International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 06 Issue: 07 | July 2019 www.irjet.net p-ISSN: 2395-0072

LOW VOLTAGE RIDE THROUGH SOLUTION FOR WIND ENERGY CONVERSION SYSTEM

Kavitha Suresh[1], K N Chandra Bose[2], Manju A S[3]

[1,2]*Department of EEE, Govt. Engineering College, Idukki, India*
[3]*Power Electronics CDAC, Trivandrum, India*

***Abstract*— Increasing popularity of renewable energy has led to increased penetration of wind farms in the power system. Thus operation and control of power system is dependent on the operation of wind farms particularly during faults. Whenever there is a fault in the grid, the voltage at the point of common coupling gets disturbed. As a result, the grid connected Wind Electric Generator (WEG) gets disconnected from the grid, such unintentional islanding causes a sudden loss of generation in the power system. If the fault is cleared within a short duration, the power system will face a huge generation load mismatch which may even lead to blackouts. To prevent unintentional islanding, the wind energy conversion system needs to satisfy the most important grid code requirement known as the Low Voltage Ride Through (LVRT) for it to be connected to the grid. In this work, LVRT capability is provided by a Static Synchronous Compensator (STATCOM). STATCOM is synchronized with the grid using Synchronously Rotating Reference Frame Phase Locked Loop (SRF-PLL) based grid synchronization algorithm. The ability of STATCOM to provide LVRT capability is analyzed through simulations in MATLAB/Simulink environment. Behaviour of the system under normal and fault conditions in the presence and absence of STATCOM is studied.**

Keywords — LVRT; Wind electric generator; STATCOM; Grid synchronization; Phase Locked Loop.

I. INTRODUCTION

Social, economic and environmental concerns demand highly efficient and more sustainable electrical power system. However, power systems need to change from its traditional conception to future power systems. New nonconventional generators are distributed in the powers systems, which have been developed and integrated to the electric grid.

Wind power is nowadays considered as one of the fastest growing and future renewable energy resources in the world. Wind power generation capacity in India has significantly increased in recent years. As of 31 March 2019 the total installed wind power capacity was 36.625 GW, the fourth largest installed wind power capacity in the world. Wind power capacity is mainly spread across the South, West, and North and East regions

The increasing penetration of wind farms in the electric grid will have a major impact on the operation and control of the power system. Wind energy conversion systems (WECS) are exposed to disturbances, faults and low grid voltages. WECs are mostly designed to disconnect and remain offline for a certain amount of time when there is a loss of grid voltage. They are not designed to differentiate between a complete loss of grid voltage and a temporary voltage dip. Transient events cause a drop in voltage that causes the WECS to turn off for 4-5 min. When the WECS turns off, net load on the distribution feeder goes to a higher level, and feeder experiences a quick drop in voltage. Drop in voltage causes the flickering of lights, poor operation of electronic equipment etc. With Low Voltage Ride Through technology integrated into WECS, it continues to generate electricity immediately after transient events. For prolonged faults, the LVRT feature will ensure for safety reasons that the WECS will automatically turn off for permanent fault condition.

II. LITERATURE SURVEY

A. Grid Code Requirements

Power system operators have implemented technical standards known as grid codes that wind turbines must meet when connecting to the grid. The typical grid codes main requirements are as follows:

- Active Power: Wind power plants must have the ability to regulate their active power output to ensure a stable frequency in the system and to prevent lines overloading.
- Reactive Power: Wind power plants should have the capability to maintain the reactive power balance and the power factor in the desired range (typically between 0.9 (lag) to 0.98(lead)).
- Frequency Operating Range: Wind power plants are required to run continuously within typical grid frequency variations between 49.5 Hz and 50.5Hz.
- Low Voltage Ride-Through: During a voltage drop, turbines are required to remain connected for specific time duration before being allowed to disconnect. This requirement is to ensure that there is no generation loss for normally cleared faults. Disconnecting a wind generator too quickly could have a negative impact on the grid, particularly with large wind farms. Grid codes require that large wind farms must withstand voltage sags for a certain percentage of the nominal voltage and for a specified duration.

B. LVRT Requirements

LVRT Standards differ from one country to another with small changes in voltage drop magnitude, fault time, voltage recovery time and final voltage magnitude. These standards specify how distributed systems should respond to abnormal grid voltages. Indian Wind Grid Code (IWGC) is similar to the international grid code standards and the fault clearing time is based on the Indian Electricity Grid Code (IEGC)[1].

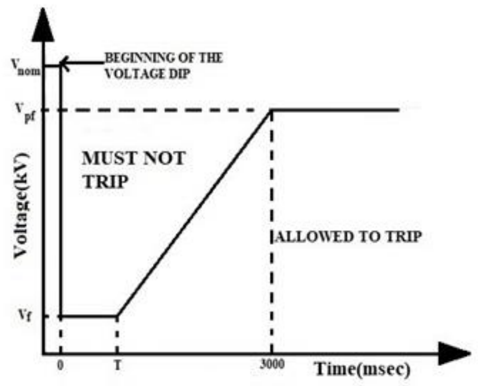


Fig. 1. LVRT Curve

The Fig. 1 shows the LVRT capability requirement for wind farms to be connected within the shaded region and can be disconnected otherwise. Vp f is the minimum voltage mentioned by IWGC, which is 85% of the nominal system voltage (Vnom) and Vf is 15% of the nominal system voltage.

TABLE I. LVRT REQUIREMENTS SPECIFIED IN INDIA

Nominal System voltage (kV)	Fault Clearing Time(msec)	V_{pf} (kV)	V_f (kV)
400	100	360	60
220	160	200	33
132	16	120	19.8
110	160	96.25	16.5
66	300	60	9.9

C. Different LVRT Methodologies For Wecs

LVRT capability can be implemented by using different methods. These methods can be classified as:

- Without energy storage based approach:Active crowbar protection,Series Dynamic Braking Resistor (SDBR) and Pitch angle control
- Energy storage based approach: Energy Storage Systems (ESS) and STATCOM technology.

Detailed explanation of STATCOM technology is presented in the next section as this is the method used in this paper to provide LVRT requirement.

III. STATCOM TECHNOLOGY FOR LVRT

The basic diagram of STATCOM integrated to WECS connected to grid is shown in the previous chapter. Flexible AC transmission systems (FACTS) based power electronic converters such as static synchronous compensator (STATCOM) is used here to provide the LVRT requirement[2]. STATCOM can provide this requirement by injecting a reactive current which in-turn maintains the voltage at the point of common coupling. The STATCOM is a shunt-connected device using power electronics which can regulate the voltage at its terminals by controlling the amount of reactive power injected into or absorbed from the power system. STATCOM consists of a coupling transformer, voltage source converter and a dc capacitor. When the grid voltage becomes low, the STATCOM generates the reactive power for adjusting the system voltage. On the other hand, when the power system voltage becomes high, it absorbs the reactive power.

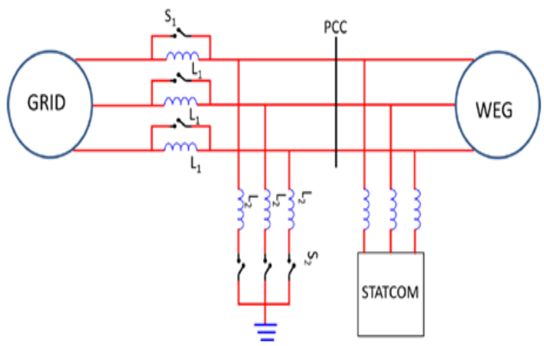


Fig. 2. Block Diagram Of LVRT Testing Scheme

Fig. 2 presents a schematic representation of a test setup to create a voltage disturbance in the electric network. When S1 is open and S2 is closed, it is like a symmetric fault. It can be seen that due to fault in the grid, the voltage available at WEG system terminal drops.

A. Control Of STATCOM

The control system of the STATCOM consists of a unit vector generation block, here since PLL technique is used, the block is given the name PLL. The phase angle θ is the output of the PLL system which is utilized to transform the three phase abc currents and voltages to the dq-axis currents and voltages. The error between the reference grid voltage and the actual grid voltage is evaluated by a PI controller and the output of PI controller is the reference q-axis reference current.

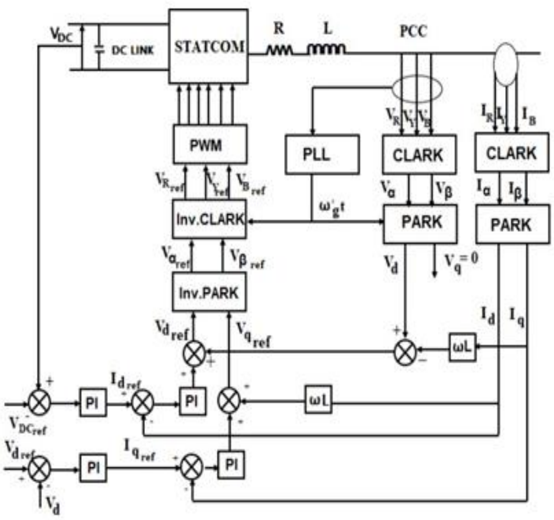


Fig. 3. Control Of STATCOM

The error between the reference DC-link voltage and the actual DC- link voltage is evaluated by a PI controller and the PI controller generates the d-axis reference current. An inner current controller loop produces the dq-axis reference voltage, and then it is converted to the three phase voltage reference.

By using sinusoidal PWM, switching pulses are generated to drive the VSC.

B. Unit Vector Generation

For the safe and efficient operation of STATCOM, proper synchronization with grid is very essential. An accurate and fast detection of the phase angle, amplitude and frequency of the grid voltage is thus essential for determination of grid condition. In order to control the flow of reactive current and to turn on and off power devices, a set of unit sine and cosine wave forms which are synchronized with the system are required. Various grid synchronization algorithms or unit vector generation methods include zero crossing detector PLL, stationary reference frame PLL, SRF-PLL etc.

Zero crossing detector PLL gives slow response with high sensitivity to frequency deviation and voltage unbalance and the stationary reference frame PLL is not capable of tracking un- balanced voltages properly. So among these SRF-PLL is the most commonly used unit vector generation method/ grid synchronization algorithm [3].

Unit vectors are two unity magnitude fundamental sinusoidal quantities, which are displaced by 90◦ from each other. One of the unit vector should be in phase with grid voltage. These unit vectors must be free from harmonics. Significance of unit vectors is that it helps to synchronize the STATCOM voltage and grid voltage.

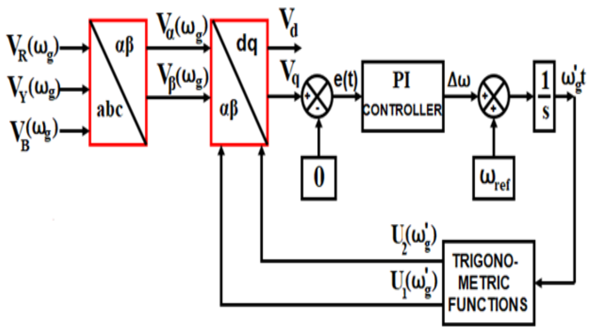


Fig. 4. Block Diagram Of SRF PLL

SRF PLL is the most commonly used PLL algorithm for unit vector generation. The unit vectors generated are used for the transformation of voltages and currents from αβ to dq frame. The unit vectors $U_1(\omega_g)$ and $U_2(\omega_g)$ are named as sinθ and -cosθ respectively. To obtain phase angle, voltage vector is synchronized with d or q axis. Basic block diagram of SRF PLL is shown in figure. If $V_q = 0$ is ensured, then $V_R(\omega_g)$ will be synchronized with unit vector $(U_1(\omega_g))$. To ensure $V_q = 0$, a simple PI controller is used.

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} \sin\omega_g' t & -\cos\omega_g' t \\ \cos\omega_g' t & \sin\omega_g' t \end{bmatrix} = \begin{bmatrix} \frac{3}{2}V_g\cos((\omega_g-\omega_g')t) \\ \frac{3}{2}V_g\sin((\omega_g-\omega_g')t) \end{bmatrix} \quad (1)$$

If the phases are not locked i.e.$\omega_g \neq \omega_g'$, then value of V_d and V_q is as shown above.

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} \sin\omega_g' t & -\cos\omega_g' t \\ \cos\omega_g' t & \sin\omega_g' t \end{bmatrix} \begin{bmatrix} \frac{3}{2}V_g\sin\omega_g t \\ -\frac{3}{2}V_g\cos\omega_g t \end{bmatrix} = \begin{bmatrix} \frac{3}{2}V_g \\ 0 \end{bmatrix} \quad (2)$$

If the phases are not locked i.e. $\omega_g = \omega_g'$, then value of V_d and V_q is as shown above.

IV. Design Of Voltage Sag

A symmetrical fault is simulated at the PCC with help of fault breaker in series with fault impedance as shown in Fig.3.1. The value of the fault impedance has been programmed to reduce the PCC voltage [4]. A dip in voltage can be created using the equation given below.

$$V_{sag} = V_{rated}\,\frac{Z_2}{Z_1} \quad (3)$$

V. Simulation And Results

The parameter values used for the simulation is given in table II

TABLE II. PARAMETERS FOR SIMULATION

Sl. No	Parameters	Values
STATCOM Data		
1	DC Link Capacitor (C)	5500µF
2	Inductance (L)	326.85µ H
3	Resistor (R)	100mH
4	Reference DC link capacitor voltage (V_{DCref})	850V
5	Current controller time constant (T1)	100µs
6	Voltage controller time constant (T2)	100ms
7	Grid frequency (f)	50Hz
8	Switching Frequency	10KHz
Wind Turbine Data		
9	Power	600kW
10	No: of blades	3
11	Rated Wind Speed	9 m/s
Generator Data		
12	Rated power	600kW
13	Rated voltage	690V
14	Rated frequency	50HZ
15	Stator Resistance	0.0092Ω
16	Stator Inductance	0.1686H
17	Rotor Resistance	0.0121Ω
18	Rotor Inductance	5.6863H
19	Moment of inertia coefficient	0.555
20	No: of pole pairs	2

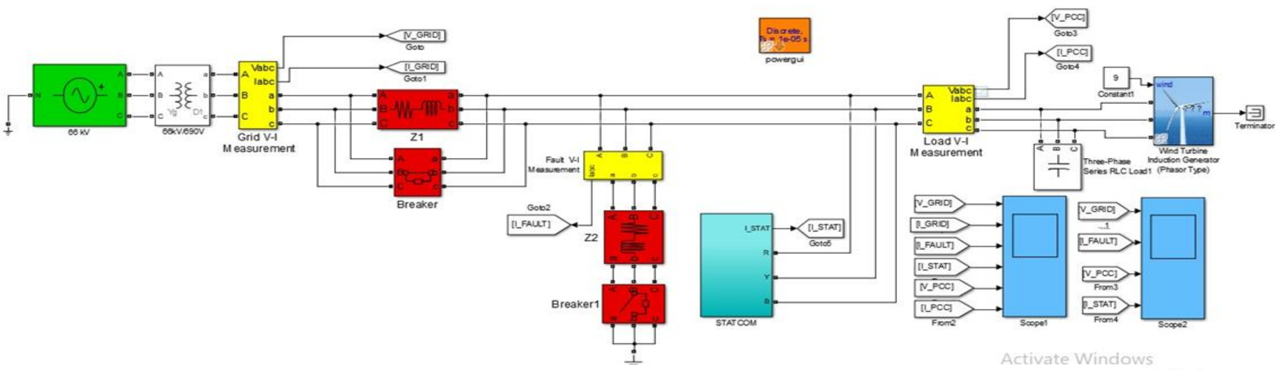


Fig 5 Simulink model of WECS with STATCOM connected to grid

The Fig. 5 shows the Simulink model of WECS with STATCOM connected to grid. In this model 66kV is stepped down to 690kV and then fed to the wind electric generator. Fault is introduced using an arrangement defined in the theory part. The STATCOM model is simulated using the equations mentioned above. In the control of STATCOM, SRF-PLL algorithm is implemented. The WECS used in the simulation takes the following values given in table II.

Fig. 6 shows the expanded STATCOM subsystem with transformer at its terminal to step up the STATCOM voltage generated.

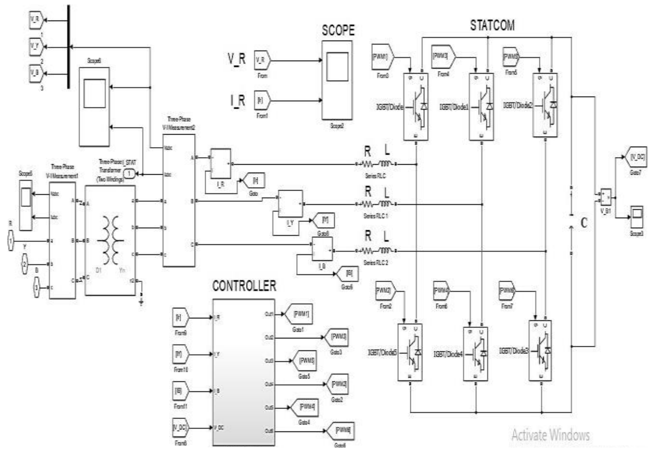


Fig 6 Simulink model of STATCOM

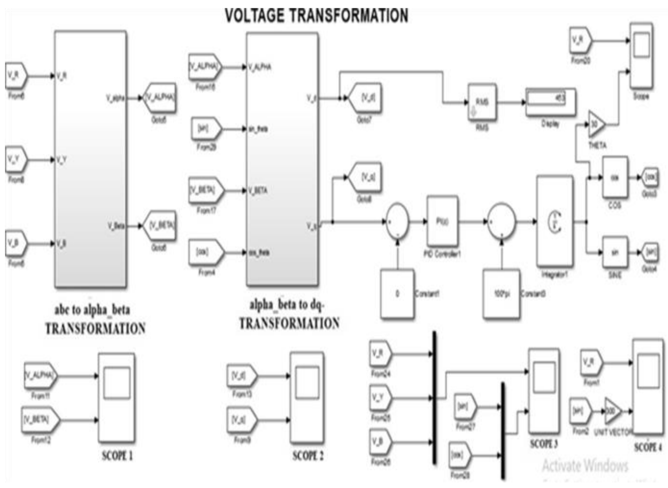


Fig 7 Simulink model of voltage transformation in STATCOM control

Fig. 7 shows the voltage transformation in STATCOM control implemented using SRF- PLL simulated in the previous section. STATCOM rated 500kVA is connected in shunt with grid at PCC through a transformer, 415V/690V, for supporting reactive power requirement of WEG during fault condition. A symmetrical fault is simulated at the PCC with help of fault breaker in series with fault impedance.

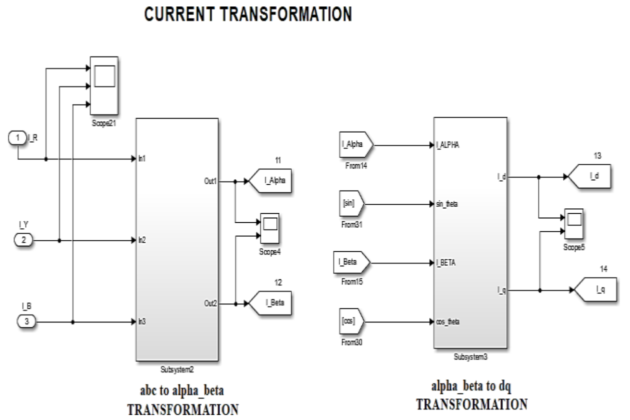


Fig 8 Simulink model of current transformation in STATCOM control

Fig.8 shows the Simulink model of current transformation in STATCOM using the unit vectors generated above.

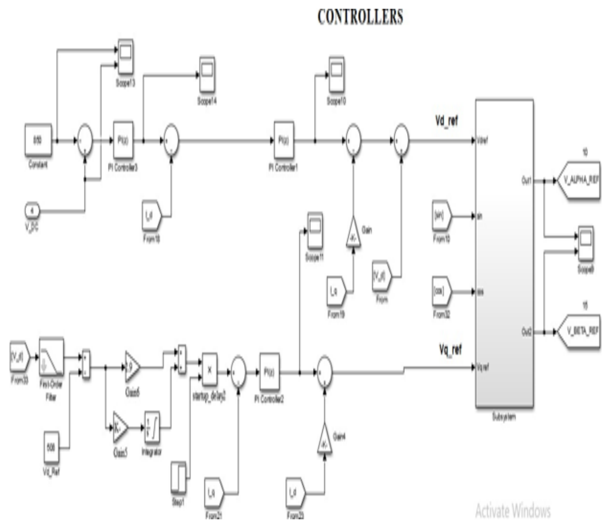


Fig 9 Simulink model of voltage and current control in STATCOM control

Fig. 9 shows the generation of alpha and beta reference voltages using the voltage and current controllers. The switching pulses for the inverter are generated as shown in Fig.10 Here sinusoidal pulse width modulation technique is used.

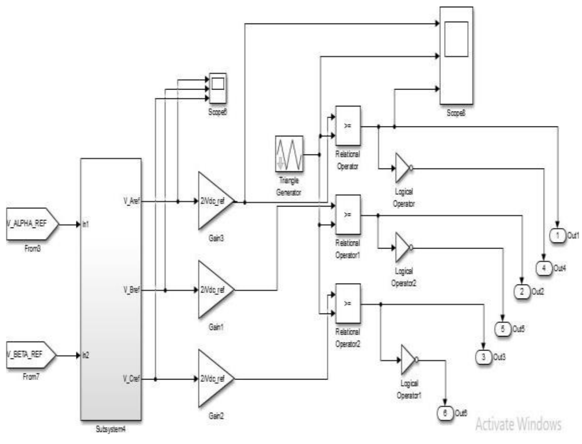
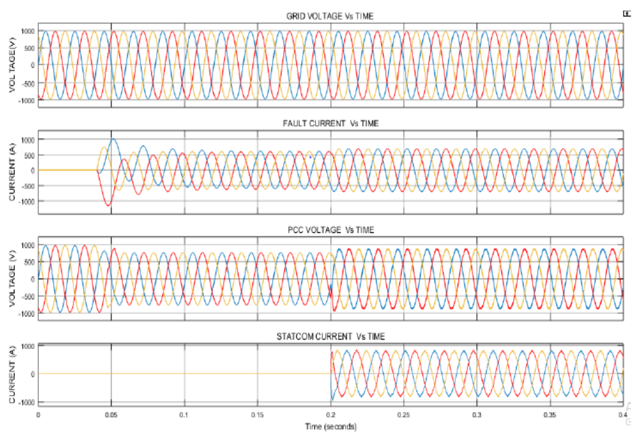
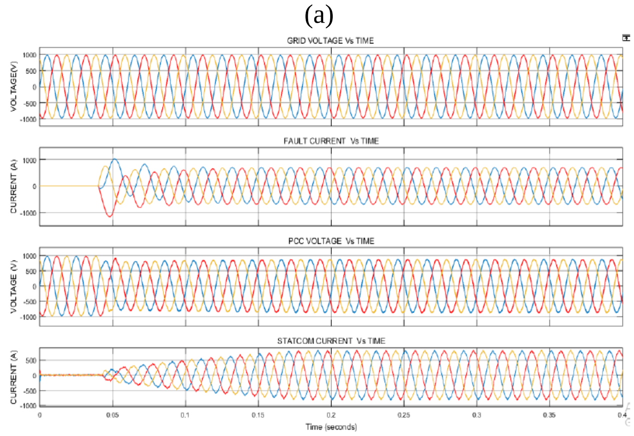


Figure 5.10 Simulink model of pulse generation in STATCOM

Case I : The value of the fault impedance has been programmed with $Z_1 = 0.02 + 0.1696\,j$ and $Z_2 = 0.084 + 0.7169\,j$ to reduce the PCC voltage to 76% of rated voltage at 40ms and STATCOM is programmed to supply the reactive current requirement of fault at 200ms.



(a)



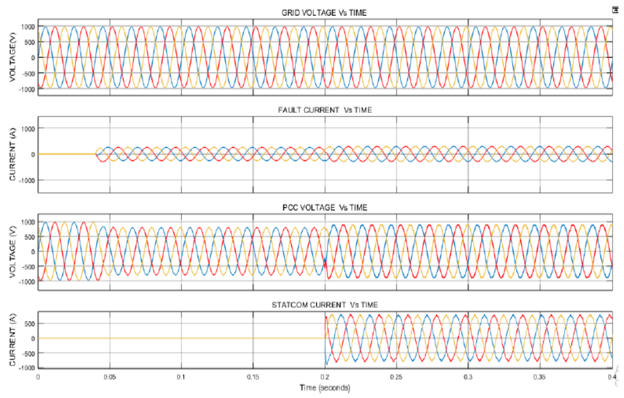
(b)

Fig 11 Output of scope 2 with STATCOM programmed to supply reactive current (a) at 200msec (b) as soon as fault occurs

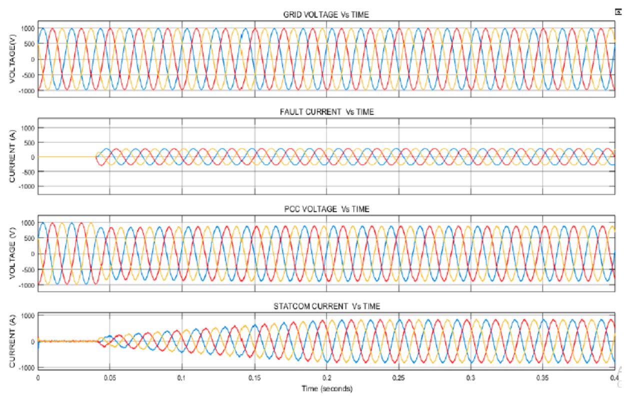
TABLE III. CASE1:VOLTAGE AT PCC DURING FAULT AND STATCOMON CONDITIONS

Normal Condition	Fault Condition	STATCOM On
690V	528V	630
690V	528V	630
690V	528V	630

From the above table III and waveforms in Fig.11 we can infer that the RMS voltage at PCC is getting improved to 630V from 528V when STATCOM is ON. This shows the capability of STATCOM in providing LVRT requirement.



(a)



(b)

Fig 12 Output of scope 2 with STATCOM programmed to supply reactive current (a) at 200msec (b) as soon as fault occurs

Case II : The value of the fault impedance has been programmed with $Z_1 = 0.08 + 0.1696\,j$ and $Z_2 = 1.5 + 0.9708\,j$ to reduce the PCC voltage to 81% of rated voltage at 40ms and STATCOM is programmed to supply the reactive current requirement of fault at 200ms.

TABLE IV. CASE 2: VOLTAGE AT PCC DURING FAULT AND STATCOM ON CONDITIONS

Line Voltage	Normal Condition	Fault Condition	STATCOM On
V_{RY}	690V	565V	637
V_{YB}	690V	565V	637
V_{BR}	690V	565V	637

From the above table and waveforms in Fig.12 we can infer that the RMS voltage at PCC is getting improved to 637V from 565V when STATCOM is ON. This shows the capability of STATCOM in providing LVRT requirement.

VI. CONCLUSION

Grid code requirements imposed by transmission system operators or grid operators are discussed. LVRT requirement is explained in detail. STATCOM technology providing the LVRT requirement is focused in this work. Simulations for STATCOM providing LVRT for grid connected WECS are carried out in MATLAB/Simulink environment. Hence it is concluded that the STATCOM technology can mitigate the voltage dip due to fault current by injecting capacitive reactive current of appropriate magnitude as per the Indian Grid code and it is a viable solution for effective integration of wind farm to electrical distribution systems.

REFERANCES

[1] Indian Wind Grid Code Draft.", 2009; pp.(15-18).

[2] Ramirez, Dionisio, et al, "Use of STATCOM in wind farms with fixed-speed generators for grid code compliance" *Renewable Energy*, vol. 37, no. 1, pp. 202-212, 2012.

[3] Andrews, Sajitha, TG Subhash Joshi, A. Saravana Kumar, A. S.Manju, and A. K. Unnikr- ishnan, "Modified SRF-PLL to operate under unbalance grid for grid synchronization of DVR", In 2014 IEEE *International Conference on Power Electronics, Drives andEnergy Systems (PEDES)*, pp. 1-6. IEEE, 2014.

[4] Bollen, Math HJ, "IEEE tutorial on voltage sag analysis," *IEEE Press*, 1999.