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PERFORMANCE OF GRID INTEGRATED WIND ENERGY CONVERSION SYSTEM: AN INVESTIGATION

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Abstract - Increased awareness towards environmental concern has led towards the efforts made to reduce harmful effects of conventional means of electricity generation on environment and to generate electricity from the renewable energy sources like wind and solar. Generation of electricity from wind energy is associated with the advantage of non-ending wind resource devoid of harmful emission or content in it. The proposed investigation in this paper is aimed to achieve the following objectives Design, modeling and simulation of grid integrated SEIG based WECS. Implementation of a SEIG based stand-alone WECS with simplified control structure. Thus the proposed thesis aims at a development of a simulation model which can be utilized for catering the energy needs for remote rural location.

Key Words: Renewable energy, Wind energy system, Induction Generator, WECS, SEIG.

I. INTRODUCTION

The expanding rate of the consumption of customary vitality sources alongside expansion in the interest of electrical vitality have offered ascend to an expanded accentuation on renewable vitality sources. Amongst the different renewable vitality sources, for example, Wind Energy, Solar Energy, Biomass and so on., wind vitality is a standout amongst the most encouraging vitality source in Indian setting. Because of short growth periods for introducing wind turbines, unwavering quality and execution of wind vitality machines, it's a favored decision for force limit expansion in India.

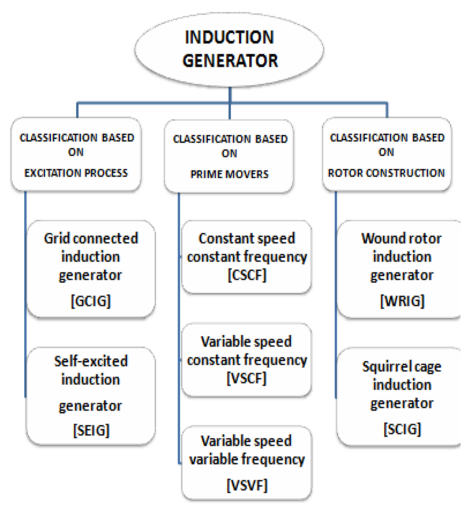
II. INDUCTION GENERATOR FASCILATITATE WIND POWER

An induction generator is a type of electrical generator that is mechanically and electrically similar to an induction motor. To excite the generator, external reactive supply is required, which can be supplied from the electrical grid or from the externally connected capacitor bank. [6]

In standalone induction generators, the magnetizing flux is established by a capacitor bank connected to the machine and in case of grid connected, it draws magnetizing current from the grid. A detailed study of the performance of the induction generator operating in various modes during steady-state and various transient conditions is important for the optimum utilization of the renewable resources, which may be scarce or intermittent. The steady-state performance is important for ensuring good quality power and assessing the suitability of the configuration for a particular application, while the transient condition performance helps in determining the insulation strength, suitability of winding, shaft strength, value of capacitor, and devising the protection strategy. [5, 7]

Classification of Induction Generators

Induction generators can be classified in different ways based on rotor construction, excitation process, and type of prime mover employed. A pictorial representation of classification of induction generator is shown in fig 1.1. [3-5]



International Research Journal of Engineering & Applied Sciences, IRJEAS
www.irjeas.org, ISSN(O): 2322-0821, Volume 8 Issue 4, Oct-Dec 2020, Page 17-23

III.GRID INTERFACE OF WIND ENERGY CONVERSION SYSTEM (WECS)

Early wind power plants were connected to distribution network, but in recent years more and larger wind farms have been connected to transmission networks. There are some specific requirements for connecting a wind power to the network. These issues are related to the stability of the grid which is influenced by power flows and wind farm behaviour in case of network faults. Grid operators develop rules for connecting generators. During the last few years there has been a special interest on the grid integration of wind turbines. The essential grid code requirements are related to frequency, voltage and wind turbine behaviour.

- Active power control, to prevent overloading of grid and to dispatch energy as conventional power plants active power control is indispensable.
- Frequency control, the frequency is kept within the acceptable limits to ensure the security of supply, prevents the overloading of electric equipment and fulfil the power quality standards
- Voltage control, some grid codes demand voltage control of the wind power plants which can be performed by controlling the reactive power.
- Voltage quality, rapid changes in voltage, flickers and harmonics are not advisable for grids. So some set of different requirements are included in grid code to maintain voltage quality.
- Fault ride through capability, to support the power system when it is unstable wind turbines should be remain connected to the grid to support the power system by injecting sufficed reactive power to ensure system stability.

IV. CONTROL OF GRID INTERFACED CONVERTER

To accomplish all the requirements mentioned above control of the grid interfaced converter, the optimum control strategy for the grid side inverter control must be chosen from the following control methods.

The control methods are

- Voltage oriented control (VOC),
- Virtual flux oriented control (VFOC), and
- Direct power control (DPC).

In grid connected applications instantaneous detection of phase angle, amplitude, and frequency of the grid voltage is necessary. According to the standards the controller of a converter is designed to deliver power near to unity power factor. Synchronization of grid and the controller of the inverter is needed and it can be done using different algorithms like phase locked loop etc.

Voltage oriented control (VOC)

This scheme is based on transformation between the abc stationary reference frame and dq synchronous frame. The control algorithm has been implemented in the grid voltage synchronous reference frame. To realize VOC the grid voltage has been measured and its angle θ_g has detected for the voltage orientation. This angle has been used for transformation of variables from stationary frame to synchronous frame and synchronous frame to stationary frame through abc/dq and dq/abc transformations respectively.

There are three feedback control loops in the system two inner current loops for the accurate control of dq-axis currents i_{dg} and i_{qg}. and one outer DC voltage feedback loop for controlling of DC voltage v_{dc}. With VOC scheme three phase line currents in the abc stationary frame i_{ag}, i_{bg}, and i_{cg} are transformed to the two phase currents i_{dg} and i_{qg} in dq synchronous frame. I_{dg} is active power component and i_{qg} is reactive power component of three phase line currents. Independent control of these two components provides effective control of the system active power and reactive power.

Virtual flux oriented control (VFOC)

The concept of virtual flux (VF) can also be applied to improve the VOC scheme. In VOC scheme the grid angle is determined using the grid voltages due to this disturbance superimposed on the line voltages influences the coordinate transformation. This degrades the control of the system. Virtual flux is less sensitive to the line disturbances. VFOC proposes the use of virtual flux by integrating the line voltages this integration acts like a low pass filter to the disturbances. The angle determined by using this flux will be in quadrature with the grid angle but less sensitive to the grid disturbances.

Direct power control (DPC)

This control method is a simplified version of VOC. The only difference between these control algorithms is that the current controllers are eliminated. The power controllers produce directly the voltage references for the space vector modulation or switching table. This is why this method is called direct power control. A conventional PLL is used in this strategy for detecting the grid angle. The power used to balance the DC voltage is estimated using the DC voltage controller output and other PI controllers are used for active and reactive power controllers.

V. POWER SPEED CURVE FOR WIND TURBINE

The power characteristics of a wind turbine are defined by the power curve, which relates the mechanical power of the turbine to the wind speed. A typical power curve is characterized by three wind speeds: cut in wind speed, rated wind speed, and cut

International Research Journal of Engineering & Applied Sciences, IRJEAS
www.irjeas.org, ISSN(O): 2322-0821, Volume 8 Issue 4, Oct-Dec 2020, Page 17-23

out wind speed as shown in Fig. 5.1. The PM is the mechanical power generated by wind turbine and V_w is the wind speed. The cut in wind speed is the speed at which turbine starts to operate and deliver the power. The rated wind speed is the speed at which the system produces nominal power, which is also the rated output power of the generator. The cut out wind speed is the highest wind speed at which the turbine is allowed to operate before it shut down. Until the wind reaches its rated value the power captured by the blades is the cubic function of wind speed. To deliver the captured power at different wind speeds the wind turbine should be operated in the operating region. As the wind speed reaches beyond the rated value it should be aerodynamically controlled to keep wind turbine in the operating range.

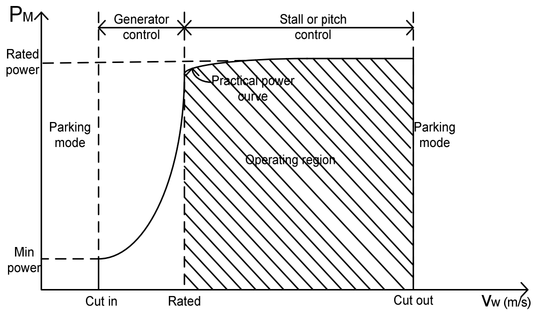


Fig. 5.1 Turbine mechanical power versus wind speed curve

Configurations of WECS

Wind power conversion has led to the development of different types of WECS configurations for accessing variety of generators listed in Sec. 3.2 A classification of WECS configuration is given in Table. 5.1.

Table 5.1 Configuration in WECS

Wind energy conversion system configurations		
1. Variable speed WECS	2. Fixed speed WECS	
a) Indirect Drive	b) Direct Drive	
SCIG	WRSG	SCIG
WRIG	PMSG	
DFIG		
WRSG		
PMSG		

VI. GRID CODE

Early wind power plants were connected to distribution network, but in recent years more and larger wind farms have been connected to transmission networks. There are some specific requirements for connecting a wind power to the network. These issues are related to the stability of the grid which is influenced by power flows and wind farm behaviour in case of network faults. Grid operators develop rules (grid codes) for connecting generators. During the last few years there has been a special interest on the grid integration of wind turbines. Essential grid code requirements are related to frequency, voltage and wind turbine behaviour.

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- Voltage quality, rapid changes in voltage, flickers and harmonics are not advisable for grids. So some set of different requirements are included in grid code to maintain voltage quality.
- Fault ride through capability, to support the power system when it is unstable wind turbines should be remain connected to the grid to support the power system by injecting sufficed reactive power to ensure system stability.

Grid interconnection of a wind turbine needs to fulfil the following requirements:

- Controlling of active power during frequency variations (active power control).
- Ability to supply or consume reactive power depending on power system requirements (reactive power control).
- Assistance for grid voltage maintenance by adjusting the reactive power (voltage control).
- Should be supportive to the grid during fault on the grid (fault ride through capability).

Limiting the power increase to a certain rate (power ramp control).

Control of grid interfaced converter

To accomplish all the requirements mentioned above control of the grid interfaced converter is indispensable. Grid side inverter can be controlled in three ways. The optimum control strategy for the grid side inverter control must be chosen from the following control methods.

The control methods are

- Voltage oriented control (VOC),
- Virtual flux oriented control (VFOC)
- Direct power control (DPC).

VII. PROPOSED SYSTEM CONFIGURATION AND PRINCIPLE OF OPERATION

Fig. 7.1 shows the system configuration of the proposed WECS. The power generated by the wind energy system is converted with the help of power electronics interface, so that it can be synchronized with grid.

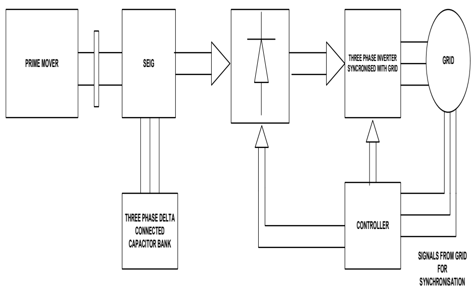


Fig 7.1 Configuration of the proposed WECS

The Simulink model of the proposed system is shown in fig. 7.2. The major components of proposed WECS such as prime mover, SEIG, uncontrolled rectifier, capacitor bank, AC to DC converter, voltage source inverter and control blocks are also shown in fig. 7.2.

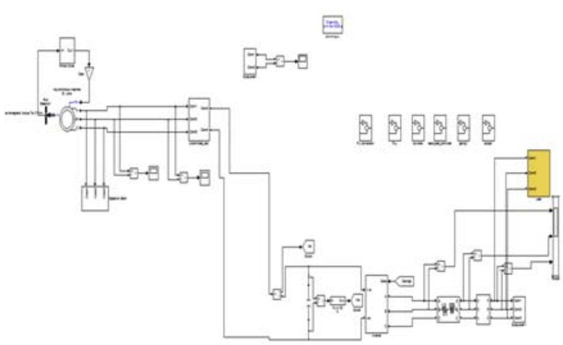


Fig. 7.2 Simulink model of proposed system

It can be seen from fig. 7.2 that the major components of the proposed WECS are:

- A prime mover
- A self-excited induction generator
- An uncontrolled rectifier
- A three phase delta connected capacitor bank for excitation
- An AC to DC converter
- A three phase voltage source inverter
- Control blocks
  The proposed WECS has been connected to a three phase load.

VIII. THE CONTROL ALGORITHM

The kinetic energy present in wind is converted into mechanical torque with the help of prime mover which is finally converted into electrical energy using a self-excited induction generator (SEIG). Since the nature of electrical power obtained from the renewable energy source in intermittent. Hence control algorithm with power electronic interface has been developed. So that a grid interface model of the proposed system can be developed. The proposed WECS can also be used in stand-alone configuration.

The AC power generated by the induction generator is converted to DC power with the help of an AC to DC converter which is further fed to a voltage source inverter, so that it can be properly synchronized with the grid through an interfacing inductance.

The control algorithm for the proposed system is implemented as follows:

- The voltage signal from the grid are sensed and then converted into respective per unit quantities by choosing a proper base values.
- The DC link voltage (output of AC to DC converter or the input of inverter) is also converted to its per unit values.

The per unit voltage signal fetch from the grid (V_g per unit) are transformed with the help of Clark transformation (a, b, c to α, β) so as to obtain $V_\alpha$and V_β per unit.

The per unit signals obtained as the output of this conversion blocks are the signals which will be utilized for grid synchronization.V_α, V_β and θ which are obtained from three phase to two phase conversion block are further converted to V_d and V_q by Park's transformation. The per unit DC link voltage is compared with reference per unit DC link signal. The magnitude of the reference DC link signal is calculated based on the magnitude of the desired AC voltage output which has to be synchronized with grid. Per unit DC link signal is passed through a low pass filter to block high order frequency. The error signal between the desired DC link voltage and reference DC link voltage is further processed to PI controller to generate the reference control signal (V_{di} pu and V_{qi} pu)

The gating signals are generated by comparing three phase reference control signals (V_a^*, V_b^*& V_c^*) with the high frequency triangular carrier signal. The PWM signals generated through these comparison blocks acts as the firing signal for the grid connected inverter.

The reference control signal which has been discussed in the previous sub-section are obtained through inverse

International Research Journal of Engineering & Applied Sciences, IRJEAS
www.irjeas.org, ISSN(O): 2322-0821, Volume 8 Issue 4, Oct-Dec 2020, Page 17-23

Park's transformation. The inverse Park's transformation requires angle θ which has been obtained from the PLL sub-system. The control signals V_d and V_q which are the output of decoupled control sub-system along the angle θ is utilized to transform V_{di}& V_{qi} to V_a^*, V_b^*& V_c^*.

IX. RESULTS AND DISCUSSION

Shown in figure 9.1 is the voltage output of the generator. It can be seen that it is having a peak value of approximately 586 V, which is equal to (415×√2).

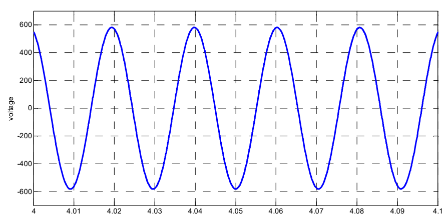


Fig. 9.1 Waveform of output voltage of generator

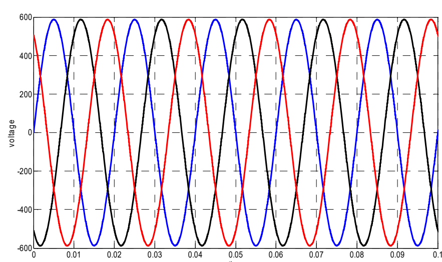


Fig. 9.2 Three phase output voltage waveform of the grid

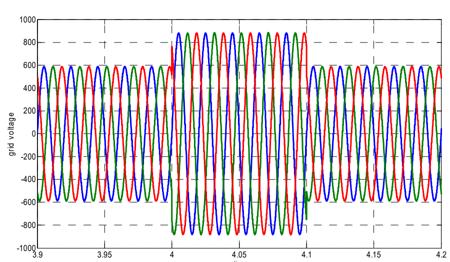


Fig. 9.3 Waveform of voltage disturbance in the form of swell

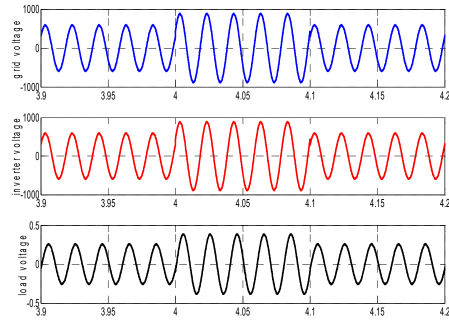


Fig. 9.4 Phase voltage waveform of grid, inverter and load

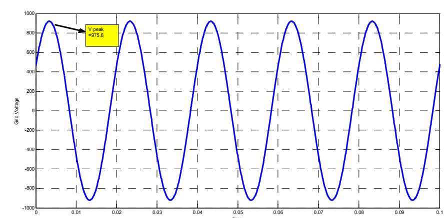


Fig. 9.5 Waveform of grid voltage at 690V

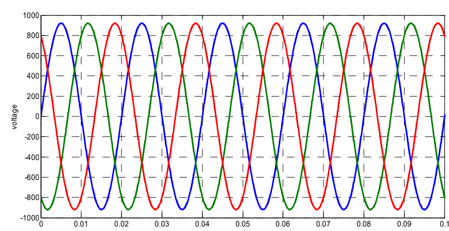


Fig. 9.6 Three phase voltage waveform at 690 V

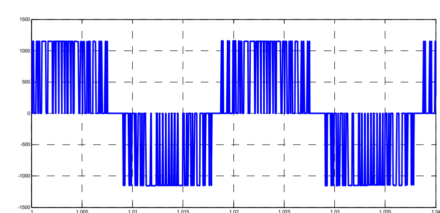
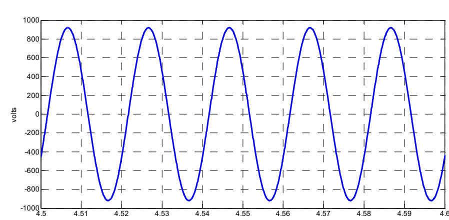


Fig. 9.7 Waveform of inverter output voltage



International Research Journal of Engineering & Applied Sciences, IRJEAS
www.irjeas.org, ISSN(O): 2322-0821, Volume 8 Issue 4, Oct-Dec 2020, Page 17-23

Fig. 9.8 Waveform of load voltage waveform at 690 V

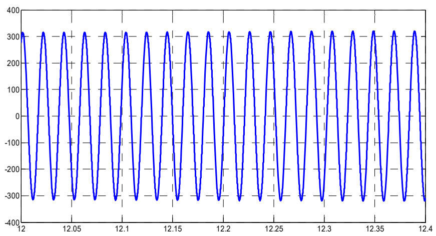


Fig. 9.9 Waveform of generator output voltage

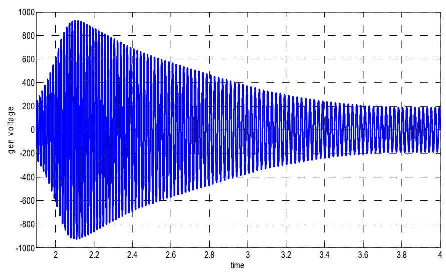


Fig. 9.10 Voltage build up process of self-excited generator

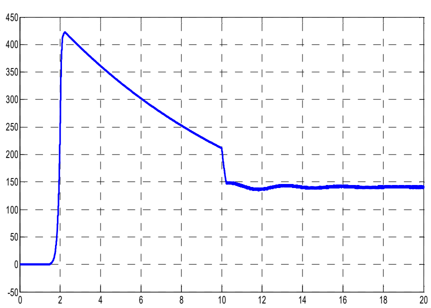


Fig. 9.11 Output voltage of AC to DC converter

X.CONCLUSION

In this thesis an investigation on a grid integrated wind energy conversion system having a self-excited induction generator is carried out in detail. The stand-alone topology of the same system also has been discussed in this thesis. From the simulation model and proposed results it has been concluded that the proposed topology helps to maintain the grid integration maintaining the frequency and voltage constant. Since the scheme involves a self-excited induction generator, hence it can be suitable for remote and rural application where maintenance is a cheap concern.

The proposed system has been tested for a variation in a grid voltage (sag and swell) and it has been seen from the simulation results that the system maintains synchronism with the grid.

A simplified scheme based on its stand-alone version (without grid integration) has also been implemented in this thesis. Since the stand-alone scheme involves less complex algorithm hence it can be suitable for remotely located areas.

Thus it can be finally concluded from this thesis that a grid integrated and stand-alone WECS has been can be implemented maintaining grid synchronism. Thus thesis has resulted into the development of a simulation model for such a system.

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