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Self excited induction generator: A review

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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 to adopt a low cost generating system, which are capable of operating in the remote areas, and in conjugation with the variety of prime movers. With wind turbine and micro/mini hydro generators as an alternative energy source, the induction generators are being considered as an alternative choice to well developed synchronous generator because of their simplicity, ruggedness, little maintenance, price , brushless (in squirrel cage construction), absence of separate dc source, self-protection against severe overloads and short circuits. In isolated systems, squirrel cage induction generators with capacitor excitation, known as self-excited induction generators (SEIGs), are very popular. This paper presents an exhaustive survey of literature of research on self excited induction generator (SEIG) over the past 30 years discussing the classification of induction generator, steady state and transient analysis, voltage control aspects and parallel operation of SEIG.

Keywords: Self excited induction generator, self excitation & voltage buildup, steady state analysis, transient analysis, parallel operation of SEIG.

I. INTRODUCTION

With the increasing trend toward the use of renewable energy sources for electricity generation such as the following: micro-hydro, wind energy, biogas, and solar energy, a greater emphasis is being laid on the development of a low-cost, least maintenance, simple and sturdy generator unit for standalone isolated applications[1]. Since small hydro and wind energy sources are available in plenty, their utilization was felt quit 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. Traditionally, synchronous generator has been used for power generation but induction generations are increasing being used these days because of their relative advantageous feature over conventional synchronous generators [2].Self excited induction generator has been a subject of considerable research over last few decades because of its perception as the simplest energy conversion device to produce electricity in off-grid, stand alone mode using different types of prime movers and employing different conventional and renewable energy resources such as oil, bio fuel, wind and small hydro .The major drawbacks in the use of self excited induction generators are the poor voltage and frequency regulations under prime mover speed and load perturbations. The generated terminal voltage and the output frequency, depend on the excitation capacitance, the three-phase induction machine parameters, the electrical passive load and the prime mover speed[3]

II. CLASSIFICATION OF INDUCTION GENERATOR

On the basis of rotor construction, induction generators are two types i) the wound rotor induction generator and ii) squirrel cage induction generator. Depending upon the prime movers used (constant speed or variable speed) and their locations (near to the power network or at isolated places), generating schemes can be broadly classified as under [4]-[6].

(A) constant-speed constant-frequency (CSCF);
(B) variable-speed constant-frequency (VSCF);
(C) variable-speed variable-frequency (VSVF).

A. Constant-Speed Constant Frequency

Induction generators are simpler than synchronous generators. They are easier to operate, control, and maintain, do not have any synchronization problems, and are economical. In this scheme, the prime mover speed is held constant by continuously adjusting the blade pitch and/or generator characteristics [6]. An induction generator can operate on an infinite bus bar at a slip of 1% to 5% above the synchronous speed.

B. Variable-Speed Constant Frequency

The variable-speed operation of wind electric system yields higher output for both low and high wind speeds [7]. This results in higher annual energy yields per rated installed kW capacity. Both horizontal and vertical axis wind turbines exhibit this gain under variable-speed operation. Popular schemes to obtain constant frequency output from variable speed are as follow:

1) AC–DC–AC Link: With the advent of high-powered thyristors and high voltage DC transmission system, the ac

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output of the three-phase alternator is rectified by using a bridge rectifier and then converted back to ac using line-commutated inverters. They utilize an ac source (power lines) which periodically reverses polarity and cause the commutation to occur naturally. Since the frequency is automatically fixed by the power line, they are also known as synchronous inverters [8].

2) Double Output Induction Generator (DOIG): The double output induction generator is described in literature[9]-[11].The DOIG 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. The variable frequency output is fed into the ac supply by an ac–dc–ac link converter consisting of either a full-wave diode bridge rectifier and thyristor inverter combination or current source inverter (CSI) thyristor converter link 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.

C. Variable-Speed Variable Frequency

Since resistive heating loads are essentially frequency insensitive, the synchronous generators can be affected at a variable frequency corresponding to the changing derived speed. For this purpose SEIG can be conveniently used. This scheme is gaining importance for stand-alone wind power applications [12].

III. SELF EXCITATION PHENOMENON AND VOLTAGE BUILDUP IN SEIG

The self-excitation phenomenon of an induction machine is still under considerable attention although it is known for more than a half century [13]–[23]. The self-excited induction generator (SEIG) has attracted considerable attention due to its applicability as a stand-alone generator using different conventional and nonconventional energy resources with its advantages over the conventional synchronous generator.

When a standalone induction machine is driven by a mechanical prime mover, the residual magnetism in the rotor of the machine induces an EMF in the stator windings at a frequency proportional to the rotor speed. This EMF is applied to the capacitors connected to the stator terminals and causes reactive current to flow in the stator windings. Hence a magnetizing flux in the machine is established. The final value of the stator voltage is limited by the magnetic saturation within the machine. The induction machine is then capable of operating as a generator in isolated locations without a grid supply. From the circle diagram of the induction machine in the negative slip region, it is seen that the machine draws a current, which lags the voltage by more than 90. This means that real power flows out of the machine but the machine needs the reactive power. To build up voltage across the generator terminals, excitations must be provided by some means; therefore, the induction generator can work in two modes (i.e., grid connected and isolated mode). In case of a grid-connected mode, the grid-connected induction generator (GCIG) takes its excitation from the lines and generates real power via slip control when driven above the synchronous speed. The operation is relatively simple as voltage and frequency are governed by the grid voltage and grid frequency respectively. In case of isolated mode, the induction generator draws reactive power by connecting a capacitor bank across the generator terminals [24]. For an isolated mode, there must be a suitable capacitor bank connected across the generator terminals. This phenomenon is known as capacitor self-excitation and the induction generator is called a "SEIG."

The process of voltage buildup in an induction generator is very much similar to that of a dc generator. When the rotor of induction generator is run, the residual magnetism present in rotor iron creates a small emf. across stator terminals. This voltage causes a capacitor current to flow. The flux due to current is added with residual flux and generates a stator terminal voltage. This voltage produces current in capacitor bank which then generates voltage. This cumulative process continues till the intersection point between saturated magnetization curve and capacitor load line. The intersection point gives no load generated e.m.f.at the magnetizing current. The voltage build process depends upon the capacitor value. Higher the value of capacitance, greater is the voltage build up. In the absence of a proper value of residual magnetism, the voltage will not build up. So it is desirable to maintain a high level of residual magnetism, as it does ease the process of machine excitation. The operating conditions resulting in demagnetization of the rotor (e.g., total collapse of voltage under resistive loads, rapid collapse of voltage due to short circuit, etc. should be avoided).

IV. PERFORMANCE ANALYSIS OF SELF EXCITED INDUCTION GENERATOR

The performance analysis of self excited induction generator can be categorized in to the following- (i) Steady state analysis (ii) transient analysis (iii) Voltage control aspect (iv) The parallel operation of SEIG.

(i) 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 both from the design and operational point of view, the steady state analysis of SEIG is of great interest. L. Sridhar[25]proposed an algorithm to predict the steady

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state performance of SEIG feeding an induction motor .Wang [26] have presented an approach to predict both minimum and maximum values of capacitance required for self excitation of SEIG, based on Eigen values .Murthy[27] present a general steady-state analysis of a three-phase self-excited induction generator (SEIG)feeding a three-phase unbalanced load or single-phase load is presented. Symmetrical component theory is used to obtain relevant performance equations through sequence quantities.

Chan [28] presents a steady-state performance analysis of a stand-alone three-phase induction generator self excited with unbalanced capacitances and supplying unbalanced loads. Symmetrical components method is used to reduce the complex three-phase generator-load system to a simple equivalent passive circuit. A function minimization technique is employed to solve this equivalent circuit in order to determine the excitation frequency and magnetizing reactance. Alghuwainem [29] has examines the steady-state analysis and performance of an isolated three-phase self-excited induction generator (SEIG) driven by regulated and unregulated turbine. Abdul rahman [30] presents a steady state analysis of three phase self-excited induction generator. The problem is formulate has a multidimensional optimization problem. A constrained optimizer is used to minimize a cost function of the total impedance or admittance of the circuit of the generator to obtain the frequency and other performance of the machine.

Rajakaruna *et al.*[31] 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 in f. C.Grantham, [32] present a scheme for calculation of Steady state self-excitation voltages and frequencies for loaded and unloaded operations ,taking into account the rotor parameter variations with the frequency. Olorunfemi Ojo [33] presents the modeling and steady-state performance of single-phase induction generators based on the principles harmonic balance including Magnetizing flux linkage saturation and flux dependent core loss resistances.

(ii) Transient analysis

The transient studies of induction generators are related to voltage buildup due to self-excitation and load perturbation. To investigate the SEIG transient performance under balanced condition, the D-Q model can be used. Many articles been presented on the transient/dynamic analysis of self excited induction generator [34]-[37].

Wang [38] presents transient performance of a stand-alone self-excited induction generator (SEIG) 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 is connected together though a neutral line. S.K. Jain [39] developed a generalized dynamic model of a delta-connected three-phase self-excited induction generator (SEIG) using d-q variable in a stationary reference frame and this model can handle symmetrical and unsymmetrical load and capacitor configurations. Bhim Singh[40]presents a transient analysis of a self-excited induction generator (SEIG) with electronic load controller (ELC) used in stand-alone micro-hydro power generation employing uncontrolled turbines**.** Bhaskara Palle [41] proposed a dynamic mathematical model to describe the transient behavior of a system of self-excited induction generators (SEIGs) operating in parallel and supplying a common load. In [42], the transient performance of a series-compensated three-phase self-excited induction generator (SEIG) feeding a dynamic load such as a three-phase squirrel-cage induction motor (IM) is discussed. Mathematical modeling and simulation study of SEIG and an induction motor (SEIG-IM) combination is carried out using MATLAB/Simulink. In [43], a generalized state-space dynamic model of a three phase SEIG has been developed using d-q variables in stationary reference frame for transient analysis. The proposed model for induction generator, load and excitation using state space approach can handle variable prime mover speed, and various transient conditions e.g. load perturbation, switching states etc.

(iii) 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. Induction generator has two major drawbacks. First is the need for reactive power support and other is poor voltage regulation. Induction generators require the supply of reactive power [44].Unbalanced reactive power operation results in voltage variation.

Sridhar [45] have discussed a methodology to choose the appropriate value of capacitor for desired regulation of short- shunt SEIG.

Swati Devabhaktuni [46] presented a method for computing the minimum value of capacitance to initiate self excitation in 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 4^{th} order polynomial. Malik *et al.*[47] have shown that the minimum capacitance requirement of SEIG is inversely proportional to the square of speed and maximum saturated magnetizing reactance.

A new strategy for controlling voltage and frequency of a self excited induction generator (SEIG) is presented in [48].An external excitation circuit, comprising permanently connected capacitors and electronically

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switched inductances is used. The external circuit allows to compensate for the generator reactive demand. Bhim Singh [49] have Presented the design of static compensator(STATCOM)-based voltage regulator for self-excited induction generators (SEIGs). To maintain constant terminal voltage, the required adjustable reactive power can be provided by a STATCOM consisting of ac inductors, a dc bus capacitor, and solid-state self-commutating devices. Selection and ratings of these components are quite important for design and control of STATCOM to regulate the terminal voltage of SEIG. In [50], the performance analysis of a static compensator (STATCOM)-based voltage regulator for self-excited induction generators (SEIGs) supplying nonlinear Loads, is discussed. A dynamic model of the SEIG–STATCOM feeding nonlinear loads using stationary $d-q$ axes reference frame is developed for predicting the behavior of the system under transient conditions.

(iv) PARALLEL OPERATION OF SEIG

A stand alone SEIG is unlikely to supply energy demand of ordinarily growing loads for long time. Thus, multiple generators operating in parallel may be required to harvest the maximum energy available at a site. Parallel operation of induction generator has the advantages of eliminating of the need for synchronization and of the associated problem with hunting etc. The references [51]-[54] are available on parallel operation of such units.Wang [55] have proposed an Eigen value-based methodology to analyze the dynamic performances of parallel-operated SEIG supplying an IM load. Determination of minimum starting value of capacitance required for self-excitation is analyzed .A.H. Al-Bahrani [56] describes two methods of analysis to control the common bus voltage of any number of parallel self-exited induction generators, SEIG's, under steady state balanced conditions. The proposed methods are general and can be used for a single or a group of SEIG's employing similar or different machines with equal or unequal prime movers speeds. SEIGs connected in parallel may lose excitation momentarily owing to large transient currents caused by differences in individual instantaneous voltages and frequency. This phenomenon cannot be easily simulated using the conventional models because it has such a fast transient nature. An innovative and automatic numerical solution for steady-state and transient analysis of any number of SEIGs operating in parallel is presented [57].The effect of parameter variations on the performance of parallel-connected SEIG operating in stand-alone mode[58].Effects of parameter deviations on the power sharing, current sharing, VAR requirements, and on the voltage regulation have been examined in this paper.

V CONCLUSION

The investigations spread over the last three decades indicate the technical and economic viability of using induction generator for electric power generation to harness the renewable energy sources, particularly in remote and far flung areas where extension of grid is not economically feasible. The induction generator's ability to generate power at varying speed facilitates its application in various modes such as self-excited stand-alone (isolated) mode; in parallel with synchronous generator to supplement the local load, and in grid-connected mode. Use of SEIG compared to the synchronous generator can reduced the system cost considerably. This article have presented a comprehensive literature survey on important aspect of SEIG such as the process of self excitation, steady state and transient analysis, voltage control, and parallel operation of SEIG, so that further work can be carried out for better results.

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