The Control of DFIG for MPPT and application of STATCOM for grid stability

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Abstract—Themodeling, analysis, control and simulation of DFIG based WECS along with STATCOM implementation to the grid is presented in this paper. To maintain DC bus voltage the GVO control method is adopted in GSC for reactive power is provided. The efficient control of active and reactive power is provided through SVO scheme in RSC. The MPPT is achieved by keeping TSR to the optimum value.In this project implementation of STATCOM to grid system is shown in order to improve voltage stability during the grid disturbances. The three phase symmetrical fault is created in the distribution system and STATCOM which is connected to distribution system regulates the voltage drop and overcurrent to normal condition. The developed system is simulated for different wind speeds and allows power distribution system to be in-service during faults. The hardware prototype consists of voltage source converter and its controls are developed to verify the results.

Keywords— *DFIG-doubly fed induction generator, VSC-voltage source converter, WECS-wind energy conversion system, TSR- Tip speed ratio, GVO- grid voltage oriented, SVO- stator voltage oriented, MPPT- maximum power point tracker.*

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I. INTRODUCTION

Energy is the most essential element of social and economic development of our country. Renewable energy is very useful tool to meet the present day energy requirements. Wind energy is recognized by energy council as the best energy resource to avoid crude oil consumption and also to focus on reduced carbon emissions. The sun's energy that is reaching the earth is converted into wind energy i.e, only two per cent. The increase in population is the main reason for energy shortage and also it is responsible for energy resources degradation due to increase in consumption. Power shortage is frequent in India and many other countries. Even during the present day most of the places don't have access to modern renewable energy resources. The main goal of many countries is to meet the present day energy needs by using RES. So government needs to bring out many energy programs for research and development in energy resources.

The production of power through renewable energy resources, which is present abundant in earth and also we can generate power at low cost. By depending on renewable energy, we can reduce our import from other countries for crude oil. This can lead reduced carbon monoxide emission, so that our environment will be clean.Wind power development program came to existence, during the year 1983-1984. The main goal of this development is commercialization of wind power generation and development. During the same time government of India made may changes and modification in incentives and schemes. During the year June 2015 the total power generation from wind increased to 22,597Megawatt. Now it is 26,743Megawatt. India was the fourth largest producer in power through wind.

India was the fourth largest producer of wind power in the world, according to global wind energy council 2015. Wind energy development program was introduced in India during the year 1983-1984. The main goal of the program was commercialization of wind energy generation, support research and development and to provide help to wind energy project [1]. The wind power productions across various states in our country are shown below.

Table 1.1: scenario of world wind power generation

COUNTRY	WIND POWER GENERATION
CHINA	145.1GW
USA	74.47GW
GERMANY	44.94GW
INDIA	25.086GW
SPAIN	23.025GW
UK	13.60GW
CANADA	11.2GW
FRANCE	10.358GW
ITALY	8.958GW
BRAZIL	8.715GW
REST OF THE WORLD	66.951GW

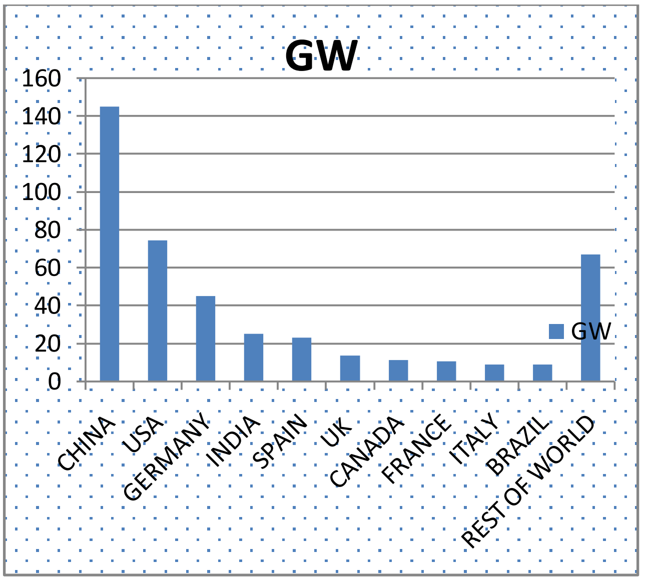

Fig 1.1: world wind power generation statistics

The grid connected DFIG system consists of WRIG, rotor is attached to back to back converter and stator to grid. In this project GVO control is adopted to GSC [2]. The RSC control is used to control P and Q components of power generation at the stator. The reactive power is set to zero by rotor side converter control the PF to unity at stator [3]. During the fault condition the blocking of rotor side converter of DFIG generally used to protect the rotor side converter from over current. The utilities disconnect the DFIG system from the grid and connect when normal operation of grid is achieved. The tripping of wind turbines from grid in wind farms will result in voltage instability during the fault [4]. In such a condition dynamic reactive power compensation is provided through a FACTS device like STATCOM and power system will remain in-service even in fault condition. The implementation of STATCOM to the power system is shown and results are concluded.

II.CONTROL STRATEGY:

The time varying parameters of induction machine cannot be controlled. Hence these parameters should be transformed into a constant quantity.

The time varying quantities are:

$$V_a = \sqrt{2}V_{RMS}\sin(\omega t) \quad (1)$$

$$V_b = \sqrt{2}V_{RMS}\sin(\omega t - 2\pi/3) \quad (2)$$

$$V_c = \sqrt{2}V_{RMS}\sin(\omega t + 2\pi/3) \quad (3)$$

HereV_a,V_b, Vc are three line voltages. These quantities are transformed into constant values by the following equations.

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (4)$$

The above equations are α and β transformations. These quantities are transformed into constant quantity, which are known as park and Clarke's transformations of induction machine and represented as D and Q components. The control is done through these transformed constant quantities.

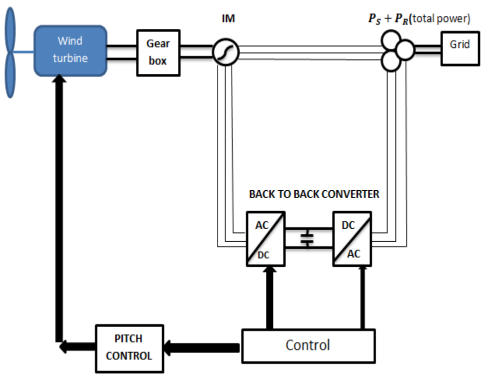

Fig 1: Doubly fed indution machine with wind turbine

A.**Grid side converter control*:***

The GSC is to control Q component of power to be exchanged between via, rotor and grid and also to regulate DC voltage across the capacitor connected between the two bidirectional converters [10]. These two objectives are met by GVO vector control i.e, by coinciding qd- axis along the direction of grid voltage. The VSC used in GSC is 3-phase two levels [9].

In this method of voltage oriented vector control the angle θ_g is measured by PLL on supply voltage [5]. The orientation is detected from grid, assuming the grid voltage as$V_{\alpha g}$, Vbg, Vcg and angle θg [8]. Grid voltage orientation is obtained by the following equations.

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix}\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} (5)$$

To implement VOC control, the supply voltage vector is coincided with D-axis of synchronous frame i.eV_{dg}=Vg and V_{qg} axis becomes zero [6].

$$V_{\alpha g} = \frac{2}{3}[V_{ag} - \frac{1}{2}V_{bg} - \frac{1}{2}V_{cg}] \quad (6)$$

$$V_{\beta g} = \frac{2}{3}[\frac{\sqrt{3}}{2}V_{bg} - \frac{\sqrt{3}}{2}V_{cg}] \quad (7)$$

$$\theta_g = \tan^{-1}\frac{V_{\beta g}}{V_{\alpha g}} \quad (8)$$

The active and reactive power is given by

$$S = P + jQ \quad (9)$$

Where S-power
P=active power
Q=reactive power

The active power is given by

$$P_g = \frac{3}{2}[V_{sd}I_{dg} + V_{sq}I_{qg}] \quad (10)$$

And reactive power is given by

$$Q_g = \frac{3}{2}[V_{sq}I_{dg} - V_{sd}I_{qg}] \quad (11)$$

Put q componentV_{sq}=0

$$P_g = \frac{3}{2}[V_{sd}I_{dg}] \quad (12)$$

$$Q_g = \frac{3}{2}[-V_{sd}I_{qg}] \quad (13)$$

By S>0, S<0, the DFIG will absorb or deliver power to supply.

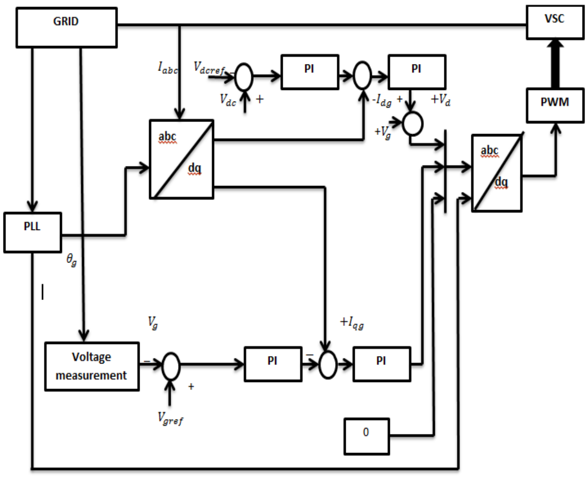

Fig 2: grid side converter control scheme

B) Rotor side converter control:
With the rotor currents the generation of torque of DFIG can be controlled. The applied voltage to the rotor windings helps to control the flow of current. Due to changing speeds in rotor the generated currents in rotor can be varied. To regulate DFIG, in terms of current, speed or power generation and torque RSC can be used.
The speed-power curve enables us to track the output of DFIG. The Q component of power can be controlled by rotor currents of DFIG [7]. In the IM, the generations of power at stator takes place due to RSC both Q and P components of power can be controlled. The frequency of slip is based on the speed of the rotor. The RSC controls the current and acts as DC/AC to enable controlling P and Q component of DFIG. During motoring, the machine runs below "Ns". During the high speeds of rotor, the voltage generated has high frequency. So RSC reduces the generated power at slip [3].

The active and reactive power of the stator is given by:

$$P_s = V_{qs} I_{qs} \qquad (14)$$

$$Q_s = \frac{3}{2} V_{qs} I_{sd} \qquad (15)$$

Since stator vector flux is aligned with the D-axis of reference frame, the q component can be considered as zero [9].

The stator flux is given by

$$\psi_s = L_s I_s + I_m I_r \qquad (16)$$

In DQ frame, d-component is given by

$$L_s I_{ds} + L_m I_{rd} = \psi_{sd} \qquad (17)$$

By taking $\psi_{sq} = 0$, we get

$$L_s I_{qs} + I_m I_{qr} = 0 \qquad (18)$$

By substituting the above equation in Ps and Qs

We get $P_s = -\frac{3}{2} V_{qs} I_{qr} \frac{L_m}{L_s}$ (19)

$$Q_s = \frac{3}{2} V_{qs} [\frac{\psi_S}{L_S} - \frac{L_m}{L_S} I_{dr}] \qquad (20)$$

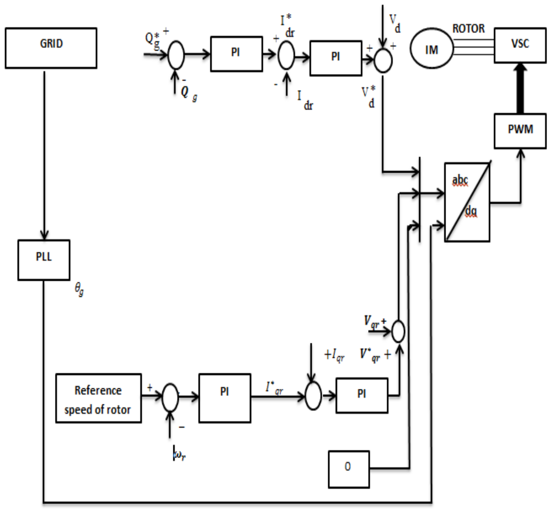

Fig 3: Rotor side converter control scheme

III.STATCOM(STATIC SYNCHRONOUS COMPENSATOR)

The static synchronous compensatoris a FACTS device connected in shunt to the transmission system it is capable of sending or receiving the Q component power from power system to which it is connected. Many industries and consumers prefer electrical energy with high quality. Suppose, if delivered power is poor in quality the products and equipment's like computers, motor drives, machines connected to a system will get damaged. By using the STATCOM to the power system shows that it improves the power and voltage quality [11]. The STATCOM has a capacitor, transformer for leakage reactance and VSC. The VSC is a three phase inverter, which has the ability to convert the capacitor voltage to AC voltage. By changing amplitude of converter, we can induce the Q component of power to supply. So current which is controlled enters from STATCOM to supply. During the fault condition, the voltage of the transmission line becomes low. So STATCOM generates active and reactive power such that the voltage is restored. When the voltage of the transmission line is high it absorbs the reactive power.
The active and reactive power absorbed or injected by STATCOM from the power system is given by:

$$P = \frac{V_{BUS} V_2 \sin \delta}{X_L} \qquad (21)$$

$$Q = \frac{V_{BUS} [V_{BUS} - V_2 \cos \delta]}{X_L} \qquad (22)$$

Where δ is the angle between V_2 with respect to V_{BUS}
V_{BUS} = bus voltage of distribution system.
V_2 =voltage generated by the voltage source converter of STATCOM.

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X_L=inductive reactance of coupling transformer.

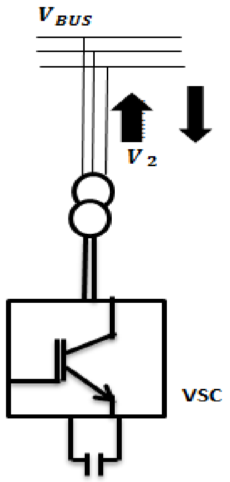

Fig 4: Symbol of STATCOM

Normally, δ=0, when VSC generated voltage is in phase with bus voltage. If the VSC generated voltage is less than V_{BUS}, then q component of power from the bus to V2.when V2 is higher than V_{BUS}, then Q component of power is induced from V2 to V_{BUS} [12].

IV. CONTROL SCHEME FOR VSC OF STATCOM:

The PI control regulates the differences between VSC voltages generated and V_{BUS} using PLL the supply system angle of position is detected. By using this angle which is locked is used to transform the 3-phase current. The error between the reference and DC voltage is regulated by PI controller and it yields direct axis current from voltage difference. The direct and quadrature axis values of reference frame are converted into three phase variables and are compared with repeating sequence, the output is used for triggering the gates of IGBT's of voltage source converter [12].

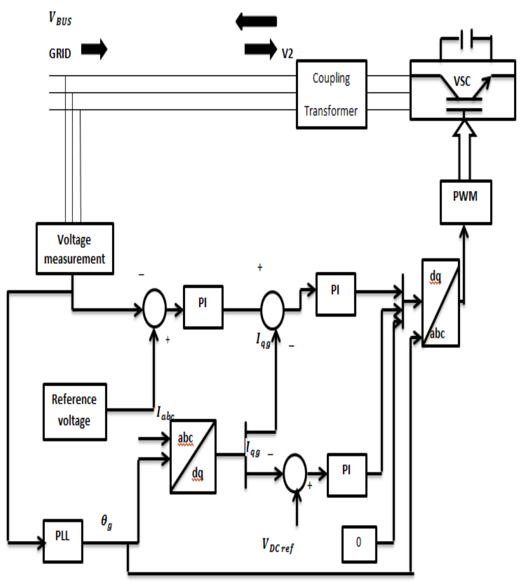

Fig 5: control scheme for VSC of STATCOM

V. SIMULATION AND RESULTS:

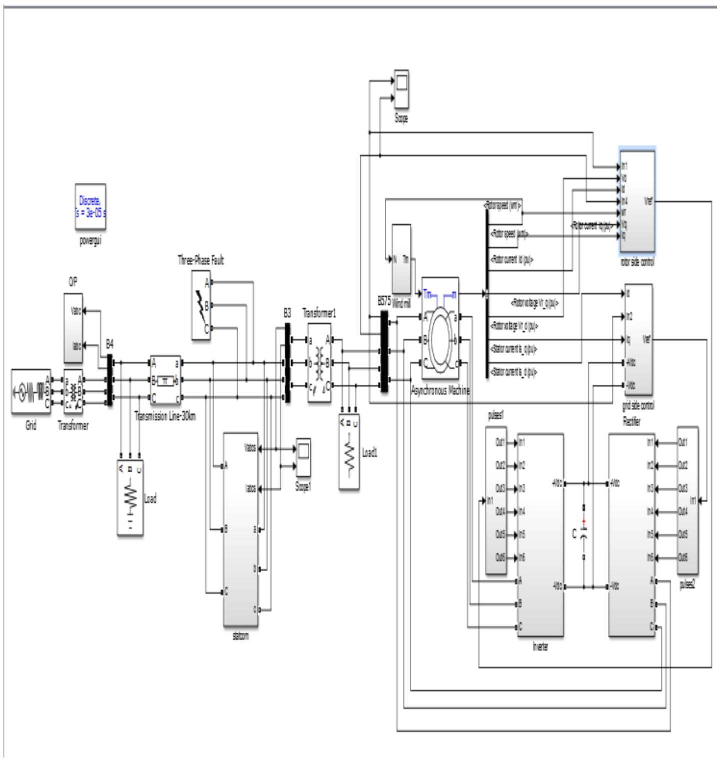

Fig 6: DFIG control and STATCOM for reactive power compensation.

The grid model which is shown in the simulation consists of 120KV, 60HZ supply, which is stepped down by step down transformer 120/25KV, 47MVA to supply 25kilowatt system and then again stepped down by step down transformer 25KV/575V, to supply 575V load system. The two loads are there in whole power system, first load at 30km rating 2MVA, PF 0.9(lag) and second 500kilowatt (575 V_{BUS}) the 30km pie model. In control circuit a reference voltage is set, then PI controller regulates the output.

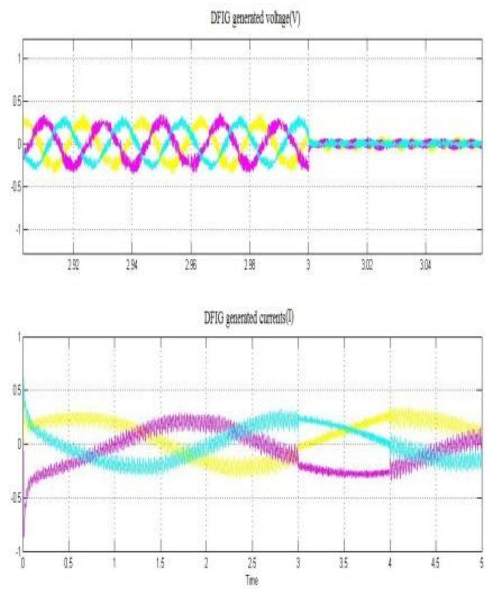

Fig 7: Stator and rotor currents of DFIG

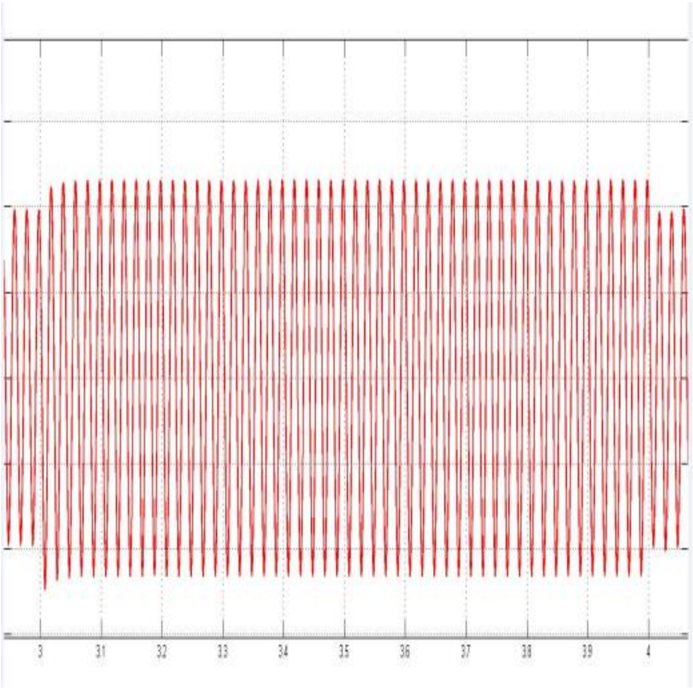

Fig 8: Fault currents during the three phase symmetrical faults in the transmission system.

The fig 8, shows the fault current, which has amplitude more than one, due to a fault. The STATCOM regulates the fault current to 1.

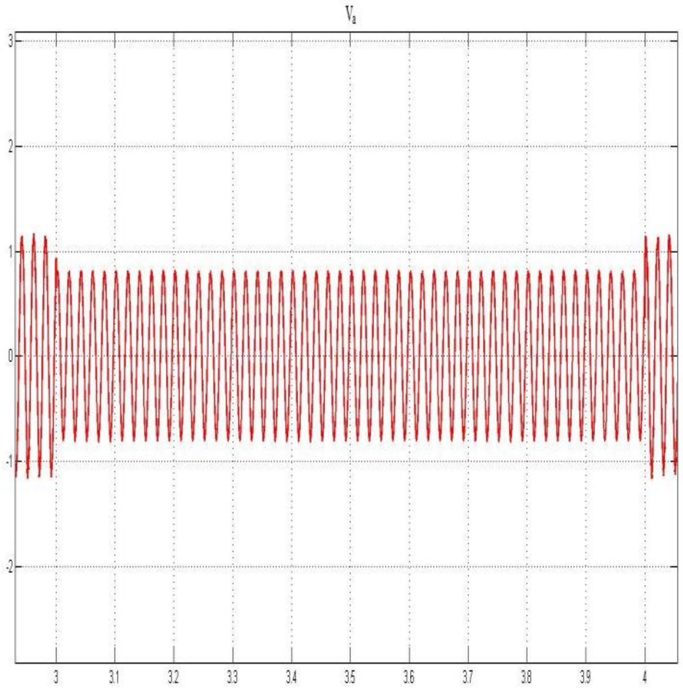

FIG 9: voltage collapse during three phase symmetrical faults and STATCOM restoring the voltage

The reactive power is maintained zero for unity power factor

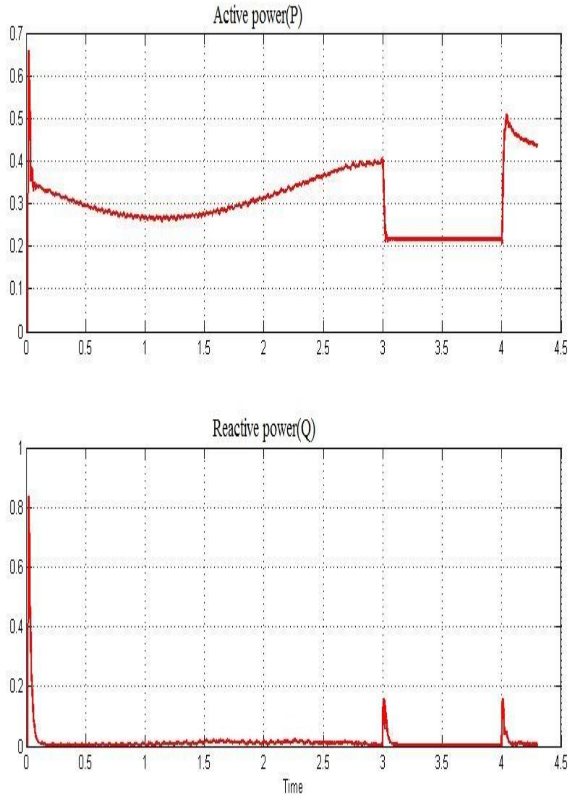

Fig 10: Active and reactive power generated

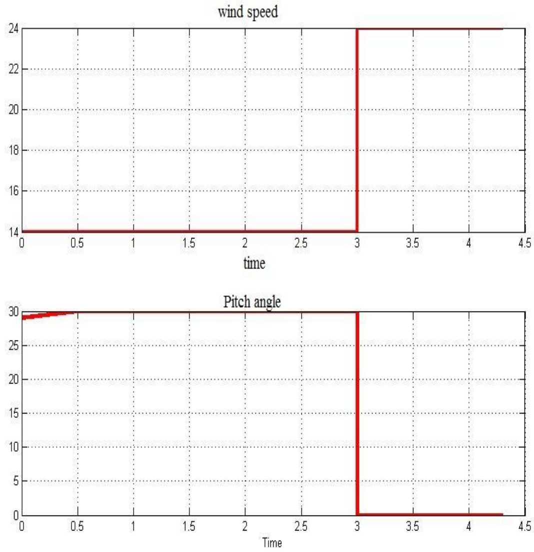

Fig 11: MPPT by pitch control

The fig 11 shows the MPPT with pitch control. When wind speed increases from 14 m/sec to 24 m/sec the output voltage reduces, due to MPPT action and during normal wind speed the generated voltage becomes normal [6].

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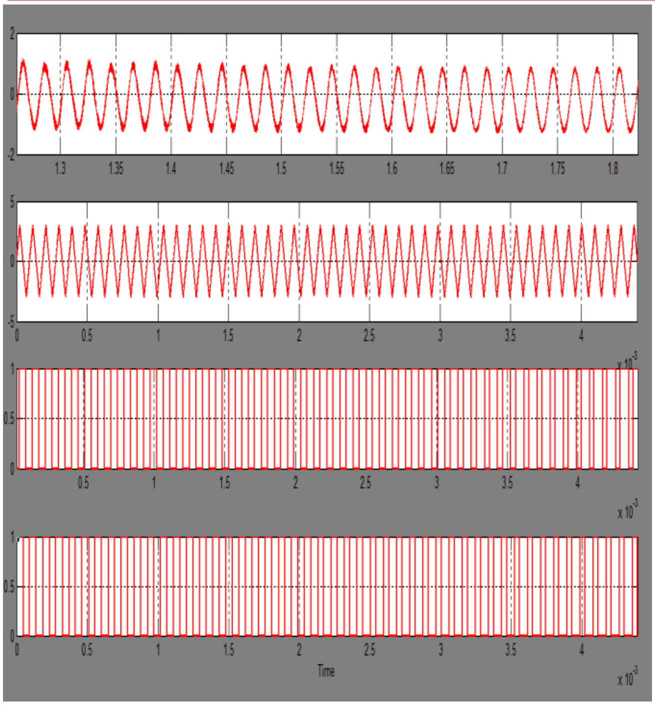

Fig 12: Switching voltages to voltage source converters.

The fig 12 shows the generation of gate switching voltages to the MOSFETS of voltage source converter. The reference voltage generated by control circuit is compared with triangular signal to produce gate signals to drive the MOSFETS. When the reference voltage is greater than triangular signal logic “1” is generated. When it is less than triangular signal logic “0” is created.

VI. HARDWARE IMPLEMENTATION

The hardware implemented in this paper is VSC. The same circuit can be used as both inverter and as rectifier, which is explained below.

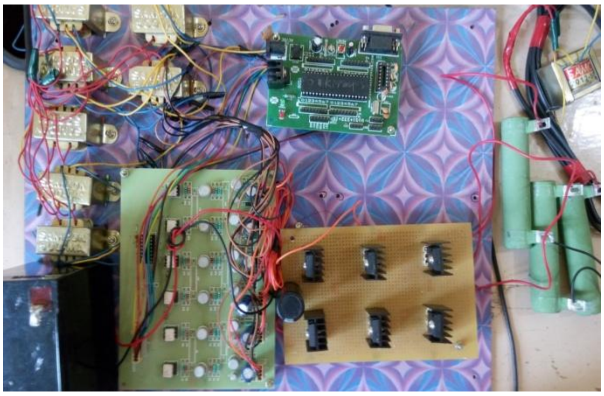

Fig 13: complete circuit of Hardware implementation

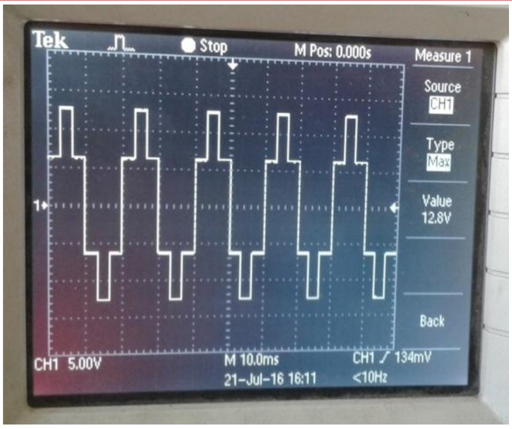

Fig 14: VSC output (inverter)

When input DC voltage is applied to voltage source converter it operates as inverter and generates waveform, which is shown in the above figure 14. The output voltage is 12V between phase to phase across two load resistors.

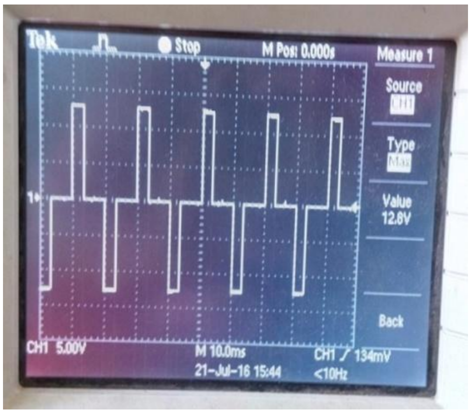

Fig 15: output voltage of VSC between phase to ground.

The output of voltage source converter across load resistor from phase to ground and the waveform is in the above figure 15.

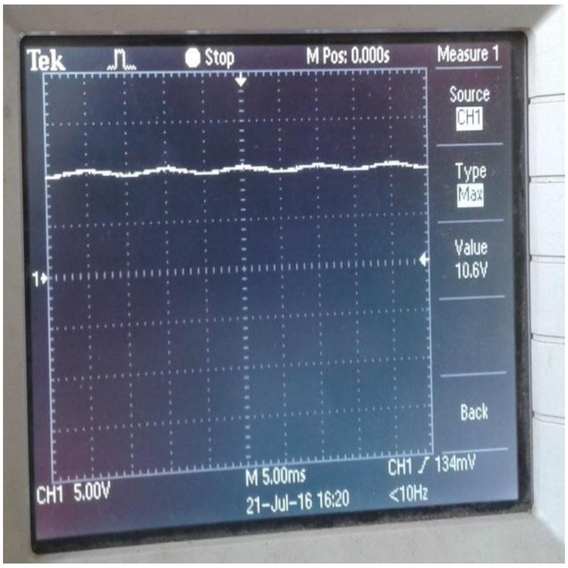

Fig 16: output of VSC acting as rectifier.

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When AC voltage is applied to voltage source converter a DC voltage appears across the DC link capacitor, which shows that the VSC is acting as rectifier. The hardware results for this case are shown in the above figure 16.

VI. CONCLUSION:

The control, simulation and reactive power compensation through STATCOM of DFIG connected to transmission system has been carried out. The vector oriented control is used for grid side converter and rotor side converter has been capable of compensating grid reactive power. By setting the reactive power of WECS, unity power factor is maintained. The STATCOM is connected to the distribution system of DFIG to compensate the reactive power and voltage support, during the faults of power system. The MPPT which is implemented in this project shows the optimum capture of power at different wind speeds. It is concluded that STATCOM connected produces the required reactive power and maintains a better voltage profile, during the three phase symmetrical faults the voltage drop is regulated to normal condition.

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