Performance Analysis of Variable Speed Wind Energy Conversion System in Grid Connected Mode

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Abstract— **This paper represents the modeling and simulation of wind energy based grid connected distributed generation system. A control scheme is presented to control the power flow of the inverter. The controller is able to restore the pre fault condition very quickly. The grid side controller is able to manage the constant dc-link voltage while maintaining the power injection according to the wind speed variations. The performance of the system for wide range of wind speed is presented. The battery is considered for energy storage and is directly connected to the dc-link. The results for variation in load and fault conditions are shown.**

Keywords— WECS-wind energy conversion system; DG- distribute generation; PMSG-permanent magnet synchronous generator; VSWT-Variable speed wind turbine.

I. INTRODUCTION

The demand for electrical energy is ever increasing. However it is difficult to meet the demand in the same phase. Due to large gap between demand and generation, the transmission system is under stress. As the technological advancement is taking place the requirement of power is also increasing drastically [1]. The expansion of transmission system as well the establishment of new power plant is subjected to economical and time constraints. With increased power requirement, the other issues like power quality, environmental concerns also gained great importance nowadays. The climatic change due burning of fossil fuels [2],[3] is one of the major issues in present day to build new power plants based on fossil fuels. The hydro power plants also have environmental concerns.

The above mentioned issues were made to look at different energy resources which can utilize local available resources for power generation. This can be achieved by local generation called distributed generation. A small scale generation near to load is called as distributed generation, which gained more importance nowadays due to numerous advantages. The distributed generation can utilize renewable energy resources like PV and wind which are environmental friendly and available freely and abundantly. DG can release the stress on the transmission system and also reduces losses .The DG can adversely affect system if proper care is not taken in placing and sizing of it [4].

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The PV, wind, microturbine, fuel cell are some of the DG systems [5] which gained more importance in present day situation. The microturbine and fuel cell are associated with cost and infrastructure issues. On the other hand the PV and wind based generation are now technologically well established and commercially available. The wind technology is one of old technology among the power generation based on renewable sources. Wind energy conversion system mainly categorized based on wind turbine control and generator used. The variable speed wind generation systems are in operation due to their ability to extract maximum power from the wind [6], [7], [8], and [9]. The WECS may consist of induction generator, doubly fed induction generator, synchronous generator or permanent magnet synchronous generator [5]. In most of the cases DFIG are employed [10], the different types of wind energy conversion systems are discussed in [5]. Nowadays use of permanent magnet synchronous generator is increased due to advantages incorporated with it. The advantages of PMSG are, turbine can be directly connected to the generator without gear system [10], simple construction, less maintenance etc. [11], [12].

The wind energy is available abundantly in nature however it is not available at constant rate. The wind speed varies in wide range during the day as well seasonally. As the wind speed varies the power generated from the WECS also varies. The varying power generation from wind energy conversion system may affect the other systems to which it is interfaced [6]. As the wind speed is unpredictable, load demand is also an unpredictable parameter. Hence to balance the generation and demand an energy storage system is required as buffer to store the energy when power is generated and release the stored energy whenever required [1],[13]. Different energy storage devices are considered namely; flywheel, ultracapcitor, superconductor magnetic coil and battery [14]. However battery is chosen for its high energy capability.

The power electronic converter plays major in distributed generation system to utilize generated power efficiently. The different converter technologies are discussed in [5]. Wind system employs different converters [10] depending upon the type of wind turbine, its control and generator employed. The different topologies of wind turbine system are discussed in [15].The DGIG uses back to back converter which will supply the reactive power to rotor and the stator is connected to utility. The rectifier and the inverter scheme are employed in variable speed wind conversion system. The generated ac power converted to dc using the rectifier. The control schemes are applied to rectifier to manage maximum power point. The usage of dc-dc converter is depends on the output voltage level of inverter and the maxim power point tracking scheme. In most of the WECS the two control schemes are used, one is generator side controller and another is grid side controller [16]. The generator side controller provides the maximum power point and grid side converter controls power injected into the utility while maintaining the dc-link voltage constant [17], [18].

In this paper a variable speed wind turbine system is considered with PMSG. The rectifier-inverter system is used to integrate the wind system to grid. The battery is considered for energy storage and it is directly connected to the dc-link. The connection of battery to common dc-link avoids usage of bidirectional converter [14] which makes the system simple and minimizes the losses. A control scheme is developed to control the power electronic converters to interface with the grid as well control the power flow. The grid side controller is able to control dc-link voltage. By varying the reference current value, according to the variation in the dc voltage which depends on wind speed. Hence if wind speed varies the generator voltage varies accordingly the current reference will be varied by the controller which will match power generated by the wind system and power output from the inverter. The model has been implemented in Matlab/simulink platform. The simulation has been carried out for wide range of wind speed. The simulation results are discussed for change in load level and wind speed. The system performance for single line to ground fault is discussed.

II. WIND ENERGY CONVERSION SYSTEM.

The wind energy conversion system is shown in Fig. 1. The system consists of wind turbine coupled with PMSG. The output of generator is rectified by rectifier. The rectified output is then fed to the inverter. The inverter is connected to the grid through filter and step up transformer. The PMSG and wind turbine parameters presented in [14] are used in this paper.

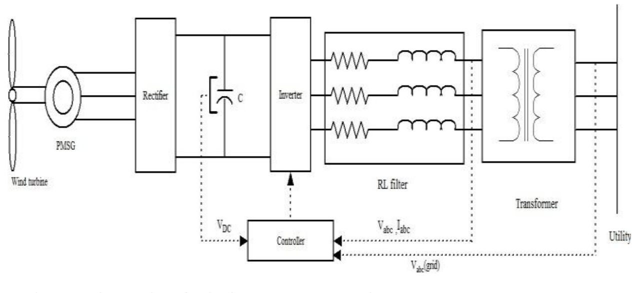

Fig.1. Schematic of wind energy conversion system.

Modeling of the wind turbine is as follows [19].

$$P = \frac{1}{2}\rho A C_P V^3 \qquad (1)$$

Where ρ = air density (kg^3), A is area swept by the rotor, V is the wind speed (m/s) and Cp is power coefficient of the wind turbine.

The torque produced by wind turbine is given by

$$T_w = \frac{P}{w_m} \qquad (2)$$

Where w_m is the angular velocity of wind turbine rotor. The tip-speed ratio λ is given in terms of rotor speed and wind speed is

$$\lambda = \frac{R w_m}{V} \qquad (3)$$

Where R is wind turbine rotor radius in meters.

III. CONVERTER CONTROL

The schematic diagram of wind turbine system with battery connected to dc-link is shown in Fig.2.

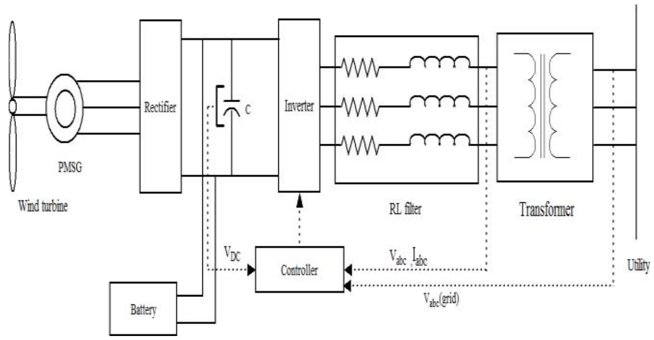

Fig.2. Schematic of wind energy conversion system with battery

The generated power from PMSG is fed to diode rectifier. The rectified voltage is given to the inverter through common dc-link. The inverter control is achieved using PQ control scheme and is shown in Fig. 3. The DC voltage is controlled using the PI controlled in outer loop. This loop will generate the required current reference in dq frame.

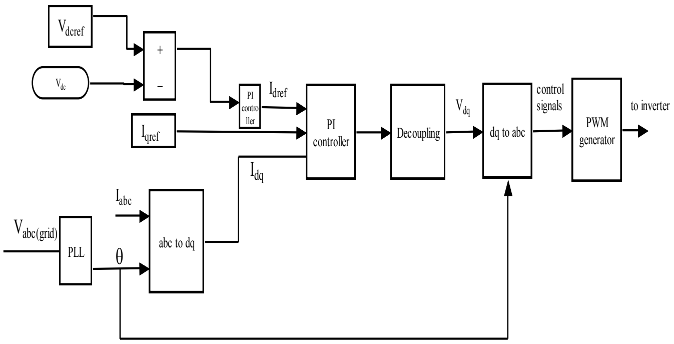

Fig.3. Converter controller for grid connected mode.

The dc bus voltage is mainly determined by the inverter ac output voltage and the voltage drop across the filter. A lower bound on the dc bus voltage can be determined from the following relation (4) at a unity power factor [20].

$$\frac{\sqrt{3}}{2\sqrt{2}} m_a V_{dc} \geq \sqrt{V_{ll}^{\,2} + 3(wL_f I_{ac})^2} \qquad (4)$$

Where:

(V_{ll})=line-line RMS voltage on the inverter side (L_f) =Filter inductance, (I_{ac}) =Maximum possible RMS Value of the ac load current ma=Modulation index of the inverter. The inverter voltage can be determined by (5).

$$V_{LL} = \frac{\sqrt{3}}{2\sqrt{2}} m_a V_{dc} \qquad (5)$$

Where m_a is modulation index and V_{dc} is the dc-link voltage.

In the PQ control, the real and reactive power exchanged with the grid is variables controlled by the inverter, since they have to meet the reference power [21], [22]. The PQ control will fail on an isolated grid due to the absence of a voltage reference. In order to have a faster response the active and reactive power channels of the inverter are decoupled. In particular, a Park transformation of the inverter output currents and voltages from the physical a-b-c reference frame to the stationary d-q reference frame allows to make use of the correlation existing between active power and direct current component (id) and between reactive power and quadrature current component (iq). The power injected into the grid is controlled by controlling the injected current. The dq synchronous frame is used to regulate the current using the PI controller in the inner loops of the control system. Grid connected mode of system using two loop control scheme in dq reference frame and controller are defined as.

$$V_d = L_f \frac{di_d}{dt} + R_f I_d - wL_f i_q$$

$$V_q = L_f \frac{di_q}{dt} + R_f I_d + wL_f i_d$$

In grid connected mode of operation DG is synchronized with utility using the PLL. The angle theta is used in dq to abc conversion. Which will intern synchronizes the inverter output with the grid.

IV. RESULTS

Simulation is carried out to study performance of system under different conditions. At first the simulation is carried out without the battery connected to dc-link link. The simulation is carried out for wide range of wind speeds, i.e. from 6m/s to 12 m/s in steps of 1 m/s. Further the model has been simulated with battery connected to dc-link. The model behavior is studied under fault conditions, for illustration the single line to ground fault is considers in the paper.

A. Without battery

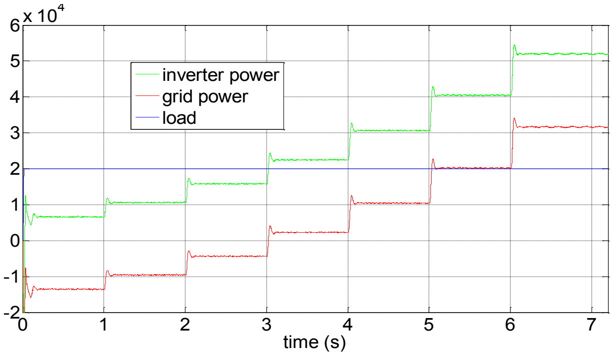

Fig. 4. Active power of WECS, grid and load.

The Fig. 4 show active power generated from WECS and power absorbed by the grid. During the simulation period the resistive load of 20kW is considered. From the above figure it can be seen that at low wind speeds the power generated from wind system is less than the load requirement hence deficit power is consumed from the grid. At high wind speed the power generation is more than the load, the extra power generated is injected into the grid.

B. With battery connected to dc-link

In this case the simulation started with wind speed of 6m/s and at t=5s the wind speed is increased to 12m/s.

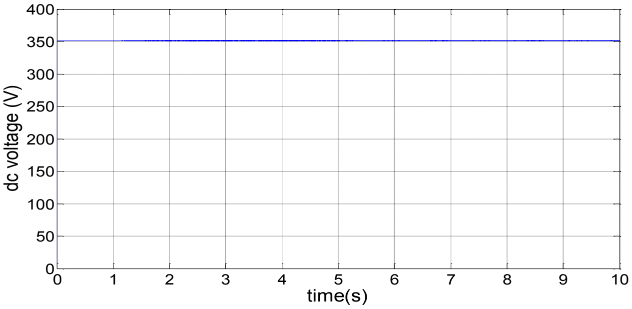

Fig. 5. dc-link voltage.

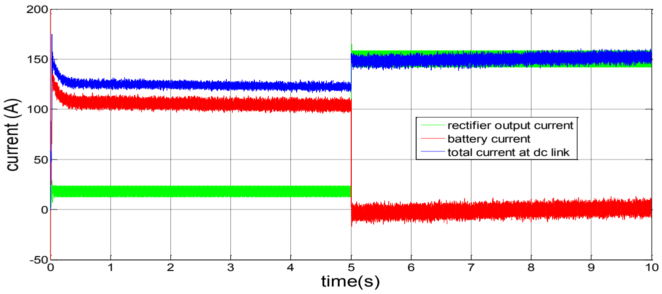

Fig. 6. Current variations of battery and WECS at dc-link.

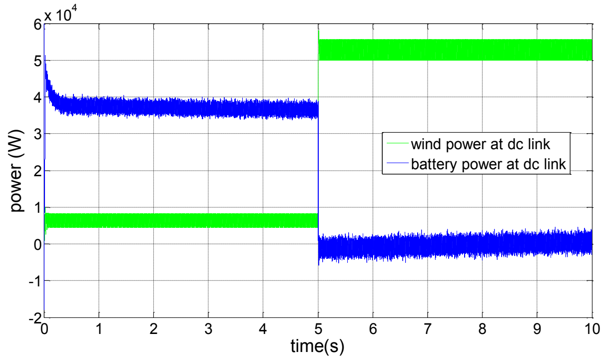

Fig. 7. Power generated by WECS and battery.

Fig. 7 shows the power injected to the dc-link by the battery and WECS. During the simulation period at t=0s the 20kW resistive load is considered and is then increased to 55kW at time t=5s.

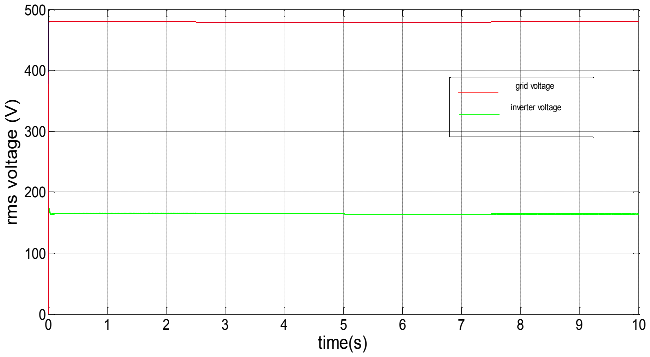

Fig. 8. rms voltage of inverter and grid.

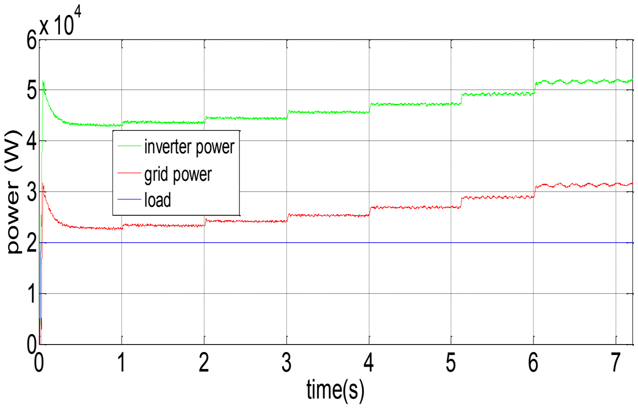

Fig. 9. Power sharing of WECS and grid for connected load.

Fig. 8 shows the rms voltage of the inverter and grid. The power sharing of WECS and grid with varying load is shown in Fig. 9. Fig. 10 shows the frequency variation of system.

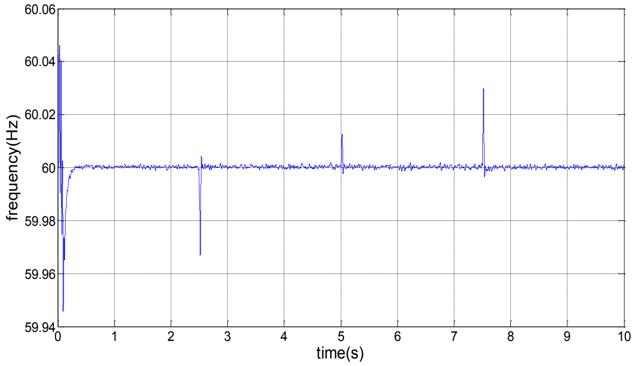

Fig. 10. Frequency of system

C. Simulation of the system for fault at load side.

In this scenario the model is simulated for fault occurrence at load side. The single line to ground fault is simulated at time intervals of t=1.5s, 2.5s, 3.5s, 6s and 8.5s with fault clearing time of 0.3s. The wind speed is increased from 6m/s to 12 m/s at time t=5s. The load is varied as, 20 kW, 55kW. and 20kW at time, t=0s, 2.5s, and 7.5s respectively. The following figures show the variation of power, current, voltage and frequency of the systems.

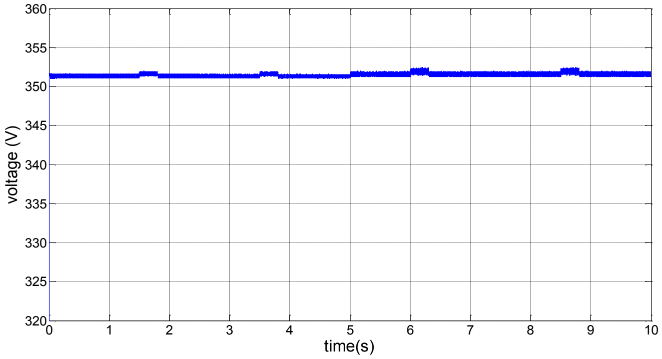

Fig. 11. dc-link voltage.

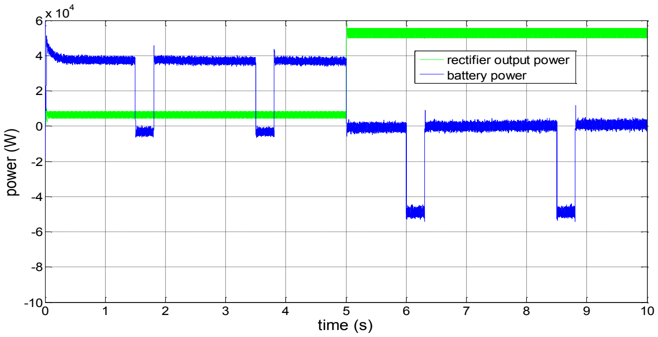

Fig. 12. Power generated from WECS and battery.

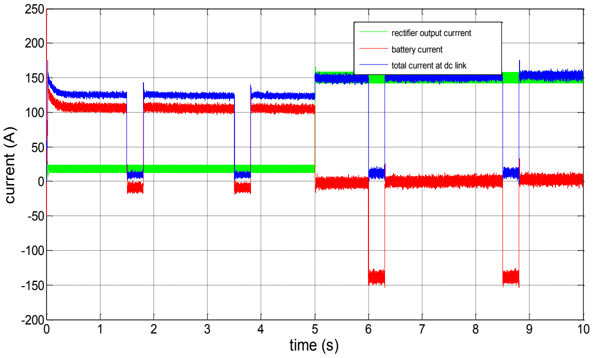

Fig. 13. Current variations at dc-link.

The Fig(s). (11), (12) and (13) shows the dc voltage, power generated from both energy sources and injected current from wind system and battery at dc-link respectively.

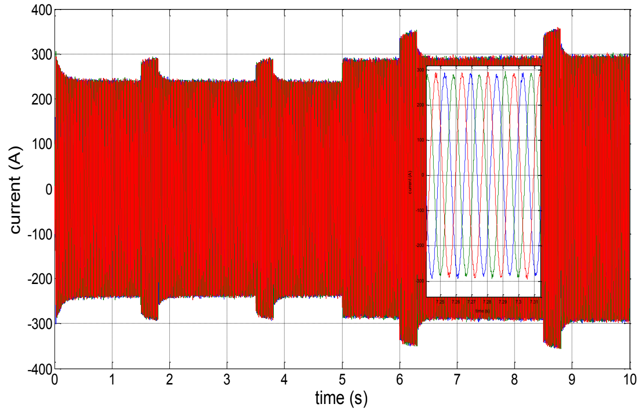

Fig. 14. Inverter current.

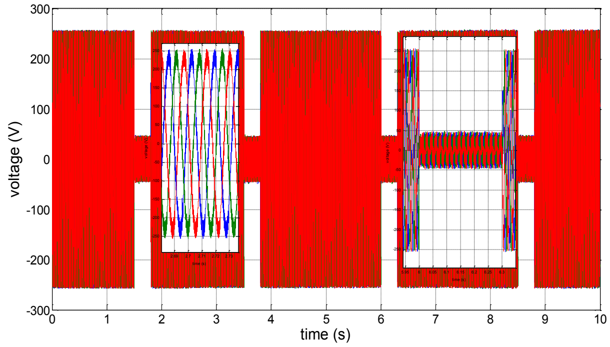

Fig. 15. Inverter voltage.

The Fig. 14 and Fig.15 shows the inverter current and voltage variation during fault. The frequency variation during fault is shown in Fig.16.

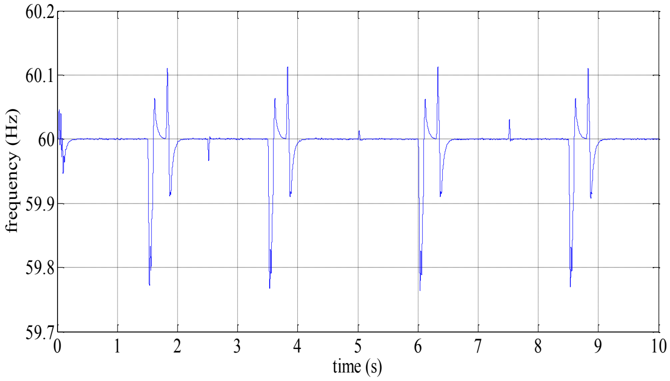

Fig. 16. Frequency of system during fault conditions.

V. CONCLUSION.

The modeling and simulation of WECS with battery as storage system is carried out. The controller manages power flow from the inverter with varying wind speed. The simulation results shows power control over wide range of wind speed variations. The energy storage system provides the power during low wind speeds and able to charge during high wind speeds and low load. The controller is able to manage the constant voltage at dc-link with variation in wind speed and load change. The grid side controller is able to maintaining the dc link voltage constant and power control for varying wind speed. The single line to ground fault simulation results shows the performance of the system in which the system recovers previous operating point after clearing the fault.

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