permanent and dynamic behaviours of self-excited induction generator in balanced mode are discussed. The effects of varying the resistive load, the excitation's capacitors and the drive speed on the stator output voltage are also presented

## V. VOLTAGE-CONTROL ASPECTS

The induction machine has no field windings; therefore the current to magnetize the machine must be supplied by the system to which it is connected. The need of reactive power support and poor voltage regulation are the two major drawbacks of

induction generators. Induction generators require the supply of reactive power [54]. Depending upon the arrangement to supply the reactive power, two modes of operation are possible for an induction generator i.e. regeneration and self-excitation. In first mode, the induction generator takes its excitation in terms of lagging magnetizing current from the power source of known voltage and frequency i.e. grid, to produce its rotating air gap field for required regeneration. In second mode, the VAR generating unit has to be connected across the terminals of induction machine, which are generally realized in the form of capacitor banks [55]. Malik et al. [56] have shown that the minimum capacitance requirement of SEIG is inversely proportional to the square of speed and maximum saturated magnetizing reactance. Swati Devabhaktuni et al. [57] presented a method for computing the minimum value of capacitance to initiate self-excitation in the SEIG. The method is based on the steady state equivalent circuit, but features the separate consideration of the load and excitation capacitance branches, which enables the frequency to be determined by solving a single 4th order polynomial. Elsharkawi et al. [58] presented a fixed and switched capacitors scheme consisting of two discrete groups of fixed and switched capacitors, which furnish enough reactive power for an induction generator throughout its desired operating region of speed. The number of switched capacitors is kept to a minimum to simplify the switching circuit, and yet provides adequate and varying reactive power compensation.

The self-excited induction generators usually operate in parallel where natural resources are available in abundance to utilize full potential of the natural resources. Parallel operation of induction generators has the advantage of elimination of the need for synchronization and of the associated problems with hunting etc. The references [59]-[61] are available on parallel operation of such units.

Chakraborty et al. [62] have analyzed the effects of parameter variations on the performance of parallel-connected SEIG operating in stand-alone mode. The investigation outlines the parameter influence on the performance of individual generators as well as on the system as a whole. Effects of parameter deviations on the voltage regulation have been examined in this paper. Rotor resistance is found to have the largest influence on current and power sharing of individual machines and also on terminal frequency. Yun et al. [63] presented a new methodology to analyze the parallel operation of single-phase self-excited induction generators in a distribution system. The model is then employed by analyzing starting currents and short circuit currents contributions from the SEIGs. The method of analysis in [60] is based on a simplified equivalent circuit, and as a result the developed expressions lack accuracy in certain situations, and also fail to meet the requirements to study many aspects of parallel connected generators. Bahrani et al. [64] studied the voltage-control behavior of multi-induction generators operating in parallel with one three-phase bank of excitation capacitors connected to a common bus and load. It has been reported that voltage regulation under varying load conditions is improved by controlling either the capacitance or speed of one or more generators. Under controlled terminal voltage operation, it is noticed that the capacitive reactive power and speed demand increases with increased load. Under the similar conditions of controlled terminal voltage, the system frequency also depends on load power and terminal voltage.

## VI. CONCLUSION

Applications of self-excited induction generator for energy conversions in remote locations offer many advantages over a synchronous generator. The SEIG is most economical solution for powering customers isolated from the utility grid. This article have presented a comprehensive literature survey on important aspects of SEIG such as the process of self excitation, modeling, steady-state and transient analysis, reactive power/voltage control, and parallel operation useful for the researchers. The better methods of reactive power/voltage control techniques will make the SEIG more suitable for isolated applications.

## VI. SCOPE

The self-excited induction generator (SEIG) is a type of AC generator that is capable of generating electricity using an induction machine that is excited by capacitors. It is widely used in small-scale wind power and hydroelectric power generation systems. In the future, the SEIG is likely to continue to be an important technology for small-scale renewable energy generation, particularly in remote areas where grid connectivity is limited. The SEIG's simple design, low cost, and reliability make it an attractive option for such applications. However, there are also some limitations to the SEIG that may need to be addressed in the future. One of the main issues is its low power factor, which can cause problems with power quality and efficiency. To overcome this, new control strategies may need to be developed that can improve the SEIG's power factor while maintaining its simplicity and cost-effectiveness. Another area of potential development for the SEIG is in the integration of energy storage systems. By adding batteries or other types of energy storage, the SEIG could become more flexible and reliable, allowing it to provide a more stable and consistent source of electricity. Overall, the future of the self-excited induction generator looks promising, with ongoing research and development likely to lead to new innovations and improvements in performance and efficiency. Further study can be conducted in these potential sections.

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