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Overview of Wind Turbine Driven Self-Excited Induction Generator

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Abstract*— this paper presents an overview of the analysis, modeling as well as controlling of self Excited Induction Generator (SEIG) which is connected by Wind Turbine. The AC capacitors are used to build up the process of an isolated induction generator starts from charge in the capacitors or from a remnant magnetic field in the core. Same process is done at the time of isolated induction generator is excited by inverter/rectifier system. . A closed loop voltage control scheme using a PWM Voltage Source Converter (VSC), dc link capacitor and a P-I voltage controller is proposed. This scheme generates constant voltage and variable frequency using the converter which also acts as a reactive power compensator. In the growing applications and environmental conditions, various types of technologies are introduced to delivering the power to the grid. The main objective of the project is to track and extract maximum power to the grid connected wind energy conversion system. This paper presents only a proposed approach of self-excited induction generator in wind energy conversion system.

***Index Terms*—Self Excitation Induction Generator, PWM Inverter, Capacitor, Series Induction Filter, voltage source, grid.**

I. INTRODUCTION

Windy areas, waterfalls, reservoirs, high tide locations are extremely helpful for generating clean and economical electrical energy by proper harnessing mechanism. Throughout the globe in last three to four decades generation of electricity out of these renewable sources has created wide interest. Growing interest in water management and sustainable environment toward a sustainable world has awakened new sources of hydro energy. Among these are the run-of-river plants to produce electricity using induction generators.

The induction generator self excitation phenomena is reviewed in [1]. The brushless construction, robustness, low maintenance requirements, absence of DC power supply for field excitation, small size, self protection against short circuits are the advantages of asynchronous generator over the synchronous and DC generators. The relatively poor voltage and frequency regulation and low power factor are its weaknesses. The frequency and magnitude of voltage generated by the self excited induction generator (SEIG) is completely governed by the rotor speed, the excitation and the load. There exist minimum and maximum capacitances for the self excitation to occur i.e., voltage build up at a particular speed. Also it requires a minimum cut in speed for successful voltage build up and it has a maximum speed limit considering mechanical safety for a fixed excitation capacitance [3-4]. The effect of dynamic mutual inductance on voltage build up process of SEIG is discussed in [5]. The application of power semiconductor devices, controlled converter circuits, and control algorithms has resulted in suitable regulating schemes for self excited variable speed squirrel cage generators.

From the electricity company standpoint, accurate controls of voltage and frequency can limit the electrical and mechanical stresses in the power system and deliver good quality energy. Already many circuits are proposed to control the output voltage and/or frequency [6, 7, and 8]. The SEIG become the most widely used wind turbine systems for low cost rugged machine. The generated speed of the induction generator is mainly depending on the wind velocity conditions and modulation index. Due to the economical view and reliable characteristics, the CSI topologies are adopted for various applications based on the performance merits such as simplicity, ruggedness, cost effectiveness, and very low switching losses. The various PWM techniques are used to get desire voltage in the inverter terminals.

The main aim of this investigation paper is to present the investigation of SEIG for wind turbine energy conversion applications; In the next sections, will first discuss the wind energy conversion system, some literature study over the different components of SEIG and finally present the proposed approach of modeling. Section II presents the literature review over the all previous works done in these same areas with different objectives, Section III discusses the proposed investigated approach with different parts of model.

II. LITERATURE REVIEW

This section of paper, aims to present most of previous works done over the area of SEIG connected with Wind turbines.

2.1 Self-Excited Induction Generator

Initially the work over SEIGs (especially three phase) excited by the three capacitors was done with goal of practical evaluation. The main methods of representing a SEIG are the steady state model and the dynamic model. The steady state analysis of SEIG is based on the steady state per-phase equivalent circuit of an induction machine with the slip and angular frequency expressed in terms of per unit frequency and per unit angular speed. The steady state analysis includes the loop-impedance method [8] and the nodal admittance method [1]. The loop-impedance method is based on setting the total impedance of the SEIG, i.e. including the exciting capacitance, equal to zero and then to find the steady state operating voltage and frequency using an iteration process.

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In the nodal admittance method the real and imaginary parts of the overall admittance of the SEIG are equated to zero. The equations are formulated based on the steady state conditions of the SEIG. The main drawback of using the per-phase steady state equivalent circuit model is that it cannot be used to solve transient dynamics because the model was derived from the steady state conditions of the induction machine.

The dynamic model of a SEIG is based on the D-Q axes equivalent circuit or unified machine theory. For analysis the induction machine in three axes is transformed to two axes, D and Q, and all the analysis is done in the D-Q axes model. The results are then transformed back to the actual three axes representation. In the D-Q axes if the time varying terms are ignored the equations represent only the steady state conditions. In these papers the initial conditions that take into account the initial charge in the exciting capacitors and the remnant magnetic flux linkage in the iron core are not given and in some of the papers the complete dynamic equations are not presented. The D-Q axes model of SEIG given in [8] reported that the dynamic generated voltage varies with the applied load, but there are no results that show what happens to the dynamic speed of the rotor when the generator is loaded. Hence it cannot be proven whether the variation in voltage is exaggerated due to a change in speed or not.

To investigate this, the characteristic of the dynamic voltage could be simulated and measured by keeping the speed at a constant value by applying a speed regulator to a DC motor which is used as a prime mover for the SEIG. For the constant speed drive test a PI (proportional and integrator) speed controller and an inner loop PI current controller is used. The dynamic frequency of the generated voltage, during loading conditions, is calculated from measured voltages or from measured voltages and currents. Three-axes to two-axes transformation is used in the calculation of the dynamic frequency value. Here the transformation is used to simplify the calculation.

The normal connection of a SEIG is that the three exciting capacitors are connected across the stator terminals and there is no electrical connection between the stator and rotor windings. However, in the literature a SEIG with electrical connection between rotor and stator windings is reported [6]. This paper deals with the steady state performance of a SEIG realized by a series connection of stator and rotor windings of a slip-ring type induction machine and solved using D-Q analysis. In this type of connection it has been claimed that it has the advantage of operating at a frequency independent of load conditions for a fixed rotor speed, however the angular frequency of the output voltage is equal to half of the rotor electrical angular speed, which means the prime mover should rotate at twice the normal speed to generate voltage with standard frequency. There is also concern regarding the current carrying capability of the rotor and stator windings because both of them are carrying the same current. Whether any wound rotor induction machine can be used in this way or not is not specified.

Shridhar et al reported that if a single valued capacitor bank is connected, i.e. without voltage regulator, a SEIG can safely supply an induction motor rated up to 50% of its own rating and with a voltage regulator that maintains the rated terminal voltage the SEIG can safely feed an induction motor rated up to 75% of its own rating. In this case the SEIG can sustain the starting transients of the induction motor without losing self-excitation [8]. Since a SEIG operates in the saturation region, it has been shown that to saturate the core, the width of the stator yoke is reduced so that the volume and the weight of the induction generator will be less than the corresponding induction motor [9]. The voltage drop for a constant capacitor induction motor used as a generator was 30% while the voltage drop of the corresponding designed induction generator was 6% [9]. A three-phase SEIG can be used as a single-phase generator with excitation capacitors connected in C-2C mode where capacitors C and 2C connected across two phases respectively and nil across the third phase [10].The steady state performance of an isolated SEIG when a single capacitor is connected across one phase or between two lines supplying one or two loads is presented in [11]. But in these applications the capacity of the three-phase induction generator cannot be fully used.

2.2 Rotor Speed as well as Capacitance in SEIG

The capacitance values like minimum and maximum are needed for the three-phase induction generator and those are previously analyzed by various current model methods. For the calculation of minimum capacitance values needed for self excitation with use of flux model. In the calculation of capacitance required for self-excitation, economically and technically, it is not advisable to choose the maximum value of capacitance. This is due to the fact that for the same voltage rating the higher capacitance value will cost more. In addition, if the higher capacitance value is chosen then there is a possibility that the current flowing in the capacitor might exceed the rated current of the stator due to the fact that the capacitive reactance reduces as the capacitance value increases. It has been shown that a de-excited induction generator can re-excite even if the load is already connected to it, but the relationship between the value of the load, capacitance and speed has not been given. The relationship between speed, capacitance and load is that the characteristics of the induction generator for self-excitation with a load can be established. This relationship is also important to find the region where the induction generator can continue to operate without loss of self excitation. Wind speed can change from the minimum set point to the maximum set point randomly and the SEIG can be started at any point within the range of speed. It is essential to find the minimum and maximum speed required for self-excitation, when the generator is loaded.

2.3 Magnetizing Inductance Representation

This is also one of the main factors SEIG driven by Wind turbine system. There are many representations of the magnetizing induction [called magnetizing inductance (*Lm*) or magnetizing reactance (*Xm*)]. One of the ways of representation is *Xm* as a function of *Vg/f* (V/Hz to relate to flux [8], where *Vg* is the voltage across *Xm* and *f* is the frequency of excitation, or *Lm* as a function of *Vg* [14] for a known frequency of operation. In these papers it has been shown that the value of *Xm*, as the value of *Vg/f* or *Vg* increases from zero, starts at a given unsaturated value, remains constant at the unsaturated value for low values of air-gap voltage or ratio of air gap voltage to frequency, and then starts to decrease up to its rated value, which is a saturated value.

In the reference paper [9] the measured values show the actual variation of magnetizing reactance. This is the magnetizing reactance as the air gap voltage increases from zero. It starts at a given value, increases until it reaches its maximum value and then starts to decrease down to its rated value, which is a saturated value. But in the SEIG analysis, the magnetizing reactances for values of air gap voltage close to zero were ignored. Since *Xm* is dependent on frequency it is not good for transient dynamic analysis, rather *Lm* should be used. The other representation is *Xm* as a function of magnetizing current or *Lm* as a function of magnetizing current. In these papers it has been illustrated that the magnetizing inductance or magnetizing reactance starts at a maximum unsaturated value and then decreases when the iron core saturates, however in it has been indicated that the value of magnetizing inductance starts at a given unsaturated value, increases and then finally decreases as the magnetizing current increases from zero [15]. Although this representation depicts the actual variation of magnetizing inductance, the significance of this characteristic has not been presented. The reason for this variation in magnetizing reactance and the effect on self-excitation is discussed. As the magnetizing reactance dependent on frequency, magnetizing inductance is used in the analysis and its effect on the initiation of self excitation and stabilization is discussed in detail and confirmed experimentally.

2.4 generated Frequency and Voltage Control

Controlling of frequency and voltage generated from SEIG is main challenge while using the SEIG due to the reason that voltage amplitude as well as frequency drops with loading as well as with a decrease in the generator rotor speed [7]. The magnitude and frequency of the output voltage of a standalone induction generator driven by a variable speed rotor can be controlled by employing the rotor excitation of a wound-rotor induction machine [8]. In a similar way it can be controlled by varying the rotor resistance of a self-excited slip-ring induction generator [2]. But a self-excited slip-ring induction generator will require more maintenance than a squirrel cage rotor due to the slip-rings and brush gear. The rms value of the generated voltage, irrespective of its frequency, can be controlled using variable capacitance values [3], or a fixed capacitor thyristor controlled reactor static VAR compensator [4], or continuously controlled shunt capacitors using antiparallel IGBT switches across the fixed excitation capacitor [5].

2.5 Wind Powered Generators

Finally the literature review discussing the one more factor related to SEIG and over which many works done previously. For a fixed speed wind turbine system that can be connected to the grid, maintaining a constant frequency is not a problem, irrespective of whether an induction or synchronous generator is used. Such systems typically employ induction machines connected directly to the grid. In grid connected systems there are two generating schemes for variable speed wind turbine systems [11].

The first scheme employs machine control using power electronics feeding the rotor circuit (wound rotor induction machine) or a second winding in the stator of an induction machine (squirrel cage rotor or wound rotor) to adjust the frequency and generated voltage when the generator rotor speed is varied. The second scheme applies to single stator winding fed induction generators which produce a constant DC output voltage that is then inverted to have an output of constant rms voltage and frequency. In a variable speed wind turbine system the mechanical stresses caused in the structural elements by gusts and varying wind speed are diminished by letting the rotor follow the wind. Also when the rotor speed is allowed to vary with the wind the turbine can be operated at peak efficiency. However, the necessary power electronics can be expensive. Brushless doubly-fed induction machines have two stator windings of different pole number. A double output induction generator is a wound rotor induction machine with the control power electronics connected on the rotor circuit. In this arrangement the induction generator gives more than its rated power without being overheated. The power generation can be realized for a wide range of wind speed. They have a rotor inverter and front end converter while the stator is linked directly to the grid.

Now in next section we are discussing the proposed model and their parts which we will further simulate and analyze their results using MATLAB/SIMULINK.

III. PROPOSED INVESTIGATED APPROACH

As we stated, in these paper we are investigating the model given in [1], further in future work on which we are going to do simulation analysis. Figure 1 below shows the voltage source inverter fed isolated wind energy conversion system. Power generation system consisting of a wind turbine with a SEIG connected to the isolated load through a power electronic converter is considered.

The variable output voltage from the generator is first rectified using diode bridge rectifier and then inverted by using PWM inverter. In these three phases inverter system consists of six MOSFETS. Three phase inverters are normally used for medium and high power applications. Shunt capacitor is used in the dc link; it acts as a low impedance voltage source. Each switch conducts for 120°. Only two switches remain on at any instant of time.

The output power of SEIG depends upon the wind velocity of the horizontal axis wind turbine. Excitation capacitors are used to reduce the reactive power burden of induction generators [4]. The value of capacitance is to determine the output power production of SEIG. The variable magnitude and variable frequency output is given to the power electronic converters. The voltage source inverter is used to get constant voltage, constant frequency. CSI is used as boost operation of inverter. The dc link voltage ripples in the rectifier output is filtered using shunt capacitor filter. The pulse width modulation technique is used to control the inverter output voltage and frequency. It is also affected by the EMI noise. The block diagram of the system is shown in Fig. 1. Below are major parts of block diagram are presented:

3.1. Wind Turbine

A wind turbine is a turbine driven by wind. Modern wind turbines are technological advances of the traditional windmills which were used for centuries in the history of mankind in applications like water pumps, crushing seeds to extract oil, grinding grains, etc. In contrast to the windmills of the past, modern wind turbines used for generating electricity have relatively fast running rotors [1].

The kinetic energy in the varying wind velocity is converted into mechanical energy by the wind turbine rotor. The rotor blades are made up of reinforced glass fiber, which is mounded on a steel shaft. The wind turbine may be stall-regulated machine or pitch regulated machine. For stall-regulated machines this pitch angle is fixed at the time of installation whereas in pitch regulated machine, it varies for various wind velocities to maintain the output power constant at rated value.

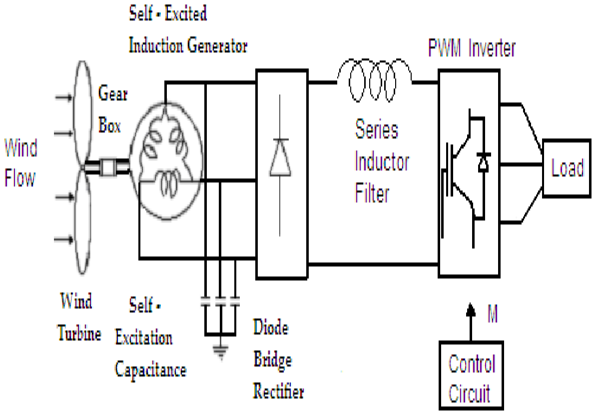

Fig 1: Block Diagram of the voltage source inverter fed Isolated Wind Energy Conversion System

$$KineticEnergy = 0.5pAV.V^2 = 0.5pAV^2 \quad (1)$$

The output power of wind turbine is given by:

$$Pw = 0.5pCpAV_w^3 \quad (2)$$

C_p is expressed as a function of (λ):

$$\lambda = \frac{R\omega_t}{V_\omega} \quad (3)$$

Dimension less power co-efficient
C_p :

$$C_p = 0.5[\frac{116}{\lambda_1} - 0.4\beta - 5]e^{\frac{-16.5}{\lambda_1}} \quad (4)$$

3.2 Self – Excited Induction Generator

The voltage developed in the induction generator due to the residual magnetism. The terminal voltage will build up from small value to a rated value over a period of several seconds [9]. When the slip becomes negative, the output power and developed torque changes from positive to negative, which indicates the motor has become a generator. The dynamic characteristics of SEIG can be represented by the calculations presented in [1].

3.3. Diode Bridge Rectifier and DC Link

Three phase diode bridge rectifier is used to convert variable magnitude, variable frequency voltage at the induction generator terminal into DC voltage [3]. The output voltage is expressed as given in [1]

Input transformer's turns ratio is 1:ηi The series reactor (L) and shunt reactor (C) acts as an input filter. The current ripples and voltage ripples are reduced by using the above components [5].

3.4. PWM Inverter

The output power of the rectifier is filtered by using the LC filter. By using PWM inverter DC power is converted into AC power employing double edge sinusoidal pulse width modulation technique [5]. The PWM signals are used to switch on the IGBT's in the inverter. The IGBT's are connected anti parallel with the diodes. If diode conducts, energy is fed back to the source. A carrier wave is compared with the reference signal corresponding to a phase to generate gating signals. The instantaneous line – to – line

Output voltage is :

$$V_{ab} = V_s(g_1 - g_3)$$

IV. CONCLUSION

In this overview paper the proposed model of self-excitation induction generator is presented and discussed. Here the model is designed using the components like SEIG, PWM Inverter, Capacitors, Diodes, Rectifiers, and three phase load offered. In the literature survey the wind turbine is discussed based energy generation, active and reactive power generations as well as harmonics. For the future work these approaches could be simulated using the three phase two winding transformer and three phase three winding transformer and analyze the results of each block individually along with FFT analysis.

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