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RESEARCH ARTICLE

Voltage Control of a STATCOM using Posicast and P+Resonant Controller at a Fixed Speed Induction Generator Wind Farm

***R Lal Raja Singh[1], R Leena Rose[2], J Chinnu[3]**

[1]Kalaignar Karunanidhi Institute of Technology, Kannampalayam, Coimbatore, Tamil Nadu, India.

[2]Sasurie Academy of Engineering, Kariyampalayam, Coimbatore, Tamil Nadu, India.

[3]Marthandam College of Engineering and Technology, Kuttakuzhi, Veeyannoor, Kanyakumari, Tamil Nadu, India.

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ABSTRACT

This paper investigates the operation of a Fixed-Speed Induction Generator (FSIG) wind farm by connecting it with a STATCOM to control the positive and the negative-sequence voltage in case of any faults in the grid and relates the effect of wind turbine behaviour. The positive and the negative sequence voltage lead to either an increase in the voltage stability of the wind farm or reduction of torque ripple which further increases the lifetime of the generator driver train. It also proposes a multiloop controller using posicast and P+Resonant controllers to improve the transient response thereby eliminating the steady-state error in STATCOM response. It also handles the disturbances in load voltage and the three-phase circuit fault caused by FSIG wind farm, limits the downstream fault current to restore the Point of Common Coupling (PCC) voltage and protects the wind farm from other disturbances.

Keywords: FSIG, STATCOM, Torque ripple, Posicast, P+Resonant, PCC.

1. INTRODUCTION

Due to the fast depleting nature of conventional fuels and its dangerous effect on climate, a situation arises to create and ensure a pollution free environment by using non-conventional sources like green electricity sources like wind energy, solar energy, tidal energy etc. Among all the other farms of renewable energies, wind is a cleaner and cheaper form of renewable resource. From 20th century itself, people have started using small wind farms. Thus wind energy has become one of the fastest growing sources of renewable energy which is used for electricity production especially in the remote rural areas in the world today. The main purpose of a wind power is to maintain the voltage between valid limits in order to ensure security and power quality purposes. As wind penetration into the grid increases, the influence of wind farms on the power system operation turns to be more important. Variable wind speed generators are able to control the reactive power exchanged within the grid due to the power electronic devices that they include. The two main functions of wind farms are reactive power control during normal conditions and handling fault ride-through capability at faulty conditions. [1] addressed the impact of STATCOM at the presence of weak transmission grids in the wind power based generation transmission systems. In this method, the Static Var Compensator (SVC) and the STATCOM are connected to the transmission system to maintain system stability at the point of coupling. It suppresses the voltage fluctuations but unable to reduce the torque ripple, which gradually decreases the life time of the generator. [2] addressed the stability of wind farms based on fixed speed induction generators and presented a Static Var Compensator (SVC) based on Auto Disturbance Rejection Control (ADRC) that avoids the problems in relation with low

*Corresponding author. Tel.: +919443371311
Email address: lalrajasingh@yahoo.com (R.L.R.Singh)
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voltage and its fluctuation. This system suffers more by using bulky transformers for stepping up voltage or during the power distribution. It may result in high maintenance cost compared with the other wind farms using STATCOM. [3] used Sub-Synchronous Resonance (SSR) to refer the electro mechanical oscillatory behaviour that was caused by coupling between turbine and the transmission system. This method uses Unified Power Flow Controller (UPFC) to enhance the systems stability, thereby decreasing the SSR of wind turbines. This system gets affected and damaged by the low wind speed rather than the high speed wind. [4] used squirrel cage generators to analyze the Low Voltage Ride-Through (LVRT) capability of wind farms, which is enhanced by the usage of STATCOM. Here in this method, the transient stability margin is developed which can be applied as the measure of LVRT capability. Incase if the DC-link voltage gets a sudden increase beyond a certain limit, then it would lead to the failure of power electronic converter. [5] focused on the technical requirements of wind farms including grid codes such as active and reactive power regulation, voltage and frequency operating limits and the wind farm behaviour during grid disturbances. It also includes a review on technologies regarding their stability and regulation capabilities directly to those conventionally generating power from the wind farms. But the chance for the occurrence of three phase fault is high. [6] proposed a Unified Power Quality Conditioner (UPQC) to deal with the grid integration problems and to enhance the fault ride through capability of the generator. If fault occurs in a system then immediately voltage sag is experienced at the machine terminals and it would result in over-speeding of the machine. Hence it's difficult to handle the voltage stability during the power transmission. [7] investigated the operations of Doubly-Fed Induction Generator (DFIG) and FISG based wind farms under unbalanced grid conditions. Unbalanced voltage causes unequal heating on the stator windings, thus, resulting in negative sequence current or voltage and torque oscillations. [8] used a STATCOM to improve the stability of the fixed speed induction generator. It ensures the fault-ride-through enhancement of wind farms by compensating it with the positive sequence voltage. But this work also fails to handle torque ripple during the grid fault. [9] provided a strategy based on both technical as well as economical consideration by introducing stringent requirements. It is designed to handle the grid faults and to promote the voltage stability, but ensuring network integration seems to be complex in this method. [10, 11] proposed four mathematical transformations and two stationary reference frames for eliminating odd harmonics from original signals and two other transformations to eliminate even harmonics, where these transformations are implemented in a synchronously rotating reference frame. It works well for handling positive sequence voltage whereas its performance in dealing with negative sequence voltage should have been improved. [12] enables the usage of Superconducting Magnetic Energy Storage (SMES) unit to improve ac/dc power system performance. Even though it uses an electromagnetic transient program power system simulation to study the forms of typical time or harmonic responses, the system is unable to provide flexible reactive power flow control. This problem is managed by using STATCOM along with a Proportional Integral (PI) controller as in [13]. While considering STATCOM, it controls the damping sub synchronous oscillations and improves the transient stability of the wind turbine, but, it would lead to positive as well as negative sequence voltage problems. [14] used an electromagnetic transient model for fixed-speed wind turbines in order to determine the impact of different model parameters on the simulated responses. It is used for assessing induced over voltage condition when wind farms are isolated from the grid, but the impact on stability of the wind farm gets varied. To retain the stability margin of the induction generator, [15] provided a control system based on STATCOM reactive power and rotor blades pitch angle. In some cases it is suffered by unbalanced fault conditions occurring in the transmission or distribution lines leading to reduced reliability. Such types of faulty conditions are solved by using bridge type Fault Current Limiter (FCL) with a discharging resistor [16, 17, 18]. In this method the squirrel cage induction generator is equipped with the Wind Energy Conversion System (WECS). Though this method takes several steps in controlling generator current and in damping of mechanical oscillation at the occurrences of faults, it is unable to limit the steady fault current that is increasing gradually.

Hence it is mandatory to perform an investigation on the fixed speed induction generator to face with the fault current or grid fault and to overcome the impacts of negative and positive sequence voltage. By doing so, a point of common coupling is achieved which protects the wind farms by preventing it from over-speeding and thereby reduces the occurrence of steady state error.

2. METHODOLOGY

The main objective of this work is to improve the transient behavior of fixed-speed wind farms using the analysis of STATCOM rating and voltage control by posicast and P+Resonant. This would be explained by the block diagram represented in figure 1.

2.1. Wind turbine

Wind turbine is a device that converts the kinetic energy from the wind into an electric current. It is designed to exploit the wind energy at the location where it has been placed. The general structure of a wind turbine with its components is represented by the figure 2.The blades in the wind mill are arranged in horizontal manner to propel the wind for electricity.

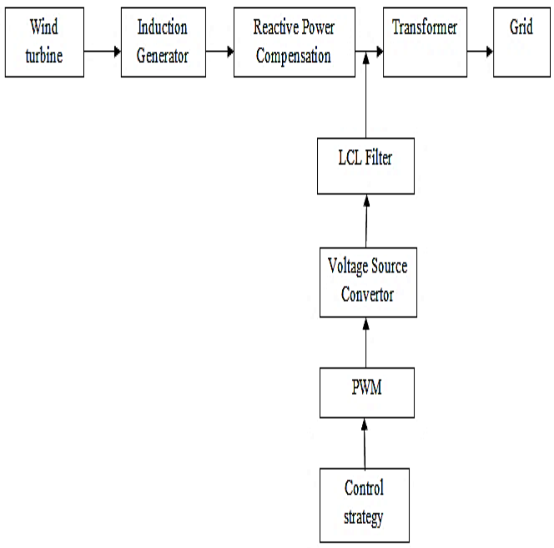

Figure 1.Block diagram of STATCOM control FSI based wind turbine

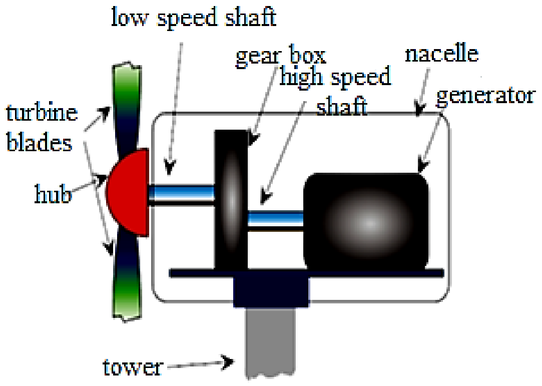

Figure 2.Parts of wind turbine

Figure A1 describes the simulation model, which is based on the steady state characteristics of the turbine. The blades in the turbine can be adjusted to face the wind direction and the blade pitch angles can be tuned in order to control the speed of the pitching system. Once the turbine starts rotating, the stiffness of the drivetrain which is shown in figure 3 will be infinite.

A drivetrain comprises the three major components of wind turbine. It includes: main bearing, gearbox and generator. A gear box is a component which is placed between the hub and the generator. It is used here to convert the slowly rotating torque power from the wind turbine to high speed low torque power used by the generator. The protection strategy of a wind turbine is described by figure A2.

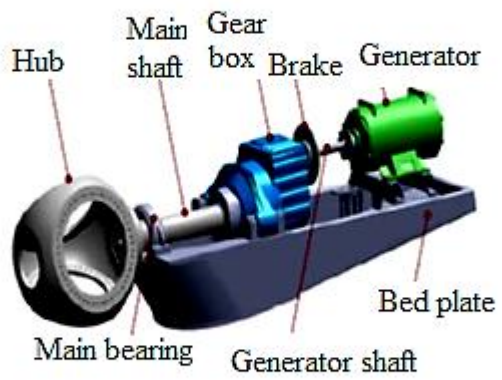

Figure 3.Wind turbine drivetrain

2.2. Induction generator

Induction generator is an asynchronous generator which works on the principle of induction motors to generate power by turning their rotors mechanically faster than the synchronous speed. It develops a counter-torque that is sufficient to overcome the force of gravity. The friction factor and the inertia of the turbine are then combined with the generator coupled to the turbine. It would generate an output power described by equation (2.1),

$$P_m = c_p(\alpha, \beta)\frac{\rho A}{2}u_{wind}^3 \quad (2.1)$$

Let P_m be the mechanical output power of the turbine, c_p be the performance coefficient of the turbine, A be the turbine swept area and u_{wind} be the wind speed, α and β be the tip speed ratio of the rotor blade tip speed to wind speed and the bade pitch angle respectively. An asynchronous machine operates either as a generator or as a motor which depends on the mode of operation dictated by the sign of the mechanical torque. If the input signal is positive then the machine works as a motor and if the signal is negative then the machine will work as a generator.

2.3. Reactive power compensation

To enhance the performance of the Alternate Current (AC) systems, reactive power (VAR) compensation will be used. There is a need to compensate the reactive power in order to adjust the power factor of a system and to maintain the voltage stability and security of the power systems. The demand of lowering the power loss, ensuring faster response to the system parameter changes and providing high stability give rise to the development of the Flexible AC Transmission Systems (FACTS).

Static Synchronous Compensator (STATCOM) is a device used as a voltage or current source invertor that will control the output current independently of the AC voltage. It allows an increase in the rate of transferring the power through the transmission lines by regulating the flow of reactive power in the system independent of various system parameters of power including voltage, current, phase angle and frequency The instantaneous reactive power is given by the formulation in (2.2),

$$p = \frac{VmaxImax}{2}\sin\theta \sin 2\omega t \quad (2.2)$$

Let p be the instantaneous power, where Vmax be the peak value of the voltage waveform, Imax be the peak value of the current waveform, ω be the angular frequency, t be the time period and θ be the angle by which current lags the voltage in phase. Several combinations of switching devices make the topology possible for a STATCOM to vary the AC output voltage in both magnitudes as well as in phase.

2.4. Power control strategy

A STATCOM consists of three phase inverter to provide Direct Current (DC) voltage for the inverter, a reactor link that connects the inverter output to the alternate current supply side and some filter components to filter out high frequency components. Figure A3 describes the power system structure that consists of a squirrel cage induction generator that is directly connected to the power grids. It represents an aggregate model of the wind farm, which ensures the sum of turbines that is modelled as one generator using a standard T-equivalent circuit. A series of Rp-Cp (Resistor and capacitance in parallel) snubber circuit is used in order to minimize the three-phase fault which is given in figure 4.

If the three-phase fault has been set in the external mode, then a control input will appear in the block icon. The input must be either 0 or 1. If the input is 0, then the breakers will be open and for input 1, they will be closed. If the three-phase fault is set in internal control mode, then the switching times and status will have to be specified in the dialog box of the block. If the three-phase fault block is in series with an inductive circuit then the open circuit must have to use the snubbers.

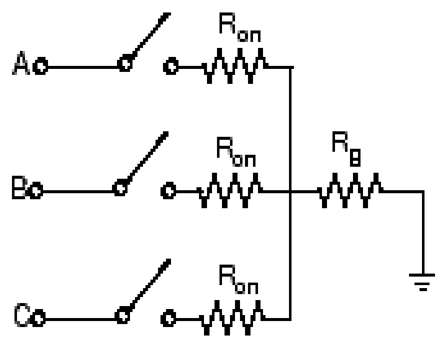

Figure 4.Three phase fault

The Torque of the induction generator T+ is obtained by the formulation (2.3),

$$T^+(s) = 3\frac{p}{2}\frac{R_r}{s\omega_s}\frac{(V_s^+)^2}{(R_s+R_r/s)^2+j(X_s+X_r)^2} \quad (2.3)$$

Let R_s, R_r, X_s and X_r be the typical stator and rotor resistance and impedance parameters correspondingly, p be the number of pole pairs, ω_s be the grid frequency and s be the slip. In some cases due to over speed the induction generator may be disconnected from the grid. Otherwise it may lead to voltage collapse in the network. When the grid voltage is unbalanced, a small amount of negative sequence voltage V_s^- will lead to a high amount of negative sequence current I_s^-. It is represented by the equation (2.4),

$$I_{s,pu}^- = \frac{V_s^-}{\omega_s\, \sigma L_s I_{s,N}} \qquad (2.4)$$

where σ be the leakage factor $I_{s,N}$ be the rated stator current and L_s be the stator inductance. The negative sequence current causes a torque oscillation of double grid frequency. Thus the magnitude of the negative sequence torque T^- can be calculated by the equation (2.5),

$$T^- \approx 3\frac{p}{2\omega_s} V_s^+ I_s^- \qquad (2.5)$$

This negative sequence stator voltage will cause torque oscillations, which may reduce the lifetime of the turbine drivetrain. To overcome this problem of dealing with negative as well as positive sequence voltage, a STATCOM control structure has been proposed and implemented using Posicast and P+Resonant, which is represented by figure A4.

2.4.1. Posicast

Posicast controller in FSIG wind farm will be used to improve the transient response. The posicast controller limits the high-frequency gain and hence it acts as being low sensitive to noise. Transfer function of the posicast controller is explained by the equation (2.6),

$$1 + G(S) = 1 + \frac{\delta}{1+\delta}\left(e^{-S^{T_{d/2}}} - 1\right) \qquad (2.6)$$

where δ is the step response overshoot and T_d is the period of dumped response signal. To limit the fault current and to protect the dc-link capacitor and the STATCOM components, a flux charge model as shown in figure A5 has been used. Here the value of the virtual inductance of STATCOM is fixed and the PCC voltage has been used as the main reference signal. In this control strategy, the control variable used for outer flux model is the inverter-filtered terminal flux, which is defined by equation (2.7),

$$\emptyset = \sqrt{V_{Odvr}}dt \qquad (2.7)$$

where ∅ be the reference flux and V_{Odvr} be the filter capacitor voltage of STATCOM. The flux error is then fed to the flux regulator, which is termed as P+Resonant controller.

2.4.2. P+Resonant control

In order to eliminate the steady state voltage tracking error, a P+Resonant controller has been implemented in this work. An ideal P+Resonant can be mathematically defined by the formulation (2.8),

$$GR(S) = K_p + \frac{2K_I}{S^2+\omega_0^2} \qquad (2.8)$$

where K_p and K_I be the gain constant and $\omega_0 = 2\pi * 50$ rad/sec be the controller resonant frequency. An infinite gain at the resonant frequency is introduced theoretically in the resonant controller to compensate and to enforce a steady state voltage error to zero. A non-ideal resonant controller has been implemented and is expressed by means of the formulation (2.9),

$$GR(S) = KP + \frac{2K_I\omega_{cut}s}{S^2+2\omega_{cut}s+\omega_0^2} \qquad (2.9)$$

Let ω_{cut} be the compensator resonance frequency. It is generally used here to eliminate the voltage tracking error thereby minimizing the sensitivity of the compensator with minute utility frequency variations.

2.5. Pulse Width Modulation (PWM)

PWM is a method of delivering energy through succession of pulses than by continuously altering the analog signals. The PWM generator block generates the carrier–based pulse width modulation converters using two set of topologies. The simulation circuit diagram of PWM is described in figure A6.

Thus by increasing or decreasing the pulse width, the controller will regulate the energy flow to the motor shaft. The motor's own inductance will act as a filter. The amplitude, phase and the frequency of the reference signals are then set to control the output voltage of the bridge that is generated by the reactive power compensator connected to the PWM generator block.

2.6. Voltage Source Converter (VSC)

The voltage source converter is a commonly used building block in FACTS methodology which acts as a shunt compensator or a hybrid compensator along with the Unified Power Flow Controller (UPFC) and the Interline Power Flow Controller (IPFC). The simple diagrammatic representation of voltage source converter is shown by figure 5.

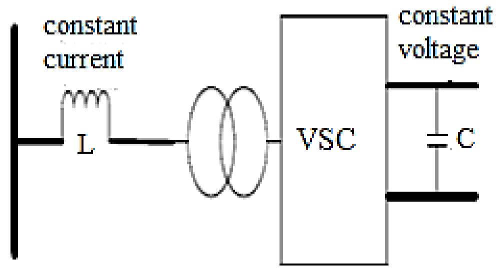

Figure 5.Voltage source converter

When VSC is connected to a three-phase load, a constant current is transferred to the voltage source converter through an inductance L in series connection. The voltage source converter immediately converts the current into a constant voltage. At the other end, a capacitor C is connected in parallel to control the voltage production. The continuous time representation of the converter will ensure better accuracy in this operation.

2.6. LCL-filter

LCL filters use small inductors in order to achieve the necessary damping of switching harmonics. The diagrammatic representation of LCL filter is described by figure 6.

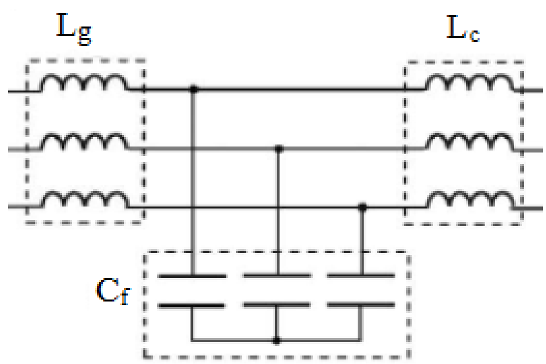

Figure 6.LCL filter

Figure 6 shows the simulation circuit structure of the LCL filter, where the resistors are connected in series with the filter capacitors actively by using control algorithms without increased power losses.

2.7. Transformer

The major component needed to perform grid connection in wind farm is the transformer. It is located beside the wind turbine for avoiding the usage of long low-voltage cables. If the size of the wind farm is large and the distance to the grid is long, then there is a need for transformer to step-up the medium voltage in the wind farm to the local high voltage transmission level. Wind turbines are equipped with step-up transformer, generally to step-up the generator voltage typically from low voltage (1kV) to medium voltage (36kV). The main function of a transformer is to increase the voltage that is suitable for transmitting the energy produced.

2.8. Grid

Grids are responsible for transferring electrical power from the wind farm using high- voltage transmission lines to the demand centers. Wind turbines that are connected to the grid may be frequently subject to grid faults, which are characterized by a change in the magnitude of voltage and with respect to the time duration. Fault- ride through requirements are used here to avoid the significant losses of power produced by wind turbine in the event of grid faults. This capability primarily addresses the design of wind turbine controller to remain grid-connected even during the grid faults.

3. RESULTS AND DISCUSSION

The proposed framework has been implemented using MATLAB SIMULINK. This section summarizes the simulation results of voltage control using posicast and P+Resonant controllers in a fixed speed induction generator wind farm. Figure 7 represents the source voltage under fault causing voltage sag, which is monitored by the STATCOM structure to control the negative and positive sequence voltage.

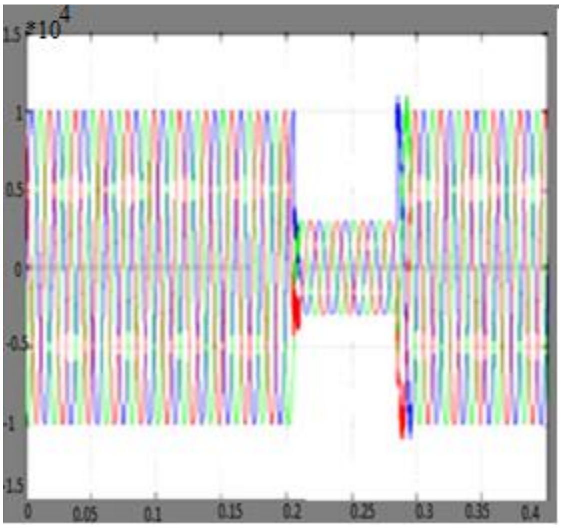

Figure 7.Source voltage under fault causing voltage sag

The capability of the STATCOM is to compensate the voltage that depends on the chosen current rate of the STATCOM and the impedance of the power system. For any particular bus voltage, there would be a minimum frequency below which the system can't generate the power. The estimation of bus voltage using MATLAB simulation for the proposed work is represented by the figure 8.

The stator current has been affected by the speed of the generator, the size of the inductance and the stator load. The simulation of the stator and the STATCOM current waveform generated by the proposed work are shown in figure 9 and figure 10.

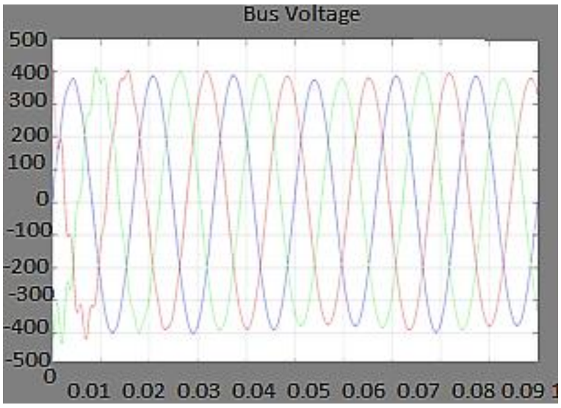

Figure 8.Bus voltage waveform

By compensating the positive and negative sequence voltage, the torque capability of the induction generator gets increased and the torque oscillations of the induction generator will be avoided. When comparing with the existing method, the proposed work eliminates the steady state error in the STATCOM responses. This can be described by the bus voltage and stator current waveform obtained from the existing methods as shown in figure 11.

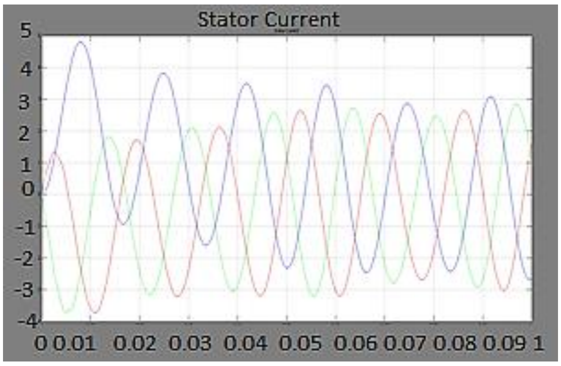

Figure 9.Stator current wave form

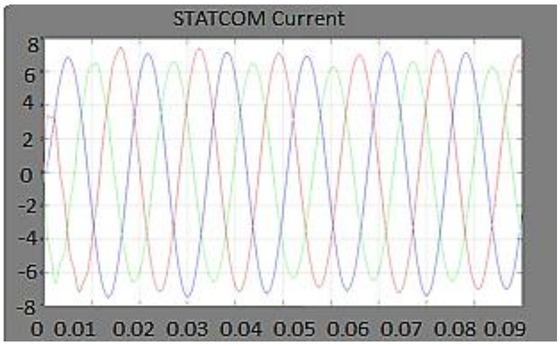

Figure 10.STATCOM current wave form

Thus the simulation results verify the effectiveness and capability of the proposed technique while compensating for the voltage sags caused by short circuits thereby restoring the point of common coupling.

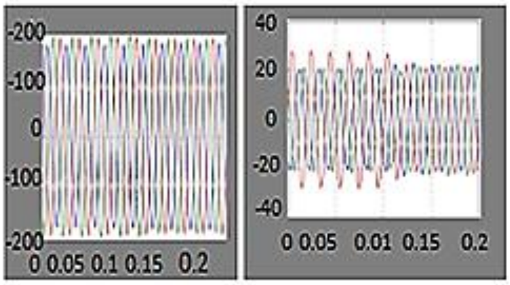

Figure 11.Bus voltage, stator current waveform

4. CONCLUSION

This project proposes a fixed speed induction generator wind farm using posicast and P+Resonant controller to handle the positive and negative voltage sequences by avoiding the oscillations and increasing the capability of the induction generator. Also, flux charge model limits the downstream grid faults, thereby protecting the PCC voltage during these faults by acting as variable impedance. The closed loop control system in the proposed work improves the transient response of the induction generator and eliminates the steady state error. Furthermore even if the voltage generated is not controlled properly, the STATCOM might contribute to voltage sag during the process of compensating the missing voltage. Hence there is a possibility of worsening the fault situation. Therefore in future the work could be expanded with more advanced techniques to compete the challenges in FSIG wind farms.

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APPENDIX A

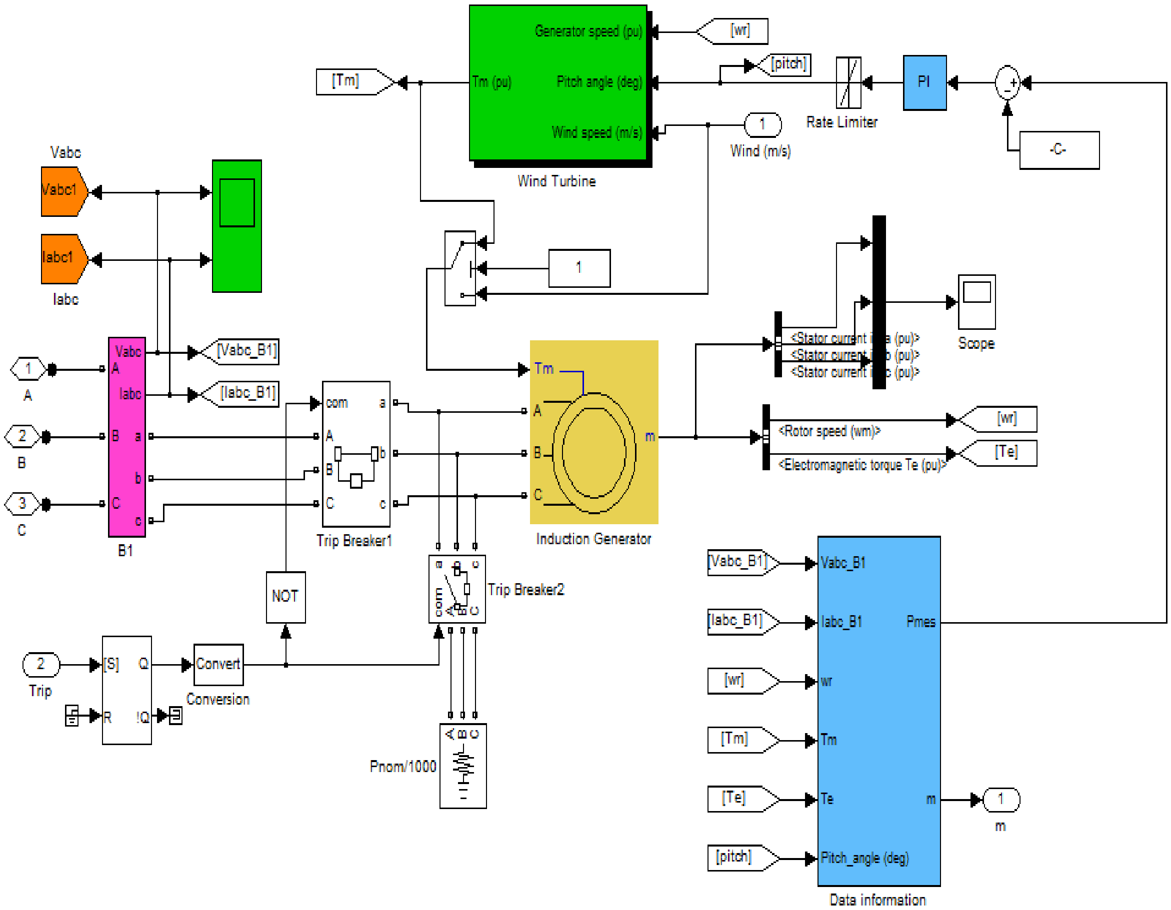

Figure A1.Simulation model of wind turbine

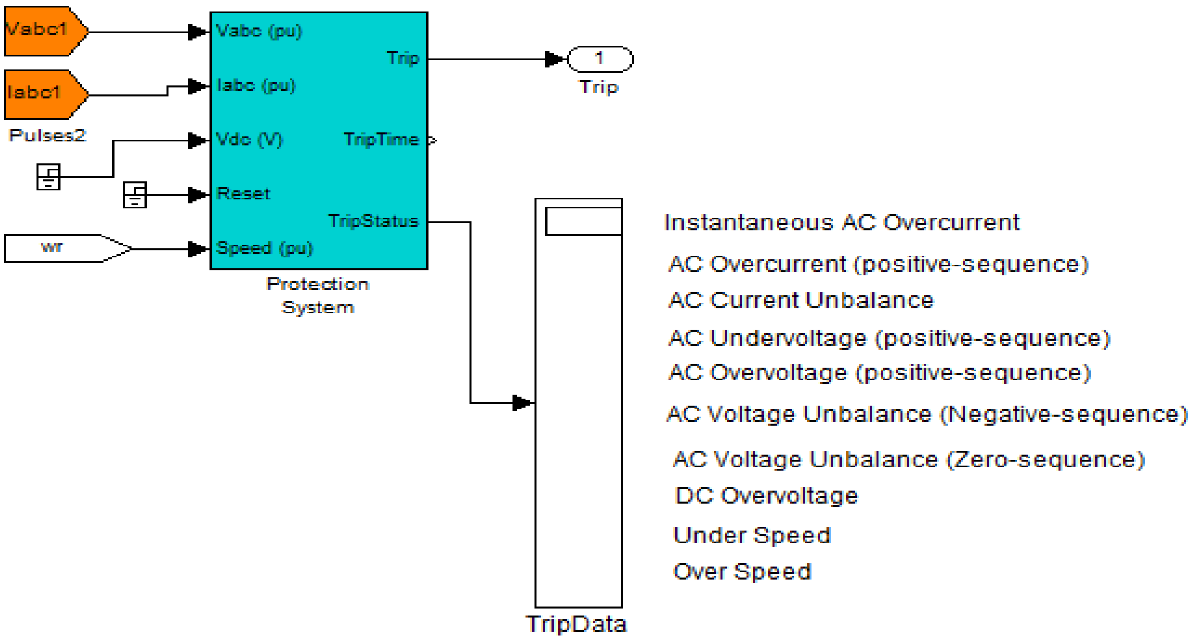

Figure A2.Wind turbine protection

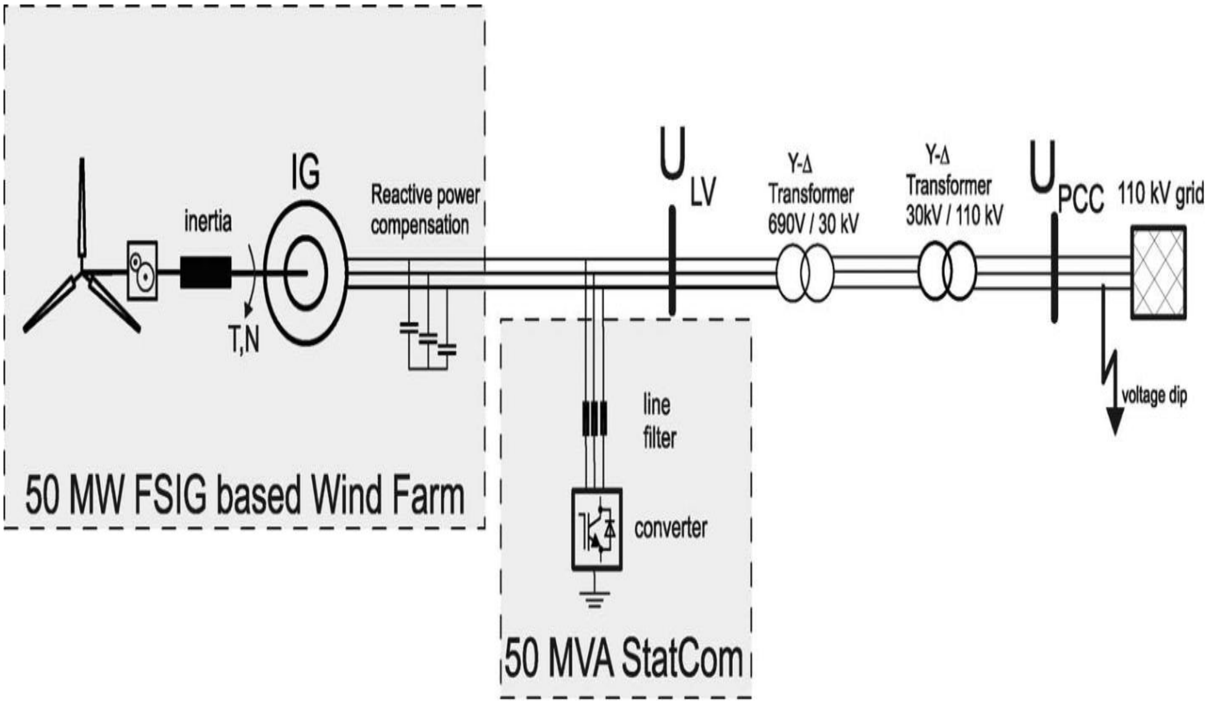

Figure A3.Power system structure

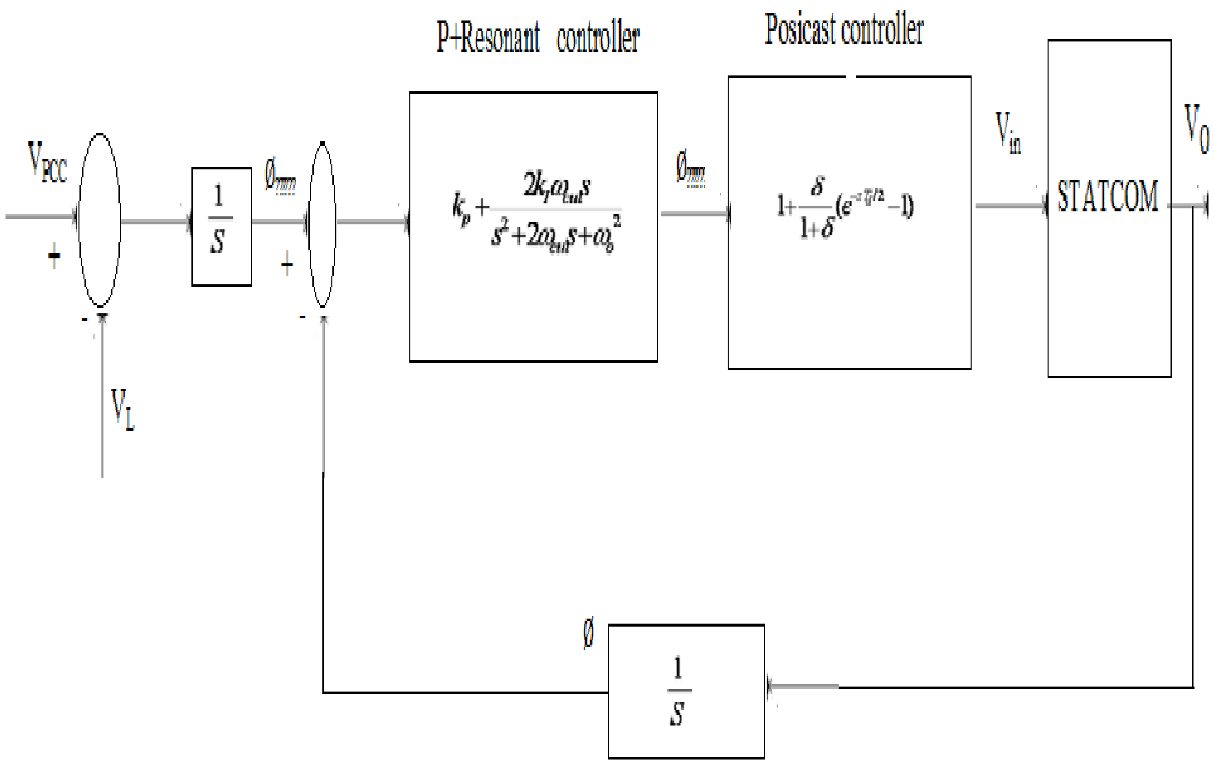

Figure A4.STATCOM control structure

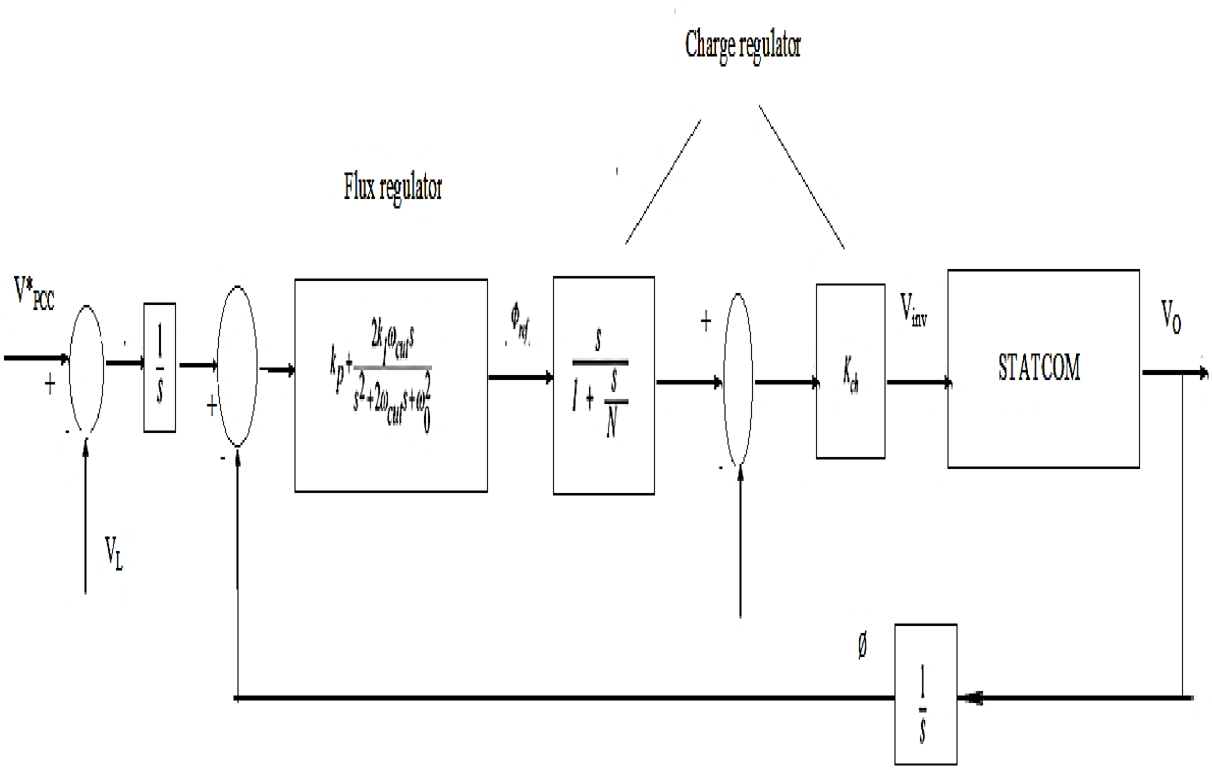

Figure A5.Flux charge model

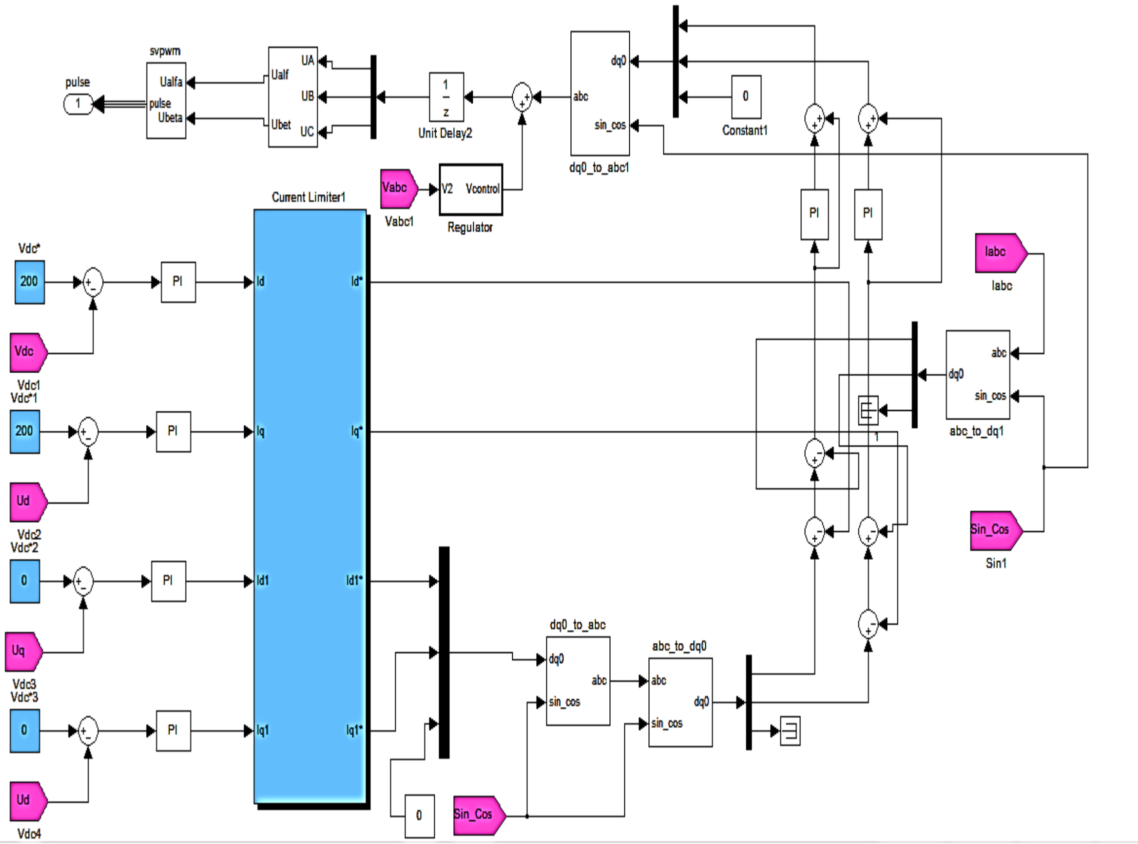

Figure A6.Simulation circuit diagram of PWM