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STATCOM Control under Asymmetrical Grid Faults at FSIG-Based Wind Farms

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Abstract: **This paper proposes a STATCOM control structure with capability to coordinate the control between the positive and the negative sequence of the grid voltage. The positive-sequence voltage compensation leads to an increased voltage stability of the wind farm and the negative sequence voltage compensation leads to reduction of torque ripple, increasing the life time of the generator drive train. In the damping of the torque ripple of the generators, the STATCOM control is more effective. It provides fast response, flexible voltage control for power quality improvement regulates voltage and improves dynamic stability and voltage stability. This paper uses d-q theory for reference compensation current generation and space vector pulse width modulation (SVPWM) for gate signal generation. The results are validated by simulating the fixed speed Induction Generator (FSIG) based wind farm with STATCOM control in MATLAB/SIMULINK environment.**

Keywords: **Statcom, wind farm, d-q theory, SVPWM, fixed speed induction generator.**

1. INTRODUCTION

Wind is a continuously varying source of energy and so is the active power generated by the Wind Turbine (WT). If a WT is connected to a weak grid, the terminal voltage fluctuates, produces flicker, harmonics and inter harmonics due to the presence of power electronic devices [1]. The conventional energy sources are limited and pollute the environment. So more attention and interest have been paid to the utilization of renewable energy source such as Wind Energy, Fuel Cell, Solar Energy etc., Wind Energy is the fastest growing and most promising renewable energy source among them as it is economically viable [2]. Wind Energy Conversion System (WECS) is the overall system for converting wind energy into useful mechanical energy that can be used to power an electrical generator for generating electricity connected to the grid [3]. Wind power is the most reliable and developed renewable energy source over past decades. The increased awareness of people towards renewable energy, support from governmental institution, and rapid advancement in the power electronics industry, which is the core of wind power systems, are the most contributing factors for the development of wind power systems [4]. With the fast advancement in power electronics technology, FACTS devices having excellent dynamic response are technically and economically feasible in power system application [5], [6]. In this paper, reactive power compensation using the STATCOM at the PCC is presented to enhance the reactive power capability and voltage controllability of the FSIG wind turbine system for improving dynamic and steady state stability of the wind turbine system as well as the interconnected weak power system for better control.

Additionally, series and shunt compensations of transmission line helps in steady state voltage regulation and enhances the transmission line power carrying capability [7]-[9]. Moreover, off grid applications of the FSIG-based WECS is very important to supply power to the remote places where there is no grid supply [10]. It involves standalone operation of the doubly fed induction generator (DFIG)-based WECS. Standalone operation of grid connected DFIG system is also needed in case of failure of the main supply due to breaking of the transmission line or permanent short circuit in the grid to supply part of an isolated load [13]-[16]. This increases the reliability of the power supply system [17]. This paper is motivated at contributing to the better understanding of the FSIG-based WECS and its interaction with the STATCOM control as well as shunt compensation of the line in regard to those aspects. In this paper, section 2 presents FSIG based wind farm, section 3 presents the principle of operation of STATCOM, section 4 presents control strategies of STATCOM, section 5 presents simulation of FSIG based wind farm with STATCOM control, section 6 presents results and discussion and section 7 presents the conclusion.

2. GRID CONNECTED WIND TURBINE INDUCTION GENERATORS

The main motivation for choosing STATCOM in wind farms is its ability to provide bus bar system voltage support either by supplying and/or absorbing reactive power into the system. The applicability of a STATCOM in wind farms has been investigated and the results from early studies indicate that it is able to supply reactive power requirements of the wind farm under various operating conditions, thereby improving the steady-state stability limit of the network. Transient and short-term generator stability conditions can also be improved when a STATCOM has been introduced into the system as an active voltage/var supporter [18-20]. The coefficient of power (CP) of a wind turbine basically signifies the conversion efficiency of the wind energy into mechanical energy, which in turn is used to drive the generators. It differs from the overall system efficiency as it doesn't include the losses in transmission (mechanical) and in electrical power generation.

CP= (Output Power of a Wind Machine)/ (Power Content of the wind stream).

A. FSIG Based Wind Farm in Power System

The block diagram of FSIG based wind farm connected to the grid is shown in Fig. 1. It consists of 50MW FSIG based wind farm connected to the grid. A StatCom is connected to the grid at PCC to compensate reactive power and voltage profile improvement.

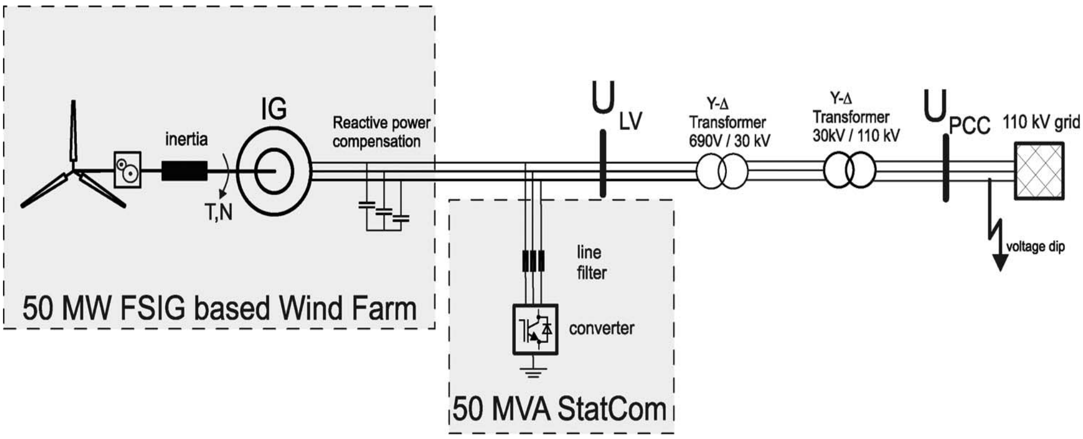

Fig. 1: Block diagram of FSIG-based wind farm and STATCOM connected to the grid.

The wind farm with squirrel cage induction generators is directly connected to the grid. For a set of connected wind turbines forming a wind farm, there exist certain grid codes or specific requirements with which each wind turbine must conform with in order to be connected to the grid [12]. Most wind power systems are based in remote rural locations and are therefore prone to voltage sags, faults, and unbalances. These unbalanced grid voltages can cause many problems such as torque pulsations, unbalanced currents and reactive power pulsations [13]. When wind farms are connected to a strong grid, that is closer to a stiff source, voltage and frequency can be quickly re-established after a disturbance with the support of the power grid itself. To wait for the voltage to re-establish after the fault has been cleared in the case of a weak grid interconnection is not reliable because there is always a risk of voltage instability initiated by the disturbance. Hence, reactive power and voltage support that can be provided by mechanically switched capacitors, SVC or STATCOM is needed to help improve the short term voltage stability and reinforce the power network.

3. STATCOM-PRINCIPLE OF OPERATION

The block diagram of the STATCOM is shown in figure 2. The STATCOM is connected to the ac system bus bar through a coupling transformer. In a STATCOM, the maximum compensating current is independent of system voltage, so it operates at full capacity even at low voltages. A STATCOM's advantages include flexible voltage control for power quality improvement, fast response, and applicability for use with high fluctuating loads.

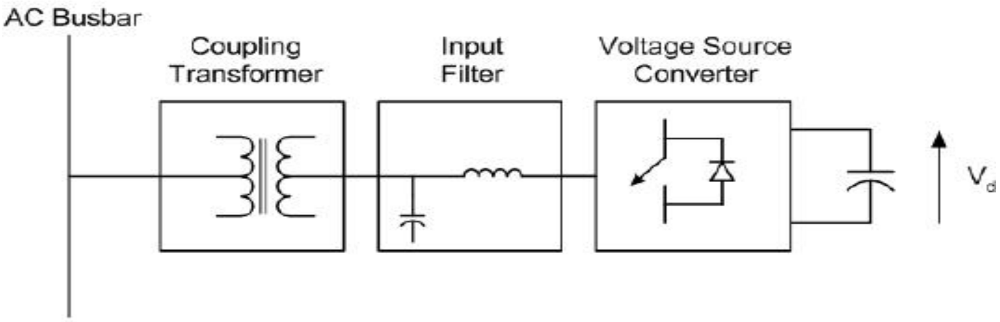

Fig. 2: Block diagram of the Static Synchronous Compensator

The shunt inverter, transformer and connection filter are the major components of a STATCOM. The control system employed in this system maintains the magnitude of the bus voltage constant by controlling the magnitude and/or phase shift of the voltage source Converter's output voltage. By properly controlling i_q, reactive power exchange is achieved. The DC capacitor voltage is maintained at a constant value and this voltage error is used to determine the reference for the active power to be exchanged by the inverter. The STATCOM is a static var generator whose output can be varied so as to maintain or control certain specific parameters of the electric power system. It is a power electronic component that can be applied to the dynamic control of the reactive power and the grid voltage. The reactive output power of the compensator is varied to control the voltage at given transmission network terminals, thus maintaining the desired power flows during possible system disturbances and contingencies.

4. CONTROL STRATEGIES

The block diagram of STATCOM control structure in FSIG wind turbine system is shown in Fig. 3. The complete control strategy of the machine is divided in two ways, one is scalar control and the other is vector control.

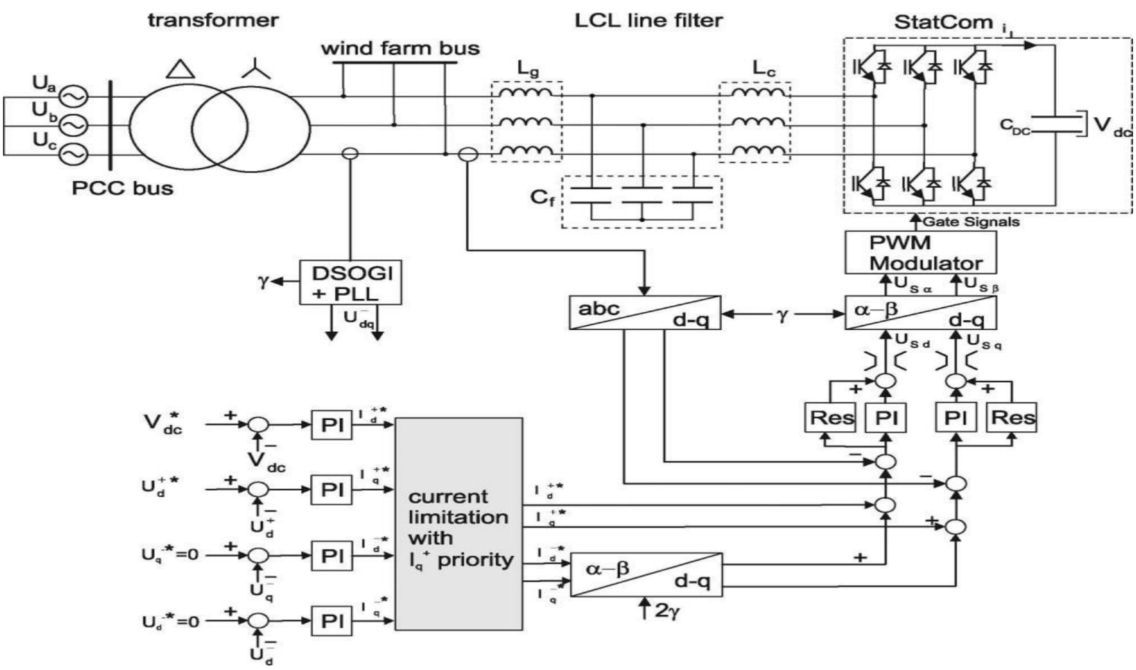

Fig. 3: Block diagram of STATCOM Control in FSIG Wind turbine

The limitations of scalar control give a significance to vector control. Though the scalar control strategy is modest to implement but the natural coupling effect gives sluggish response. The inherent problem is being solved by the vector control. Using this control strategy an Induction Machine can be performed like dc machine. Because of dc machine like performance vector control is also known as orthogonal, decoupling Or Transvector Control. Different Vector control strategies have been proposed to control the active and reactive power of an induction generator. The basic of the vector control theory is d-q theory. To understand vector control theory knowledge about d-q theory is essential.

A. D-Q theory

The d-q theory is also known as synchronous reference frame theory which is proposed to overcome the problem of time varying parameters with the ac machines that formulates change of variables which replace the variables related to the stator windings of a synchronous machine with variables related with fictitious winding which rotates with the rotor at synchronous speed. Essentially they transform the stator variables to a synchronously rotating reference frame to fixed frame in the rotor. With such transformation (Park's transformation) time varying inductances that occur due to an electric circuit in relative motion and electric circuit with varying magnetic reluctances can be eliminated.

B. Space vector pulse width modulation

In sinusoidal PWM, the inverter can be thought of as three separate push-pull driver stages, which create each phase waveform independently. SVPWM however treats the inverter as a single unit. The space vector method is a d,q model PWM approach. Its Modulation index is high. SVM produces 15% higher than the sinusoidal PWM in output voltages. It treats the sinusoidal voltage as a constant amplitude vector rotating at constant frequency. This PWM technique approximates the reference voltage V_{ref} by a combination of the six switching patterns. This is Coordinate Transformation (ABC reference frame to the stationary d-q frame). A three-phase voltage vector is transformed into a vector in the stationary d-q coordinate frame which represents the spatial vector sum of the three-phase voltage. The vectors divide the plane into six sectors. V_{ref} is generated by two adjacent non-zero vectors and two zero vectors.

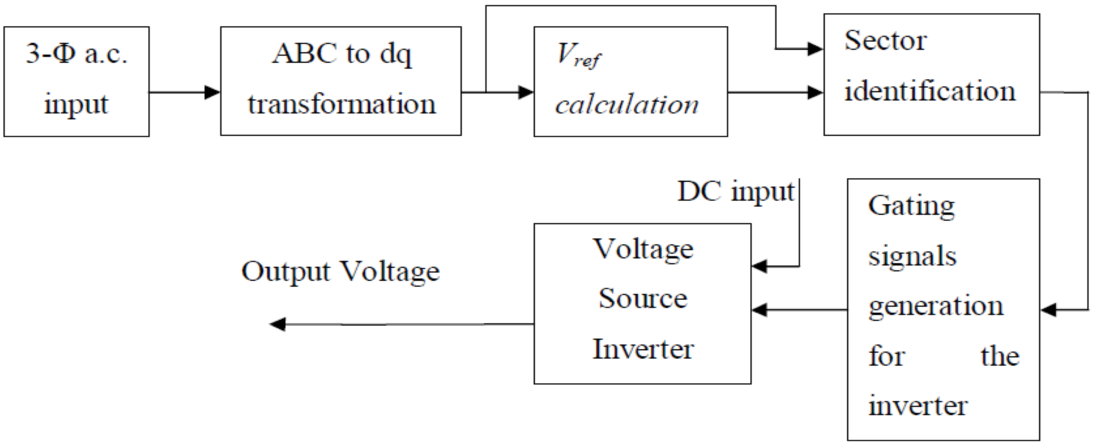

Fig. 4: Block diagram of the SVPWM

5. SIMULATION MODELS OF FSIG BASED WIND FARM WITH STATCOM CONTROL

The Simulink model of FSIG based wind farm connected to the grid is simulated using MATLAB/SIMULINK and is shown in Fig. 5. It consists of 3-phase programmable source connected to the grid through distribution line parameters through 110kV/33kV transformer. A wind farm is connected to the same system through a 33kV/110kV transformer as shown in figure 6.A three phase fault is introduced at PCC between 1 sec to 1.5 sec. The power system with FSIG based wind farm with STATCOM control is shown in Fig. 7. The StatCom consists of 3-phase VSI with MOSFETS with a capacitor on DC side.

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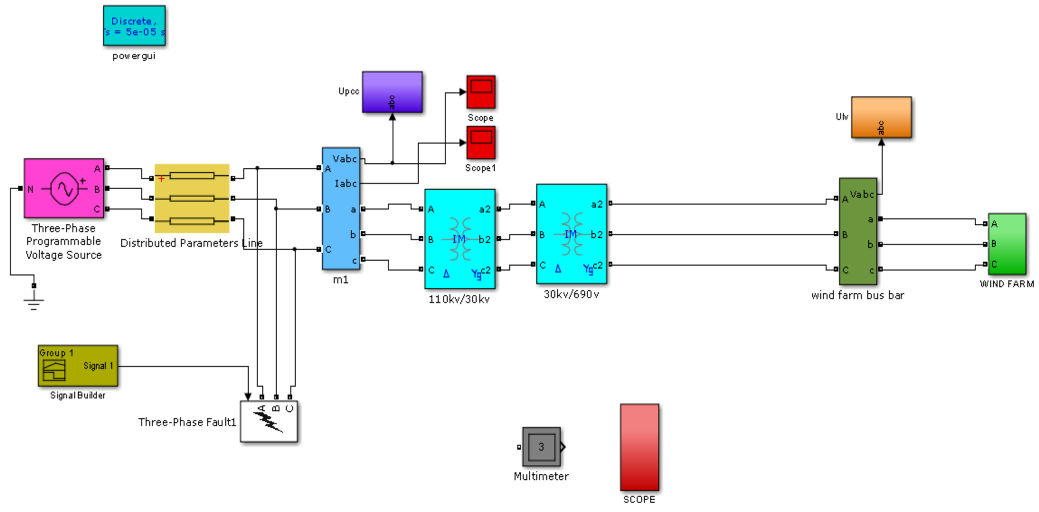

Fig. 5: Simulink Model of Wind Turbine Fed FSIG – Without STATCOM

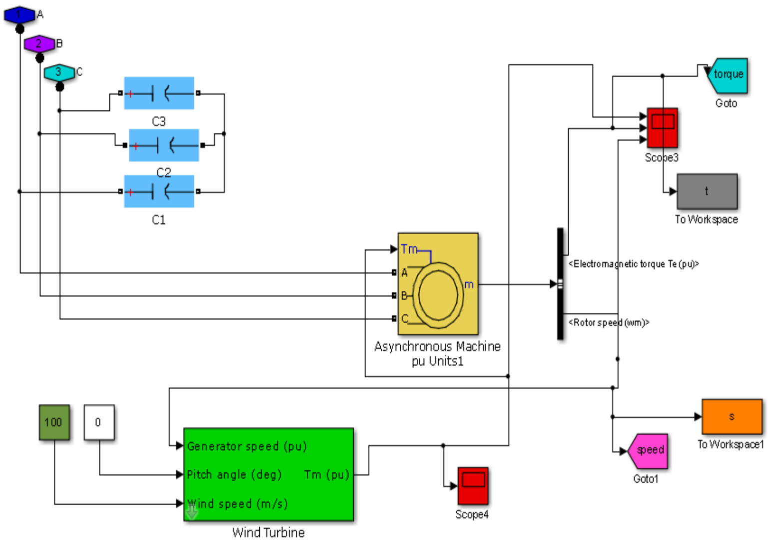

Fig. 6: Simulink Model of the Wind Farm

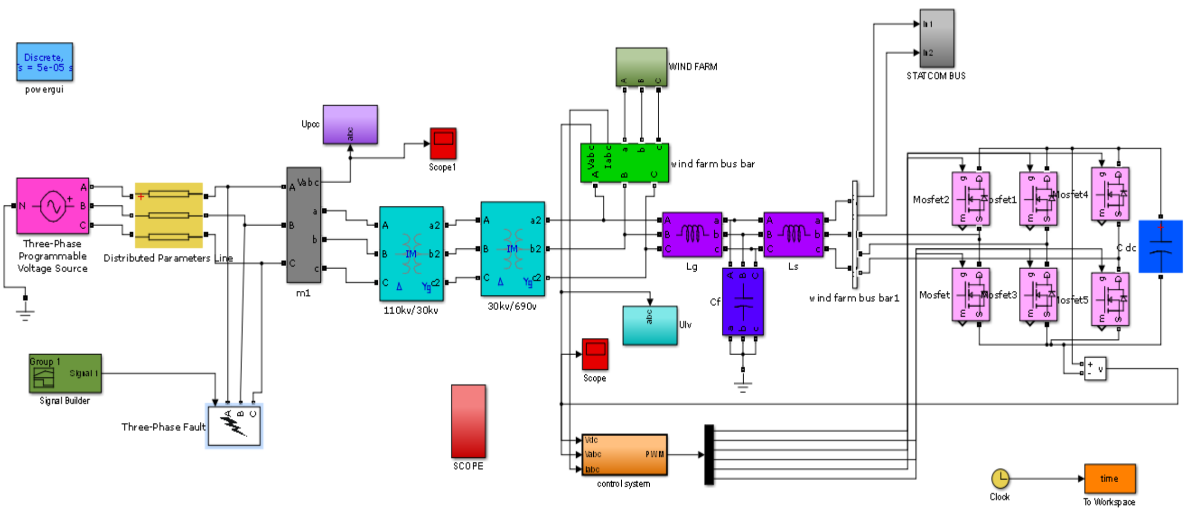

Fig. 7: Simulink Model of Wind Turbine Fed FSIG – With STATCOM

The control block of STATCOM includes d-q theory for reference compensation current estimation which is shown in Figure 8.

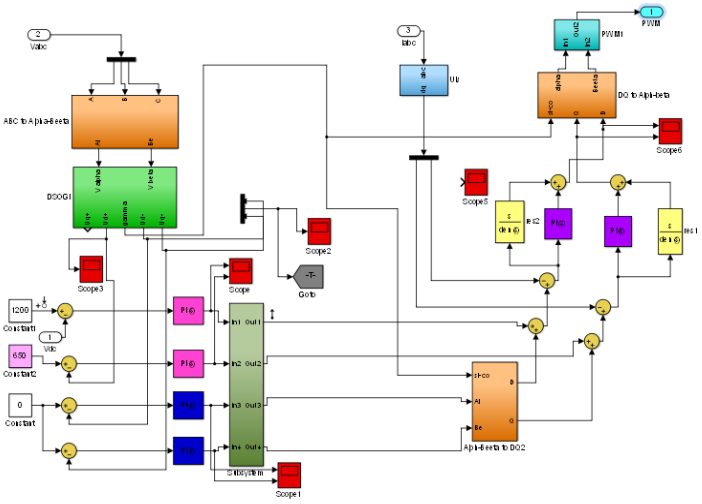

Fig. 8: **D-Q Reference Frame controller**

6. RESULTS AND DISCUSSION

In this, the stabilization by the STATCOM under an un-balanced grid voltage dip of 500ms duration is presented. An unbalanced fault (single phase amplitude drops to 50%) is introduced at the high voltage bus of the power system. The values and ratings of the system components are presented in TABLE I and TABLE II. In the given model, the source voltage is selected as 230V rms value. Thus the line is maintained at 230V automatically through the transformers. The output of the three phase transformer is given to the grid. The capacitors are storing the D.C. value of voltage and these are feeding to the wind farm through the STATCOM.

TABLE I: WIND FARM INDUCTION GENERATOR AND STATCOM PARAMETERS

Wind Farm Induction Generator	Simu.
Base apparent power	57,5 MW
Rated active power	50 MW
Rated voltage (line to line)	690 V
Stator resistance (R_S)	0,0108 pu
Stator stray impedance ($X_{S\sigma}$)	0,107 pu
Mutual impedance (X_h)	4,4 pu
Rotor resistance (R'_R)	0,01214 pu
Rotor stray impedance ($X'_{R\sigma}$)	0,1407 pu
Compensation capacitors	0,17 F
Mechanical time constant H	3 s
StatCom	
Rated Power	50 Mvar
Rated voltage	690 V
Line filter L_{filter}	0,15 pu
L_{Netz}	-
DC voltage U_{DC}	1200 V
Current capability	1 pu

TABLE II: GRID AND TRANSFORMER PARAMETERS

	Grid	HV transf.	MV transf.
Base apparent power	1000 MW	100 MW	100 MW
Rated voltage	110 kV	30 kV	690 V
Stray impedance (X_g)	0,98 pu	0,05 pu	0,1 pu
Resistance (R_g)	0,02 pu	0,01 pu	0,02 pu

The output voltage, torque, speed and real power and reactive power at PCC without STATCOM control is shown in Fig.9.

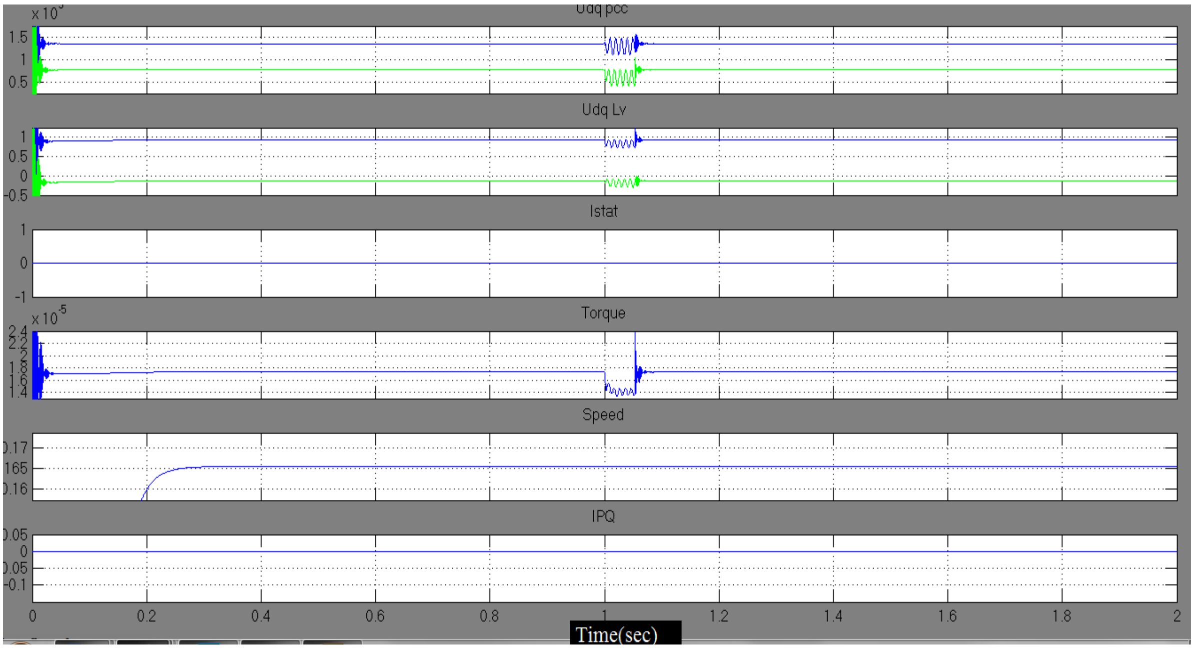

Fig. 9: **No load voltage, output voltage, torque and speed at Without StatCom 1ph-50 %.**

The required voltage for the line under the fault is to compensate the voltage dip. Then it draws required voltage to convert it into alternative voltage and it feeds to the filters. The inductive filters and capacitive filters are filtered the harmonics and provide the alternating voltage to the line through the transformers. Here the fault is created and the fault block is connected. The fault which is selected is three phase fault. The No load voltage, output voltage, StatCom current, torque, speed, active and reactive power With StatCom control- 1ph-50% is shown in Fig. 10.

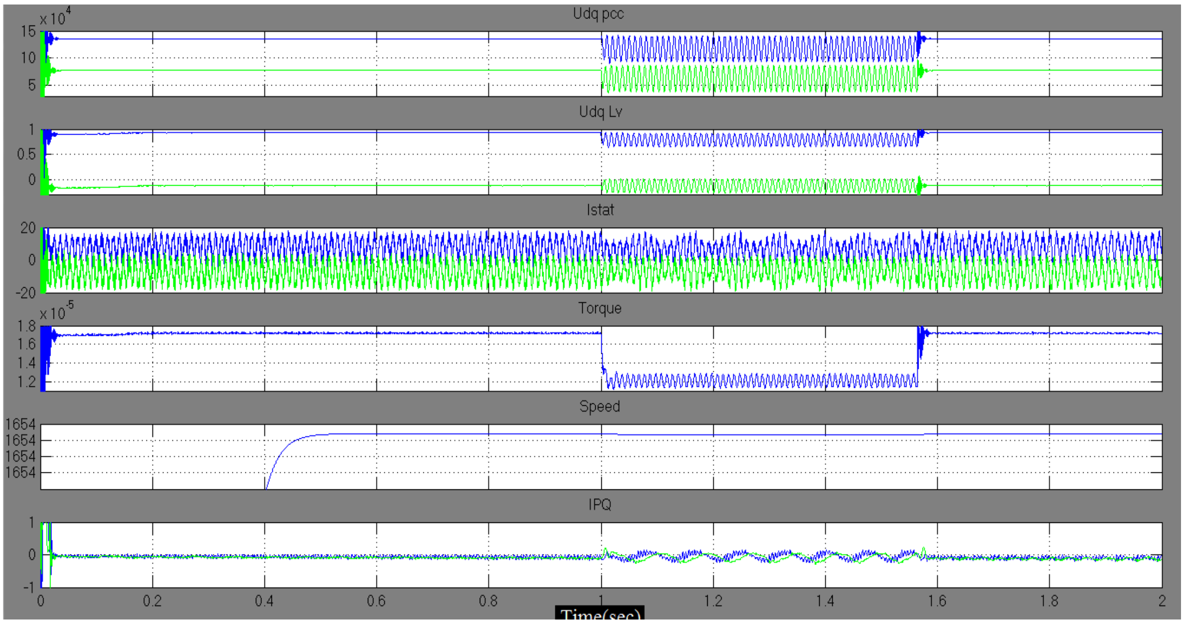

Fig. 10 **Output voltage, StatCom current, torque, speed, active and reactive power at PCC with StatCom 1ph-50%.**

The control signal is multiplied with computed voltage magnitude gives the required control voltage signal. Similarly, with phase angle difference the differential second order general integrator (DSOGI) signals for other two phases are generated. These three injected voltages are compared with sensed three-phase pulse voltages and the errors are then processed by PI controller to generate the required switching signals for the FSIG with StatCom. Similarly, the Output voltage, torque, speed With StatCom – 1ph-60 % is shown in figure 11 and 1ph-0% in figure 12.

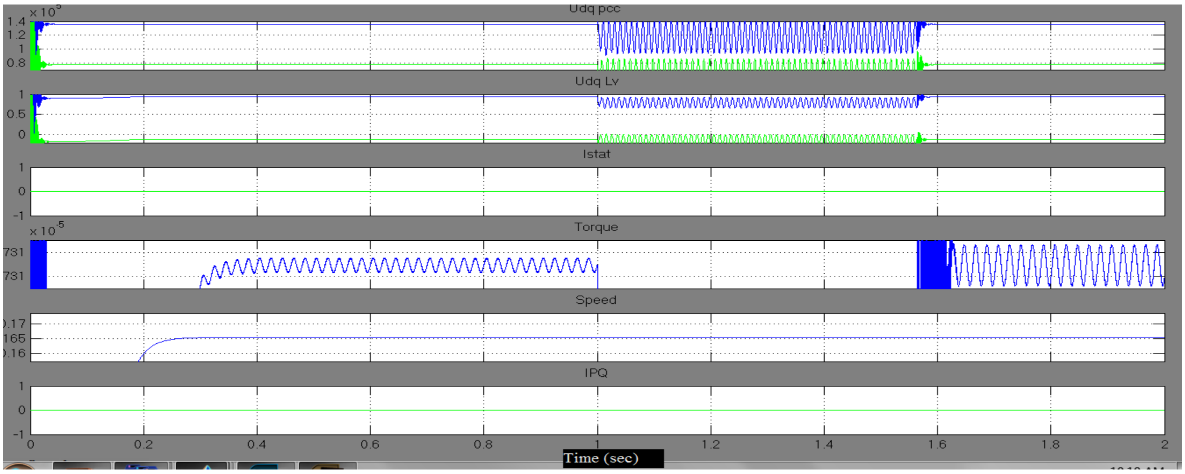

Fig. 11 **Output voltage, torque, speed at With StatCom – 1ph-60 % - Coordinated Positive - Negative Sequence Compensation.**

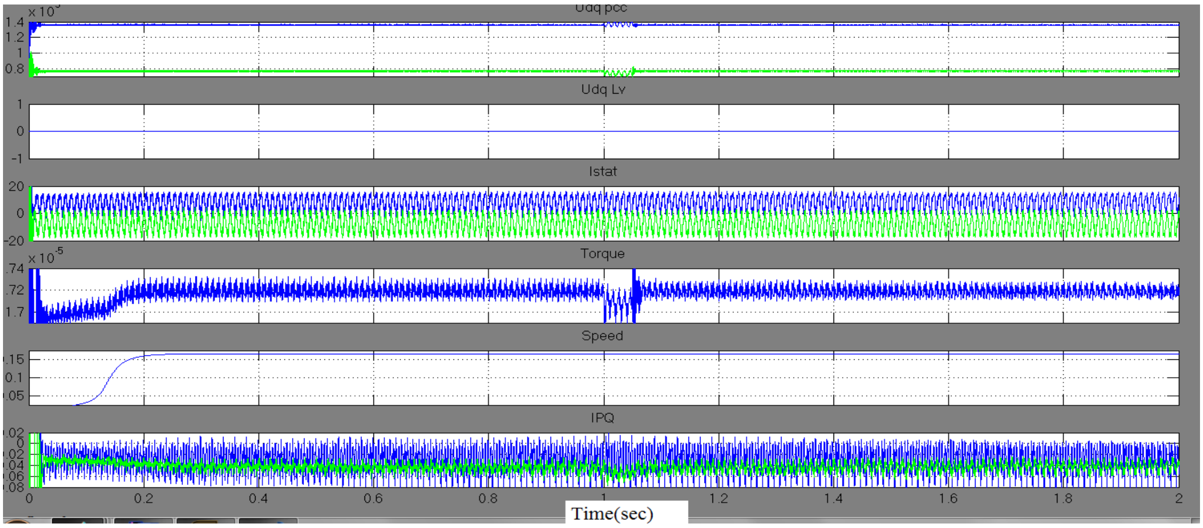

Fig. 12: Output voltage, torque, speed at With StatCom – 1ph-0 %.

7. CONCLUSION

In this, a static compensator is introduced in the wind turbine fed fixed speed induction generator to mitigate the faults. The respective waveforms are verified for without and with static compensator under asymmetric grid fault 1ph-50%. Similarly the same procedure is evaluated for 1ph-60% and 1ph-0% and the wind turbine characteristics have been worked out. The results shown that the STATCOM compensated the voltage dip and reactive power at PCC under asymmetrical fault.

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