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Design of SVC for Dynamic Compensation to Improve LVRT of Small Wind Turbine

Sangamesh Y. Goudappanavar[1], Vijayalaxmi R. H.[2]

Assistant Professor, EE, Basaveshwar Engineering College, Bagalkote, India[1]

PG Student, Basaveshwar Engineering College, Bagalkote, India[2]

Abstract: This paper presents a control scheme for voltage and reactive power support of wind turbine generator connected to 11 kV grid. The proposed system consists of variable speed wind turbine coupled to PMSG through gear box, transmission line, transformer, and grid. The generated power is fed to the resistive load (1158W) of admission block of Basaveshwar Engineering College Bagalkote (BEC) and excess generation is fed to the grid. The proposed system employs design of Static VAR Compensator (SVC) comprises shunt capacitor or reactor banks which is switched by the thyristors by means of phase angle modulation to provide a continuous variable VAR injection to the electrical network and helps to improve the capability of Low Voltage Ride Through (LVRT). It is observed from the simulation results during fault condition the voltage dip occurs and when SVC is added to the system the voltage support is increased by 38% and by this the capability of LVRT improves and it maintain the continuity of WTG with grid. The system is also tested by considering hourly and monthly variable wind speed data measured from BEC SCADA for Distribution & Automation Research Centre from the wind mast which is located at Energy Park of BEC Bagalkot. Furthermore the proposed system shows the advantage of voltage and reactive power support at PCC.

Keywords: Permanent magnet synchronous generator (PMSG), Wind energy conversion systems (WECS), Low Voltage Ride Through (LVRT). Static VAR Compensation (SVC).

I. INTRODUCTION

Currently wind energy is one of the most supportable energy resources the tremendous growth of large scale grid connected wind forms have become a necessary part in the whole energy structure [1]. Though wind energy generation provides great opportunities to supply the power they also encompass many challenges such as voltage dip, grid voltage unbalance and grid insecurity, so to overcome those challenges power electronic control schemes are equipped such as FACTS devices. With rapid increase in penetration of wind power in the power system it is necessary for wind forms to behave as much as possible as convention power plants to support the network voltage and frequency not only during steady state conditions but also during grid disturbances. Due to this requirement the utilities have established grid codes for operation of grid connected wind farms. As a results of small scale wind power generation, Interconnecting wind turbine to power grids and the relevant influences on the host grids need to be carefully investigated. Wind turbines are now required to comply with stringent connection requirements including reactive power support, transient recovery, system stability, voltage and frequency regulation. Further to increase the maximum power extraction the variable speed generators are employed. These variable speed generators are employed. These are necessitating a AC-DC-AC conversion systems. The aim of these grid codes is to ensure that the continued growth of wind generation does not compromise the power quality as well as the security and reliability of the electric power system. The main grid codes which are important for the operation of wind turbine to be connected with grid are frequency and voltage range, active power control, reactive power control. The turbine must be required to operate within the range around the rated voltage and frequency at point of common coupling to avoid instabilities due to the grid disturbances. To provide reactive power during system fault and provide control depending on the needs of system wind turbine generators are retrofitted with LVRT.

In this paper a SVC is studied to enhance the LVRT capability of wind turbine generators, the main advantage of SVC is its capability to inject a controllable reactive current independently on the grid voltage and thus compensating the current. Three phase unsymmetrical faults are studied as this fault produces highest fault current. FRT capability of SVC connected wind energy conversion system is understood with the help of simulations. The design of SVC used the phase locked loop and proportional integral controller in order to control the reactive current injection into the grid during transient’s condition. The main purpose of SVC is to improve the voltage and reactive power support during voltage instability condition. The mathematical modeling of PMSG, SVC is done and integrating with grid. Single line diagram is considered the distribution part of BEC Bagalkot. The proposed system is tested for daily and monthly wind data measured from 1/6/2017 to 30/6/2017 in energy park BEC Bagalkot.

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The results show the behaviour of SWT under fault conditions. In section II PMSG connected wind energy conversion system is discussed. The LVRT capability is evaluated in section III. Section The control strategy of SVC is explained in section IV. The compensation of SVC during fault is represented in section V.

II. WIND ENERGY CONVERSION SYSTEM

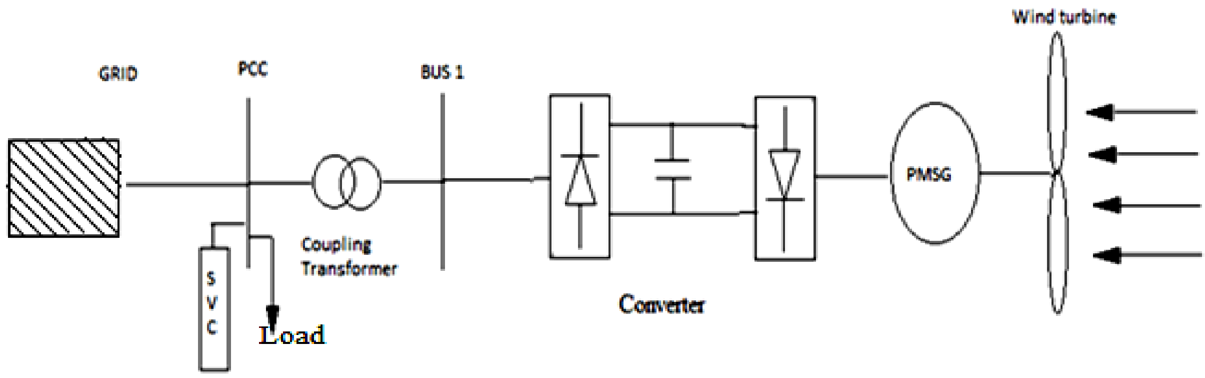

Fig 1. Single line diagram of proposed system

Considering the single bus with load and generator of seven bus distribution system of Basaveshwar Engineering College Bagalkot in which wind, solar and grid are considered as source of generation. In this paper the 1.5 kW wind turbine is considered as source, generation power is supplied to the Electronic and communication department which consumes active power 90.88W, inductive reactive power 167.5W and capacitive reactive power as 1015.2W.

The wind turbine driven PMSG can be represented in the rotor reference frame as [3].

$$V_{qg} = -R_s i_q + L_q \frac{di_q}{dt} - \omega_r L_d i_d + \omega_r \lambda_m \quad (1)$$

$$V_{dg} = R_s i_d + L_d \frac{di_d}{dt} + \omega_r L_q i_q \quad (2)$$

In rotor rotating reference frame the torque equation can be expressed as

$$Te = \frac{P_m}{\omega_m} = \frac{P_m}{\omega_r}(P/2) \quad (3)$$

Where Te is the electromagnetic torque in Nm

$$T_e = \frac{3P}{4}\left[i_d i_q \left(L_q - L_d\right) + \lambda_m i_q\right] \quad (4)$$

From these above equations

$$\frac{d\omega_r}{dt} = \frac{P}{2J}(t_m - t_e) \quad (5)$$

There is a relation between generator angular velocity as well as the rotor mechanical angular velocity of wind and it can be given as

$$\omega = \frac{\omega_r}{PG/2} \quad (6)$$

The generator input torque can be obtained by dividing the turbine torque by gear ratio

$$T_m = \frac{T_t}{G} \quad (7)$$

The generator d-q component current can be calculated as

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$$\frac{di_q}{dt} = \frac{1}{(L_{sr}+L_q)}\left[-R_s i_q - \omega_r i_d(L_{sr}+L_d) + \omega_r \lambda_m + V_{qr}\right] \tag{8}$$

$$\frac{di_d}{dt} = \frac{1}{(L_{sr}+L_d)}\left[-R_s i_d - \omega_r i_q\left(L_{sr}+L_q\right) + V_{dr}\right] \tag{9}$$

PMSG in comparison to induction generators are becoming popular in WECS, as they have advantages of reduced size, weight and absence of excitation system. In literatures, to extract optimum power from wind turbine generator at unity power factor there are several topologies reported [2]. One of such topology is the DC-DC converter was employed with controlled and uncontrolled rectifier to draw the current in phase with voltage. It has the switching complexity and additional cost of the system. In order to control the generator connected wind turbine, usually vector control technique is employed [1].

There is consequently a need for a universal model with freely available and described parameters that quickly and reliably predicts the performance of PMSG system to voltage dips. The development model should have similar abilities as a real wind turbine system, mainly for severe voltage dips. The PMSG model with standard operation and FRT operation facility is developed and analysis is performed using simulation.

III. LOW VOLTAGE RIDE THROUGH

A low voltage ride through (LVRT) or fault ride through (FRT) is the ability of a power-generating device to maintain its output voltage in short-term power dips. During the LVRT, the wind turbine remains connected to the electric system and returns to its normal operation quickly after the disturbance ends. Modern large-scale wind turbines are normally required to include LVRT that allow them to operate through such an event, and thereby "ride through" the low voltage. During a fault that causes a voltage drop at the wind turbine terminals, the reactive power demand of permanent magnet synchronous generators increases. Unless a reactive power support is available at the generator terminals, the reactive power will be drawn from the grid., to transfer active power and cause further drop in voltage at the point of common coupling.

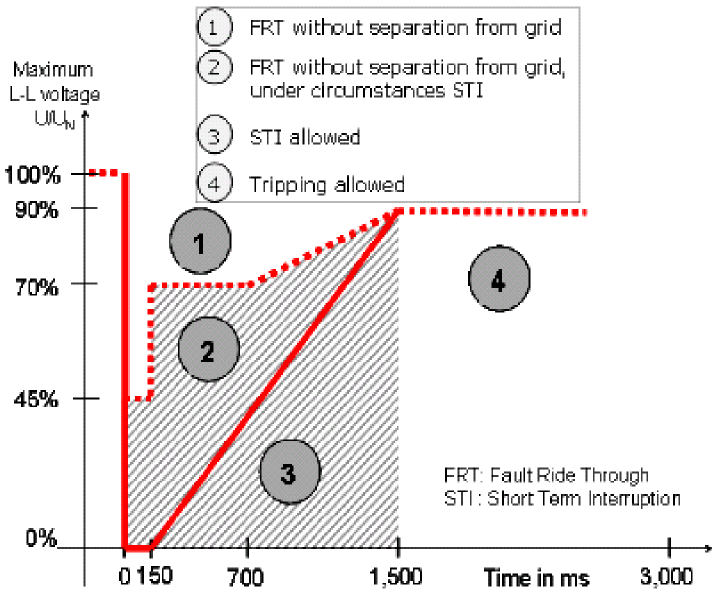

Fig. 2: Permissible voltage v/s time characteristics of LVRT [6]

The grid code thus stipulates that only under certain circumstances shall wind power plants be disconnected from the grid following a grid fault. The timeframe and the circumstances under which wind plants can be disconnected from the network are summarized in Fig. 2. In the area above the dotted line (area 1), fault related voltage dips must not lead to the disconnection of the wind generation plant from the grid. Only when the voltage dip persists for longer than 1500 ms (area 4), immediate disconnection is permitted. Similarly, a short interruption is permitted in the event of a voltage versus time scenario corresponding to any of the points in area 3. In the area between the dotted and solid lines (area 2) all generating plants should negotiate through the fault without interruption.

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But if the internal configuration of any generating plant does not allow it to comply with this requirement, a short disconnection is permitted with the provision that a minimum reactive power in-feed is guaranteed whatever the source of the reactive power. If the interruption occurs as a result of the machine becoming unstable or by the action of the protection system, a resynchronization must take place within 2 s of the event and the active power ramp-up rate upon synchronization must be no less than 10% of the rated power per second [4].

IV. STATIC VAR COMPENSATION (SVC)

SVC is mainly used for voltage regulation in power system. The main goal is to increase the transmittable power, improves the steady state transmission characteristics and enhances the overall system stability.

A static VAR compensator is suitable for direct and rapid control of voltage, has advantage over series capacitors where compensation is required to prevent voltage sag at a bus involving multiple lines. A shunt-connected static var generator or absorber whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific parameters of the electrical power system (typically bus voltage).

The reactive current of the circuit is given by

$$I = \left(\frac{V-E}{X}\right) \tag{10}$$

The reactive power of the system is given by

$$Q = \frac{1-\frac{E}{V}}{X}V^2 \tag{11}$$

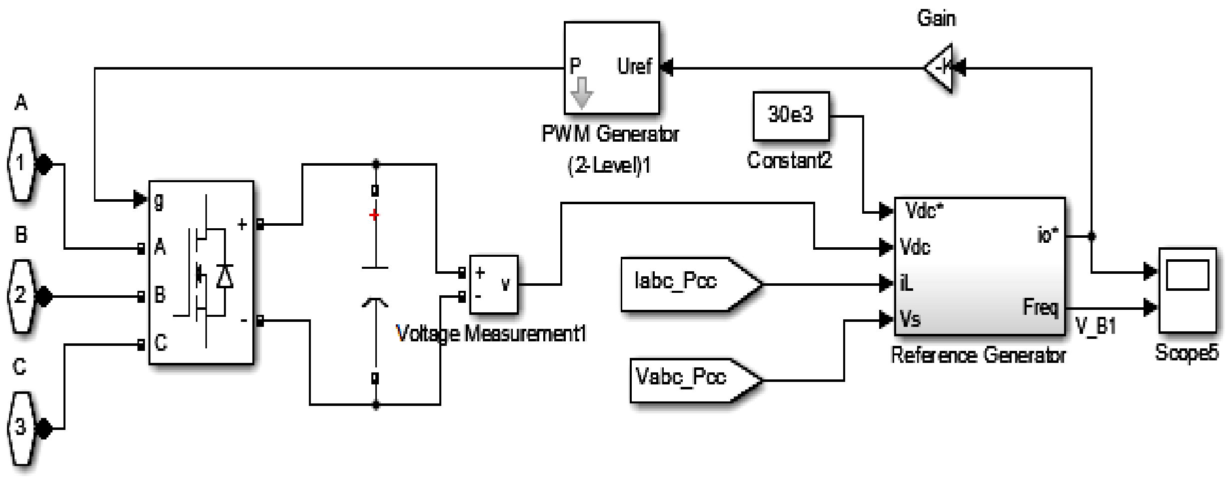

Fig. 3: Basic controlling block diagram of static VAR compensator

The converter internal control is presented in the Fig 3. The bus voltage and line current are the input signals, and that reference frame current can be converted into d-q axis, by taking V_{dc} reference that is compared with DC link voltage which is amplified by error amplifier (PI controller), Ziegler and Nichols method is applied for finding the gain values of PI controller. The PI controllers are tuned for stability and good transient performance.

The proportional gain K_P and Integral gain K_I values in the PI controller are tuned manually according to the above said method [3]. The PLL will provide phase angle then it converts d-q to abc this park transformation is used to reduce harmonics in the system and which is determined from compensation requirement, after the amplification the current component is converted in to magnitude and phase angle which is required for the converter, the internal control scheme is the essential part of the converter. Its operation is to control the converter power switches in order to develop fundamental output voltage, magnitude and phase angle.

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$$V=\begin{cases} V_{ref}+X_s I & if\ regulation\ (-B_{cmax}<B<B_{lmax}) \\ -\frac{I}{B_{max}} & if\ SVC\ is\ capacitive(B=B_{cmax}) \\ \frac{I}{B_{max}} & if\ SVC\ is\ inductive\ \ (B=B_{lmax}) \end{cases}$$

The SVC performs reactive power exchange and voltage improvement with the transmission system. The flow of reactive power is determined by the difference between the converter output voltage and the PCC bus voltage. The SVC with suitable size improves the LVRT capability of the system.

The SVC along with its controller is used to maintain the PCC voltage close to the normal value. Fig 3 shows the I_L which is obtained from the DC voltage regulation, after suitable amplification I_o provides the magnitude and angle for the required output current which is set to the PWM generator to generate appropriate signal to converter in relation with PLL to provide phase reference. The real power exchange and reactive power requirement can be achieved by current which provides the magnitude and phase angle.

V. MATHEMATICAL SIMULATION

The analysis and performance of the control scheme are verified using simulations. The MATLAB/SIMULINK model is shown in Fig 4.

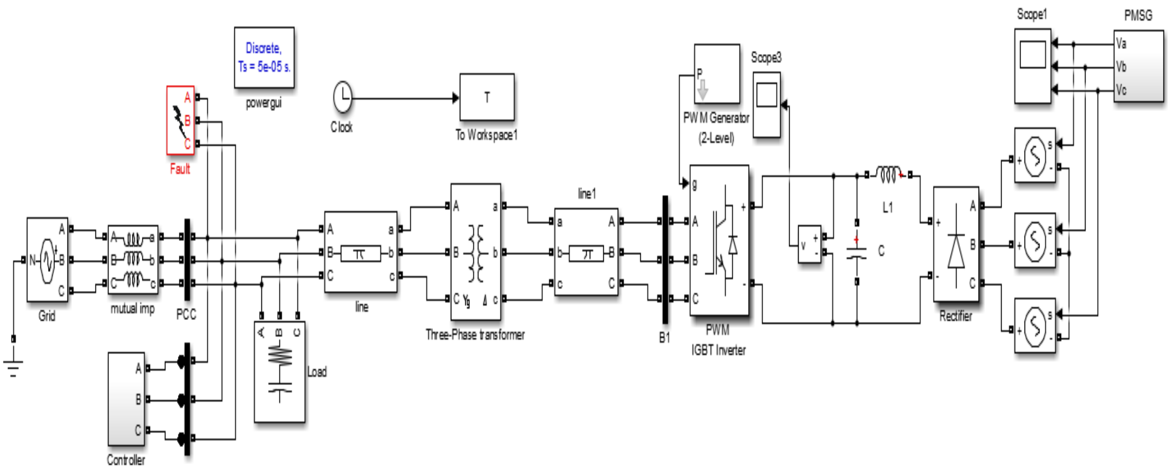

Fig. 4: Simulink model of WTG integrated with grid during transient and with SVC

The simulation diagram consists of a SVC connected to the grid. Proposed system of WTG integrated with grid having L-G fault of resistance 1e $^{-3}$ Ω and ground resistance of 1e $^{-3}$ Ω the fault is initiated manually at time instant 5sec and continuous until 5.15sec, the distribution system is simulated the model is simulated for the time period of 50seconds as shown in Fig.5-10.

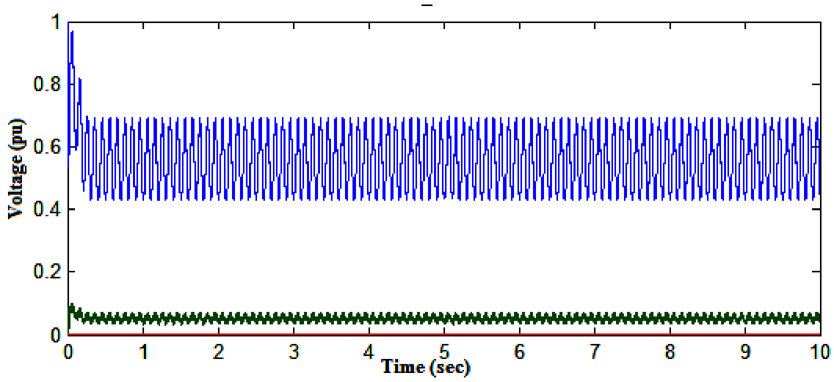

Fig. 5: Voltage v/s time characteristics of proposed system with fault at bus1

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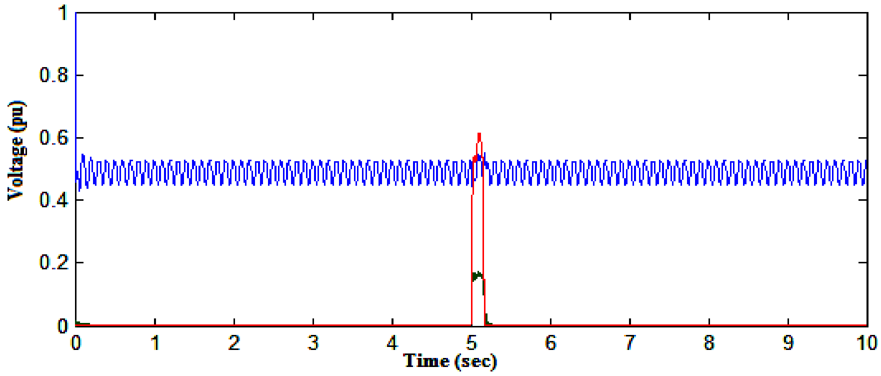

Fig. 6: Voltage v/s time characteristics of proposed system with fault at PCC

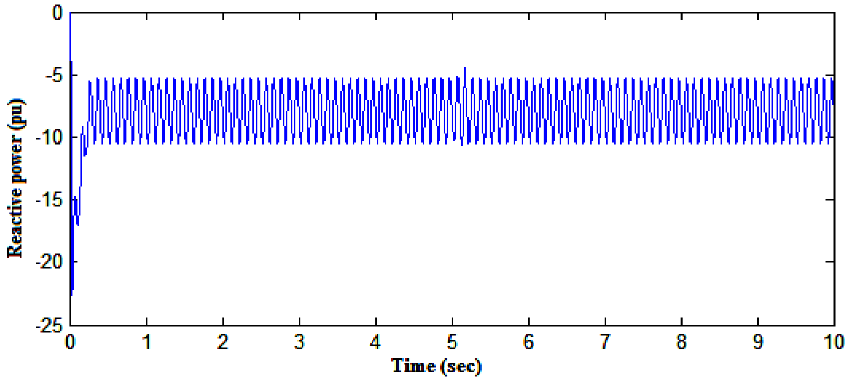

Fig. 7: Reactive power v/s time characteristics of proposed system with fault at Bus1

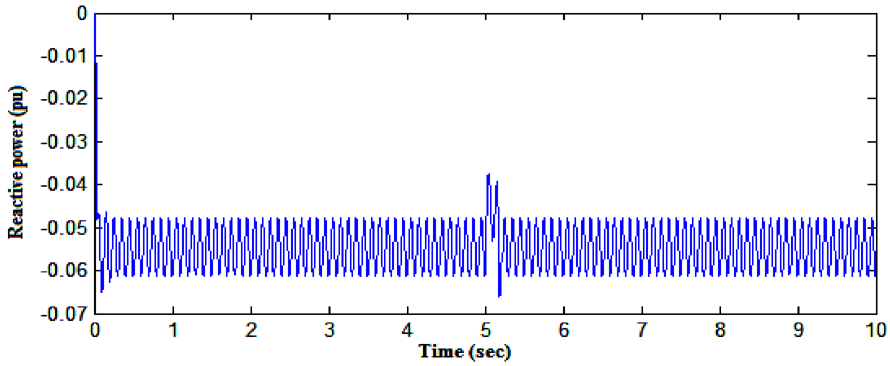

Fig. 8: Reactive power v/s time characteristics of proposed system with fault at PCC

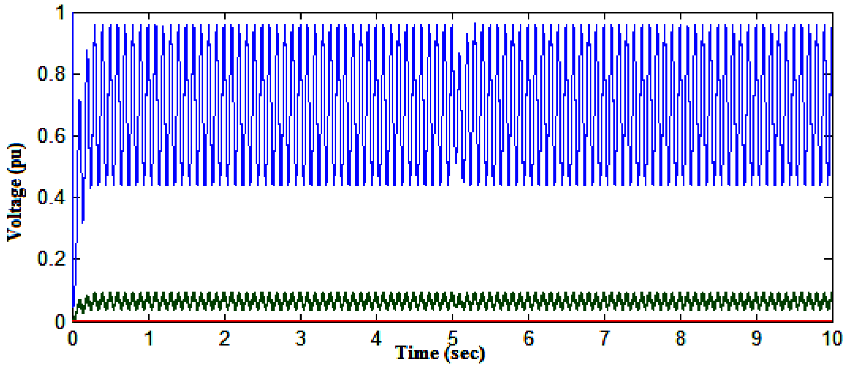

Fig. 9: Voltage v/s time characteristics of proposed system with L-G fault with svc at bus1

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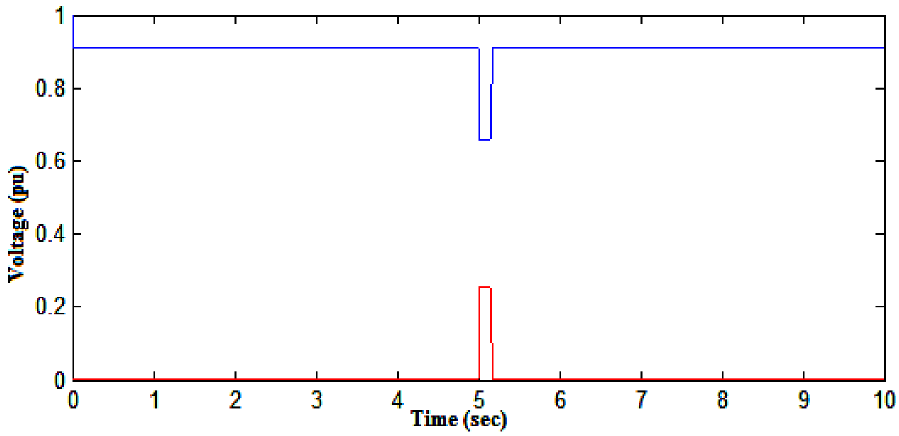

Fig. 10: Voltage v/s time characteristics of proposed system with L-G fault with svc at PCC

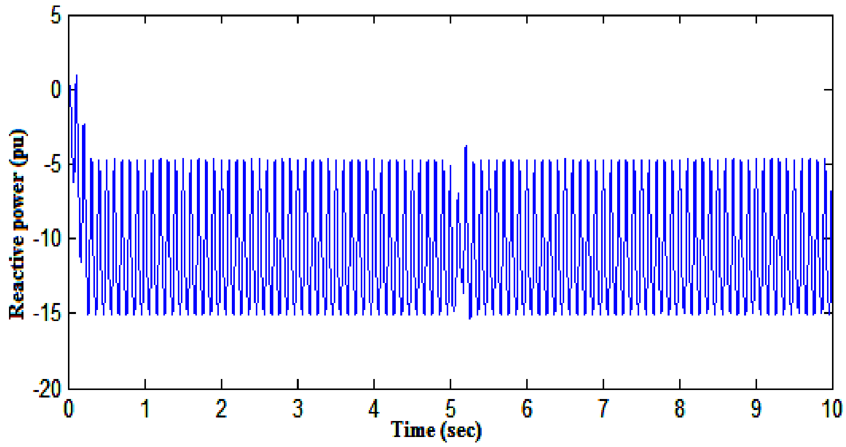

Fig. 11: Reactive power v/s time characteristics of proposed system with L-G fault with svc at bus1

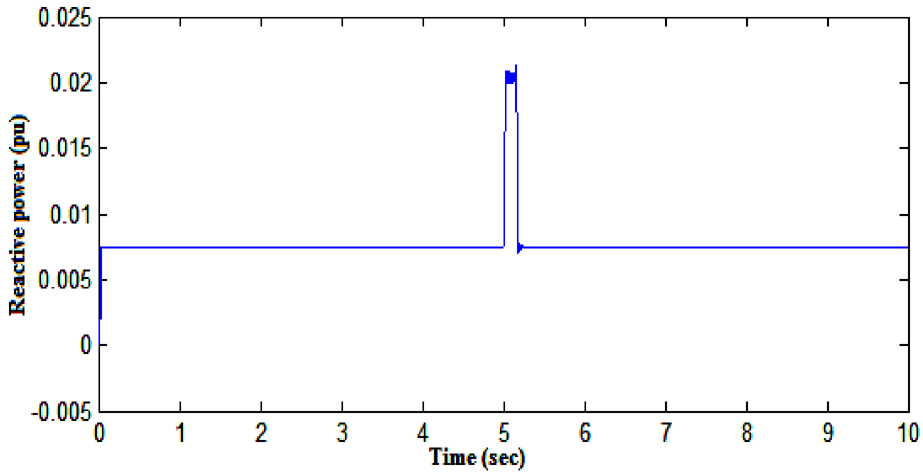

Fig. 12: Reactive power v/s time characteristics of proposed system with L-G fault with svc at PCC

The above Fig.11-12 shows the voltage and reactive power characteristics at bus one and PCC during transients condition. The proposed system having WTG connected to grid is reproduced using MATLAB, analyzed the performance under normal operating condition and transient condition at constant wind speed.

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Table 1: Analysis of voltage support and reactive power generation

Condition	Voltage at PCC (pu)	Voltage support (%)	Reactive Power at bus1	Reactive Power at PCC
WTG without fault and SVC	1	--	-7.65	-0.066
WTG with fault without SVC	0.52	--	-7.405	-0.061
WTG with fault and SVC	0.909	38	-6.79	0.0074

The Table 1 shows voltage and reactive power at three different conditions when considering the constant wind speed of 12m/sec. Based on conditions voltage support and reactive power compensation can be studied and tabulated. Above table also shows reactive power generation of wind turbine before and after fault with compensation and without compensation, after the compensation the 38% of voltage support improved.

Case study: Considering variable wind speed data measured from wind mast which is located at BEC campus of 1.5kW Unitron wind turbine measured in June 2017, study has been carried out and analyze the voltage support for one hour variable wind speed data's.

Table 2: Analysis of voltage support and reactive power generation for one month data

Condition	Voltage at PCC (pu)	Voltage support (%)	Reactive Power at B1 (pu)	Reactive Power at PCC (pu)
WTG without fault and SVC	0.544	--	-6.072	-0.0654
WTG with fault without SVC	0.523	--	-5.854	-0.0605
WTG with fault and SVC	0.90	42	-4.94	0.007

The Table-2 shows voltage and reactive power at three different conditions when considering the variable wind speed of June month data based on conditions voltage support and reactive power compensation can be studied and tabulated. Above table shows reactive power generation of wind turbine before and after fault with compensation and without compensation, after the compensation the 42% of voltage support is improved.

VI. CONCLUSION

The single line diagram is designed with rating of 1.5 kW, 50Hz, 11 kV with 100 kVA transformer connected load. The model is simulated using MATLAB/SIMULINK. The voltage drop during line to line fault is simulated and is compensated using SVC. This voltage drop can be compensated to some extent and the performances of external circuits are compared, LVRT is retrofitted in order to recover the voltage profile of system, for small rating turbine the PMSG having more advantage compared to DFIG. DFIG ride the fault up to 0.17sec to clear the fault where as PMSG clear the fault in 0.15sec voltage support is increases by 38%, reactive power support increases so PMSG is more efficient then DFIG.

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BIOGRAPHY

Sangamesh Y. Goudappanavar (S'10, M'13) was born in Guledagudda, Bagalkot, Karnataka, India on May 15, 1987. He obtained B.E (Electrical and Electronics Engineering) degree from BIET Davangere and M.Tech. (Power and Energy Systems) from BEC Bagalkot. Presently pursuing Ph.D in VTU Belagavi. His areas of interest are power and energy systems, small wind turbines in distribution system, microgrid, FACTS and Advanced control system. Presently, he is a Asst. Professor in the department of EE at Basaveshwar Engineering College (Autonomous), Bagalkot.

Vijayalaxmi R. H. was born in Gulbarga, Gulbarga District, Karnataka on 17th Aug 1993. She obtained Electrical & Electronics Engineering Degree from Visvesvaraya Technological University, Belagavi in the year 2015. She is currently Pursuing the M. Tech degree in Power and Energy Systems at Visvesvaraya Technological University, Belagavi. She is a student member of IEEE and member of Power and Energy Society. Her area of interest is Power System and Power and Energy System.