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Use of DVR & LVRT System for Controlling the ESS in PMSG Turbine

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***Abstract*—Renewable energy is a green and sustainable source of energy that is clean, available in abundance. Wind energy generation has been experienced the largest growth among renewable sources due to lower cost and advanced technologies. The increasing higher penetration of wind energy is participating a lot in grid operation and economics. Variable wind speed leads to variable wind power generation, voltage fluctuations, and frequency deviations, which are the main problems related to wind energy integration into a grid. These problems become more evident in weak grids. In addition to this, wind farms have to take the grid problems into consideration and have to provide support during grid instability and transients. In this paper, a PMSG wind turbine full energy conversion system design and modelling have been performed using Matlab Simulink. The system is grid integrated and applies MPPT control to extract the maximum power from the wind and utilizes full conversion to interface the unregulated generator AC power to the grid. Modules of Lithium-Ion Capacitors (LIC) have been placed on the DC bus in order to support the grid with wind energy power smoothening and LVRT, which is further controlled by the DVR. LICs offer high power density and reasonable energy density. During grid faults, wind energy can be stored in the LICs and discharged into the grid as soon as the voltage is restored. This feature will support the grid to stabilize the voltage. Detailed modelling of the architecture and controls has been performed to verify the viability of the proposed system. To make DVR more effective firefly optimization technique will be used to generate high duty cycle pulse form PWM.**

***Index Terms*— Dynamic voltage restorer, Permanent Magnet Synchronous Generator, Maximum Power Point Tracking, Lithium-Ion Capacitor, Low Voltage Ride through.**

I. INTRODUCTION

Wind turbines should be properly controlled to overcome the grid faults that lead to voltage and frequency drop. It has to have a fault ride capabilities to protect the turbine generator form accelerating and damaging mechanical part due to instability that increases vibration and stress on the mechanical parts like the speed conversion system (gear box). Generator acceleration also leads to over current and overvoltage in the DC bus of the electrical conversion system that makes the mechanical system unstable and may damage the electrical converter. [9]. Wind energy is converted into a usable type of energy which may be electrical or

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mechanical. In the ancient time, wind power was used to power boat and ships by using attached sails to capture the wind energy. It was used after as a wind driven wheel to drive a machine for example irrigation Machines used by The Babylonian emperor Hammurabi and since the 4th century a prayer machine used in Tibet and China[10]. In the early middle ages, wind power started to be commonly used as windmills to grind grains like corn. People started using the horizontal windmills and then the vertical windmills by the 1180s for flour grinding.

A. Wind turbine types

Wind turbine design is recognized as two main types, vertical axis wind turbines and horizontal axis wind turbines. The type of each turbine is referred to the rotation of the blades, the horizontal axis wind turbine has blades that rotate around a horizontal axis. However, the vertical wind turbine has blades that rotate around a vertical axis. Wind turbines harness the power of the wind and use it to generate electricity. The energy in the wind rotates two or three blades around a rotor. The rotor is connected to the generator shaft, either through out a gear box or directly. The electrical generator shaft rotates and the generator generates electricity. The electrical power produced passes through a power conversion system then to the grid [11].
The function of the Anemometer is to Measure the wind speed and so that a speed velocity is an output from this device and an input for the controller. The controller takes the wind speed as an input and starts the machine or stops it according the allowed speed range. It also controls different parts on the machine like the convertor, yaw angle and pitch angle of the blades which is most likely three blades and these blades extract the power from the wind according to its design. Lift force will be acting on the blades due to the pressure difference on the top and bottom surfaces of the blade and the Lift forces on the blade make a rotation that rotates the generator shaft.

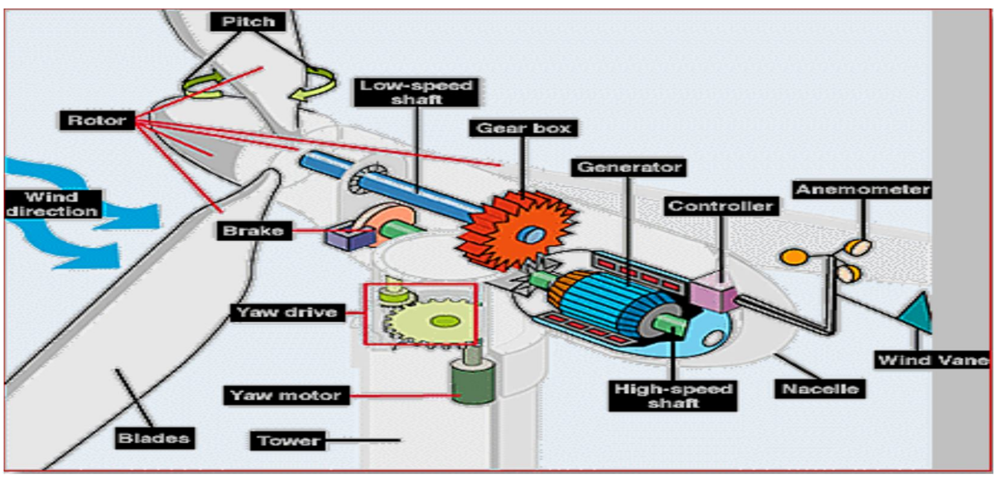

Figure 1. Main components of wind turbine [11]

B. Problem with Wind Grid Connection

One of the main problems in wind energy generation is the connection to the grid. Injection of wind power into the grid affects the power quality resulting in poor performance of the system. The wind energy system faces frequently fluctuating voltage due to the nature of wind and introduction of harmonics into the system. Injection of the wind power into an electric grid affects the power quality[12]. A second complication is instability of the "inner" control loop (carrying the inductor current signal) at duty cycles above 50 %. A further challenge comes from the fact that because the control loop is derived from the inductor output current, resonances from the power stage can introduce noise into this inner control loop.

II. LITERATURE REVIEW

T. RIOUCH (2015) presented a specific control strategy of Doubly Fed Induction Generator (DFIG) conceived for a wind turbine system operating under electrical grid disturbance. Two mains aspects related to

DFIG behaviour are studied. First fluctuation of its output power and secondly Low-Voltage Ride Trough capability (LVRT) of wind turbine generator system.[1]

P.SELVARAJ (2015) presented the PMSG-based wind turbine system configuration that includes not only an auxiliary converter to control ESS but also a coordinated control strategy that enhance the low voltage ride through capability to improve power quality.[2]

S. RAJKUMAR(2014) proposed the generator side converter which incorporates the maximum power point tracking algorithm to extract maximum energy from wind turbine system. A hybrid control scheme for energy storage systems (ESS) and braking choppers for fault ride-through capability and a suppression of the output power fluctuation is proposed for permanent-magnet synchronous generator (PMSG) wind turbine systems.[3]

HARIKA G, JAYAKUMAR (2014) proposed the design and simulation of dual inverter based Energy Storage Systems (ESS) for wind energy systems. A dual inverter consists of MAIN inverter which is connected to grid side and an auxiliary inverter for which an energy storage system is interfaced. Typical grid connected wind energy systems includes wind turbine, PMSG, DC-DC converters, three phase dual inverter ,energy storage system and related power electronic devices.[4]

HUI HUANG (2014) investigated the use of an Electronic Power Transformer (EPT) incorporated with an energy storage system to smooth the wind power fluctuations and enhance the low voltage ride-through (LVRT) capability of directly driven wind turbines with permanent magnet synchronous generators (D-PMSGs).[5]

MARWA EZZAT (2013) dealt with low-voltage ride-through (LVRT) capability of wind turbines (WTs) and in particular those driven by a doubly-fed induction generator (DFIG). This is one of the biggest challenges facing massive deployment of wind farms. With increasing penetration of WTs in the grid, grid connection codes in most countries require that WTs should remain connected to the grid to maintain the reliability during and after a short-term fault.[6]

S. M. MUYEEN (2012) presented a system using an energy capacitor system (ECS) to smoothen the output power fluctuation of a variable-speed wind farm. The variable-speed wind turbine driving a permanent-magnet synchronous generator is considered to be connected to the ac network through a fully controlled frequency converter.[7]

S.VENKATESHWARAN (2012) proposed a STATCOM based control scheme to improve the power quality in grid connected wind generating system. The operation of the control system developed for the STATCOM-two battery energy storage system in MATLAB/SIMULINK for maintaining the power quality is simulated for 275kW capacity of wind turbine. It has a capability to cancel out the sag and swell of load voltage. It maintains the source voltage and current in-phase and supply reactive power for the wind generation during demand and STATCOM with two battery energy storage systems have shown the outstanding performance and improve the power factor up to 0.89.[8]

III. Proposed Work

At present, modern industrial devices are typically based on power electronic devices such as programmable logic controllers and adjustable speed drives. The electronic devices are very fast responsive to disturbances and become less tolerant to power quality problems such as voltage sags, swells and harmonics. Renewable sources like wind power generation plant are connected to grid, but there is always fear of fault occurring in the transmission line and that will be a loss of power. This is called low voltage ride through. To avoid this battery source in conjunction with grid is used which is further connected to DVR which will introduce power in the system when fault occurs. For this purpose controlling scheme of DVR is used. Before discussion of scheme a DVR functioning will be discussed. Among the power quality problems like sag, swell, harmonic etc., voltage sag and harmonic are the most severe disturbances in the distribution system. To overcome these problems the concept of custom power devices is introduced lately. One of those devices is the Dynamic Voltage Restorer (DVR), which is the most efficient and effective modern custom power device used in power distribution networks.

A. Voltage Source Converter

Voltage Source Converters has been used in HVDC transmission network. A Voltage Source Converter is a power electronic system consists of a storage device and switching equipment, which can produce a sinusoidal voltage at any necessary frequency, magnitude and phase angle. In the DVR application, the VSC is used to replace the supply voltage momentarily or to produce the part of the supply voltage which is missing. The purpose of storage devices is to supply the necessary energy to the VSC using a DC Link for the generation of injected voltages. The different kinds of energy storage devices are superconductive magnetic energy storage batteries and capacitance.

B. Equations related to DVR

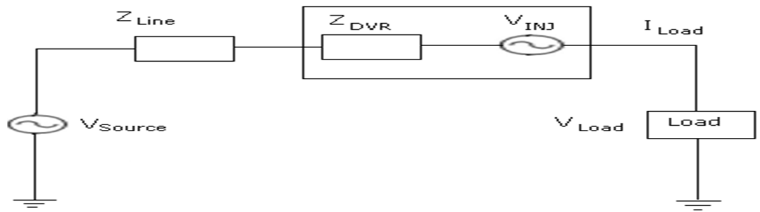

Figure 2. Equivalent Circuit Diagram of DVR

The load impedance Z_{TH} depends on the fault level of the load bus. When the system voltage (V_{TH}) drops, the DVR injects a series voltage V_{DVR} through the injection transformer so that the desired load voltage magnitude V_L can be maintained. The series injected voltage of the DVR can be written as

$$V_{DVR} = V_L + Z_{TH} I_L - V_{TH} \quad \text{……………………..(I)}$$

The load current I_L is given by,

$$I_L = \frac{[P_L + jQ_L]}{V_L} \quad \text{……………………… (II)}$$

When VL is considered as a reference equation can be rewritten as,

$$V_{DVR}\angle\alpha = V_L\angle 0 + Z_{TH}\angle(\beta - \theta) - V_{TH}\angle\delta \quad \text{……………………….(III)}$$

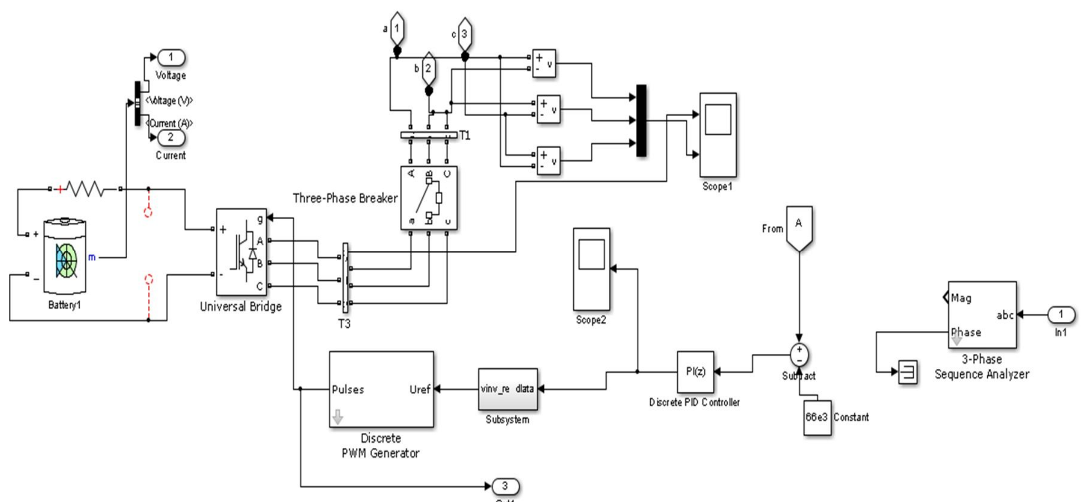

Figure 3. DVR controlled battery Simulink

In this paper wind power plant is combined with grid and in case of occurrence of fault an extra power source from battery is applied which provides extra power during fault time. This fulfils the purpose of low voltage ride through technique. The significance of work lies with the fact that, battery should introduce extra power at the time of fault. We have used as discussed above, DVR to control the power introduction time. MATLAB Simulink is used to implement the proposed algorithm. The simpower toolbox in MATLAB provides a wide range of blocks which can be directly used in any research work or simulation work. It saves the time required for design purpose. Pulse-width modulation (PWM), or pulse-duration modulation (PDM), is a modulation technique that conform the width of the pulse, formally the pulse duration, based on modulator signal information. Although this modulation technique can be used to encode information for transmission, its main use is to allow the control of the power supplied to electrical devices, especially for loads such as motors. The average value of voltage (and current) fed to the load is controlled by turning the switch between supply and load.

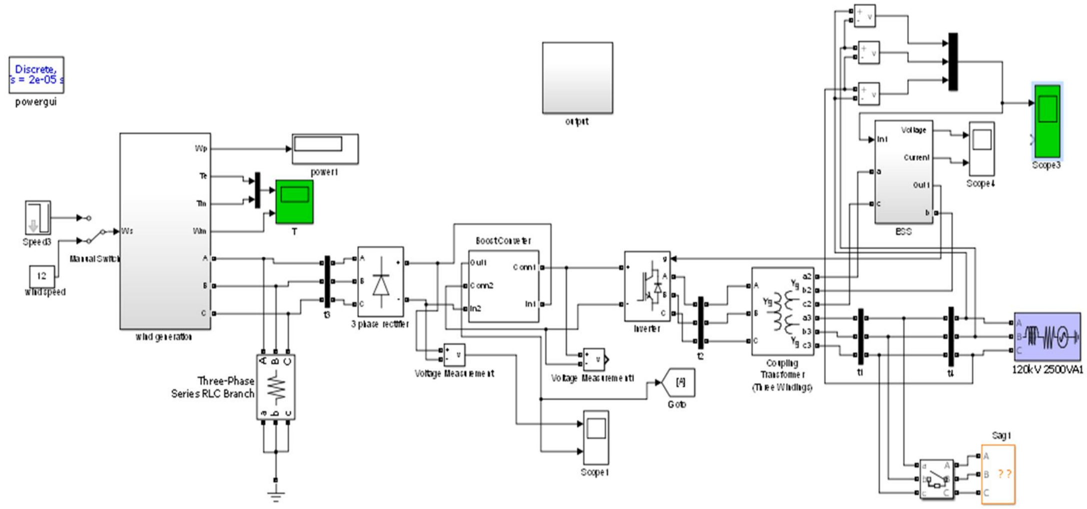

Figure 4. Simulation diagram of the proposed work

IV. RESULTS

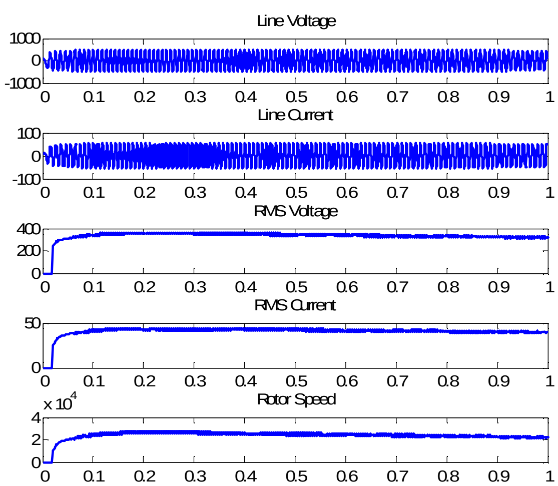

Figure 5. Wind plant output at generator side

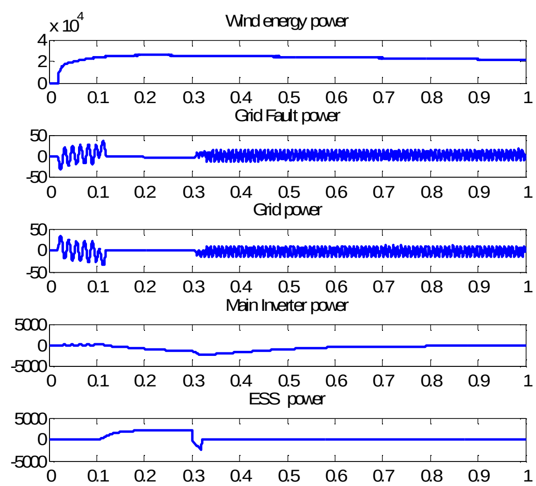

Figure 6. Output in case of fault at 0.1-0.3sec

Initially suppose fault is remains for 0.1sec to 0.3sec at the grid. When fault occurs then controlling of DVR introduces the extra power from the battery during the fault time. After Voltage recovers to 0.9; Active power was controlled to achieve a ramp rate of 90% of the available wind generated power in 1 second. Wind turbine system was integrated with a grid voltage profile that will dip to zero and recover to 0.9 per unit within the none trip zone. To make DVR more effective firefly optimization technique will be used to generate high duty cycle pulse form PWM.

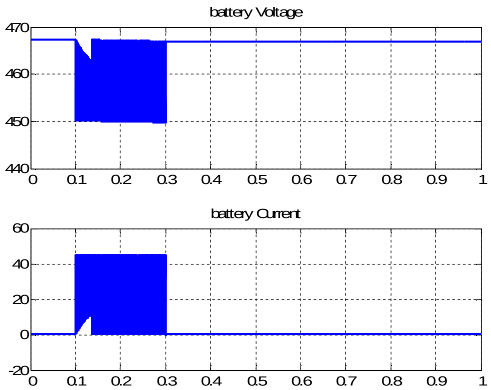

Figure 7. Battery voltage and current at fault time 0.1-0.3 sec

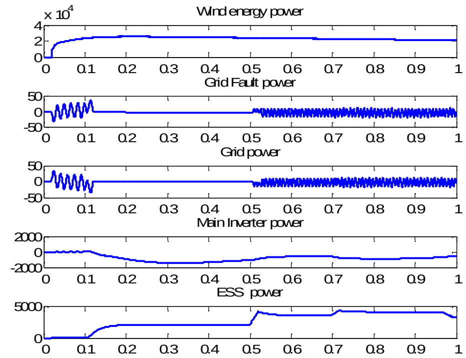

Figure 8. Output in case of fault at 0.1-0.5sec

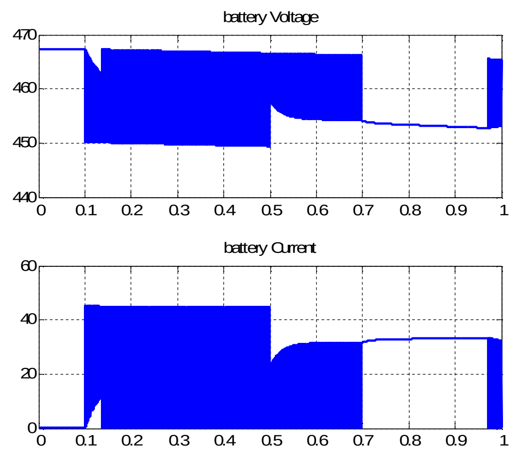

Fig 9: battery voltage and current at fault time 0.1-0.5sec

V. CONCLUSION

Simulation shows good results in active an reactive power control. Active power goes to zero when voltage dips and reactive power support should take a place to support the grid voltage. Reactive current was controlled to be 1 per unit or up to 2 per unit during the LVRT. After the voltage recovers to 0.9, active power was controlled to achieve a ramp rate of 90% of the available wind generated power in 1 second.

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