Transient Stability Analysis of PMSG Based Wind Energy System

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Abstract— **In this paper, the variable speed wind turbine connected to the ac grid through power converter system consist of two voltage source converters namely, generator side converter and grid side converter and a common dc link. Active and reactive powers of converters were controlled independently by using vector control method to improve low voltage ride through (LVRT) capability of wind energy system. Analysis of the system is performed by using voltage dip as network disturbances and stability of variable speed wind turbine driving PMSG is performed. Simulation result shows that LVRT capability of grid connected wind energy system is achieved during network disturbances for different voltage dip magnitude and duration. Simulation is carried out in MATLAB/Simulink.**

Keywords— Low Voltage Ride Through, Permanent Magnet Synchronous Generator (PMSG), Variable Speed Wind Turbine

I. INDRODUCTION

Now days the generation of wind power is increasing hence the impact of the wind generation on the power system has to be considered. It is necessary to integrate wind energy into the power system without affecting the overall system stability. Hence it is mandatory to mitigate the possible negative impacts such as loss of generation for frequency support, voltage flicker, voltage and power variation due to the variable speed of the wind, the risk of instability due to lower degree of controllability and low voltage ride through (LVRT) capability of wind energy system as a huge number of wind generators will be connected to the existing network in the near future.

The constant speed wind turbines and induction generators were often used, in the early stages of wind power development. Some of the disadvantages of the fixed speed generators are the low efficiency, poor power quality, high mechanical stress but also that by having a fixed speed operation the maximum coefficient of performance is obtained only at a particular wind speed. Due to development of power electronics and their falling costs, the variable speed operation became the most attractive option. By running the wind turbine generator in variable speed, variable frequency mode, and the maximum power can be extracted, at low and medium wind speeds. Among all kinds of wind energy conversion systems (WECSs), a variable speed wind turbine (WT) equipped with a multi pole permanent magnet synchronous generator (PMSG) is found to be very attractive and suitable for application in large wind farms. With gearless construction, such PMSG concept requires low maintenance, reduced losses and costs, high efficiency and good controllability.

Transient stability analysis for fixed speed wind generators has been presented in much of the literature.[1-3] With variable speed wind energy conversion system (WECS) stability, control, and FRT analyses have been reported for the doubly fed induction generator (DFIG) [5-7], wound field synchronous generator (WFSG), switched reluctance generator (SRG). Recently, permanent magnet machines are becoming very popular in wind power application. In PMSG, the excitation is provided by permanent magnets instead of the field winding. Permanent magnet machines are characterized as having large air gaps, which reduce flux linkage even in machines with multi-magnetic poles. As a result, low rotational speed generators can be manufactured with relatively small sizes with respect to its power rating. Moreover, the gearbox can be omitted due to the low rotational speed in the PMSG wind generation system, resulting in lower cost.

II. SYSTEM DESCRIPTION

Fig. 1 shows the block diagram of proposed wind farm system, here PMSG based wind turbine is connected to grid through the two back to back converters namely, generator side converter (GSC) and grid side inverter (GSI). The control of both converters is obtained by using vector control method. The active and reactive power and dc link voltage is controlled by using vector control method.

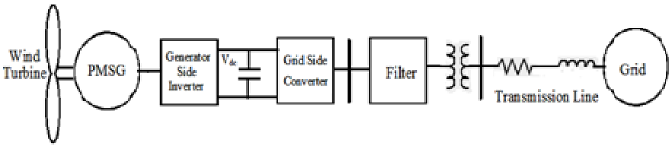

Fig. 1. Block Diagram of Wind Farm System

A. *Wind Turbine Characteristics*

The mathematical relation for the mechanical power extraction from the wind can be expressed as follows,

$$P_w = \frac{1}{2}\rho\pi R^2 V_w^3 C_p(\lambda\, \beta) \qquad (1)$$

Where P*w* is the extracted power from the wind, ρ is the air density [kg/m3], R is the blade radius [m], V*w* is the wind speed [m/s], and C*p* is the power coefficient which is a function of tip speed ratio, λ, and blade pitch angle, β [deg]. The turbine characteristic is shown fig. 2.

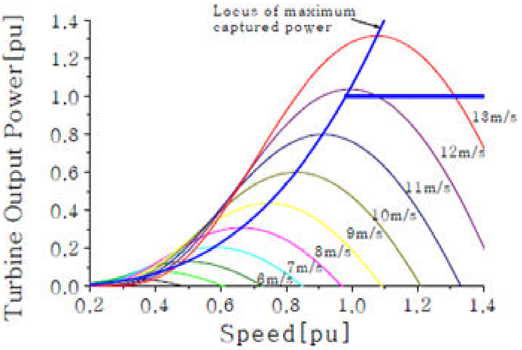

Fig. 2. Wind Turbine Characteristic

B. *Permanent Magnetic Synchronous Generator*

Nowadays, permanent magnet machines are becoming very popular in wind energy system applications. In case of PMSG, the excitation to the machine is provided by permanent magnets instead of the field winding. Permanent magnet machines are having large air gaps, which reduce flux linkage As a result, low rotational speed generators can be manufactured with relatively small sizes with respect to its power rating. Moreover, the gearbox can be omitted due to the low rotational speed in the PMSG wind generation system, resulting in lower cost. The generator parameters are given below [16],

TABLE I. GENERATOR PARAMETERS

Rated Power	5Mw	Stator Resistance	0.01pu
Rated Voltage	1Kv	d-axis Resistance	1.0pu
Frequency	20Hz	q-axis Resistance	0.7pu
Number of Poles	150	Field Flux	1.4pu
H	3.0Sec		

III. CONTROL OF POWER CONVERTER

In this section, the control strategy of fully controlled converter is explained. The power converters consist of generator side AC/DC converter, DC link capacitor, and grid side DC/AC inverter. Each of converter/inverter is a standard 3-phase two-level unit, composed of six IGBTs and anti-parallel diodes. The control strategy is explained in fig. 3.

Fig. 3 shows a schematic diagram of a current-controlled real-/reactive-power controller and DC link voltage control illustrating that the control is performed in dq-frame. Thus, Ps and Qs are controlled by the line current components i*d* and i*q*. The feedback and feed-forward signals are first transformed to the dq-frame and then processed by compensators to produce the control signals in dq-frame. Finally, the control signals are transformed to the abc-frame and then fed to the VSC. To protect the VSC, the reference commands i_{dref} and i_{qref} are limited by the corresponding saturation blocks. The inner current control loop is used to control the reactive and reactive power at grid side converter.

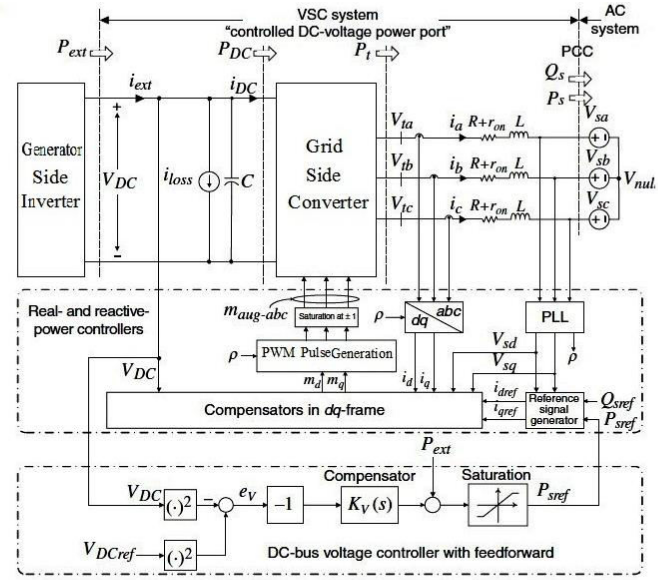

Fig. 3. Grid Side Converter Control

A. *Real and Reactive Power Control*

The real and reactive power can be controlled in dq-frame. Dynamics of the AC side of the GSC system are described by the following space-phasor equation,

$$L\frac{d\vec{i}}{dt} = -(\mathrm{R} + \mathrm{r}_{\mathrm{on}})\,\vec{i} + \vec{V}\mathrm{t} - \vec{Vs} \qquad (2)$$

Fig. 3 shows a block representation of the d- and q-axis current controllers of the VSC system in which u_d and u_q are the outputs of two corresponding compensators. The d-axis compensator processes $e_d = i_{dref} - i_d$ and provides u_d that contributes to m_d. Similarly, the q-axis compensator processes $e_q = i_{qref} - i_q$ and provides u_q that contributes to m_q. The VSC then amplifies m_d and m_q by a factor of $V_{DC}/2$ and generates V_{td} and V_{tq} that, in turn, control i_d and i_q. The PI controller gains can be obtained by using following equations.

$$K_p = L/\tau_i \text{ and } K_i = (R+r_{on})/\tau_i$$

Where, τ_i is time constant of the closed loop system [4].

B. *DC Link Voltage Control*

The closed-loop system is composed of the compensator $K_v(s)$, real-power controller $G_p(s)$, and control plant $G_v(s)$, Fig. 4 indicate that $K_v(s)$ is multiplied by -1 to compensate for the negative sign of $G_v(s)$. $K_v(s)$ should include an integral term and a lead transfer function. The lead transfer function compensates for the plant phase lag and ensures an adequate phase margin at the gain crossover frequency. For this system compensator transfer function is obtained by using lead compensator and it is given by,

$$G_v(s) = \frac{-103S+1882}{S^2+137.4} \qquad (3)$$

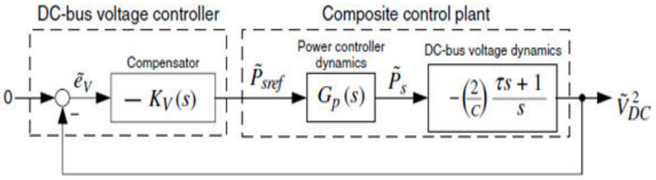

Fig. 4. Control of DC-Link voltage controller

The time constant τ_i is taken as 10 ms therefore corner frequency will be ω_c = 100 rad/sec.

IV. SIMULATION RESULTS

Simulation results of the system are carried out for two different cases

- **Case 1**: Voltage Dip Magnitude = 0.4 pu and Duration = 1.0 sec to 1.05 sec
- **Case 2**: Voltage Dip Magnitude = 0.8 pu and Duration = 1.6 sec to 1.65 sec

A. *Simulation Results for Case 1*

Simulation results for first disturbance are shown below for active power, reactive power, grid voltage and dc link voltage.

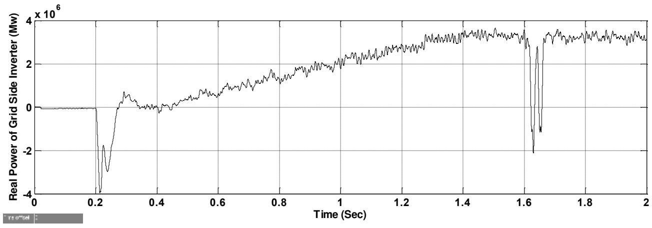

Fig. 5. Active Power of the Grid Side Inverter

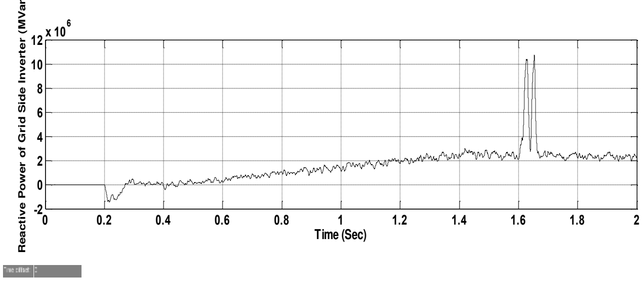

Fig. 6. Reactive Power of the Grid Side Inverter

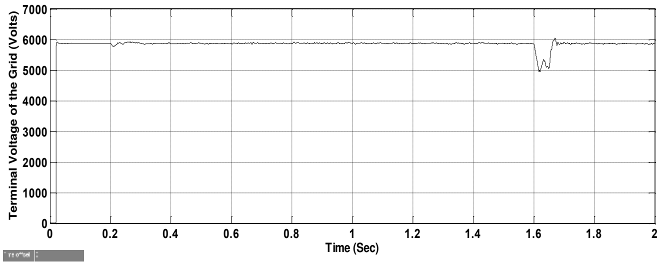

Fig. 7. Terminal Voltage of the Grid

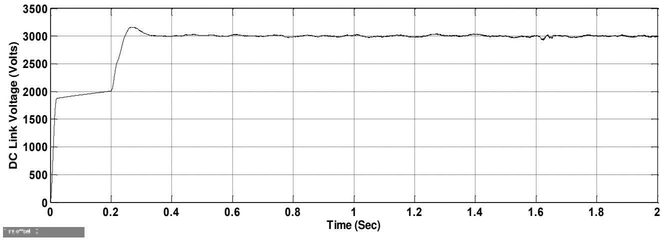

Fig. 8. DC Link Voltage

B. *Simulation Results for Case 2*

Simulation results for first disturbance are shown below for active power, reactive power, grid voltage and for dc link voltage

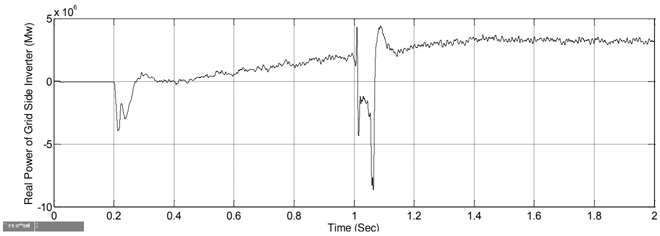

Fig. 9. Active Power of the Grid Side Inverter

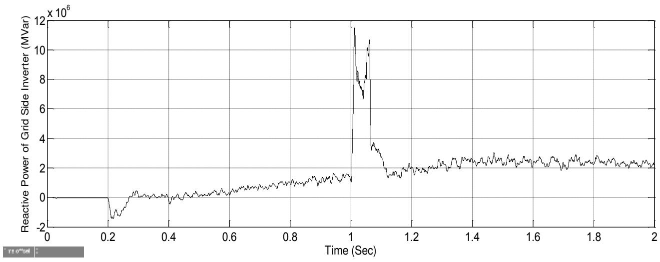

Fig. 10. Reactive Power of the Grid Side Inverter

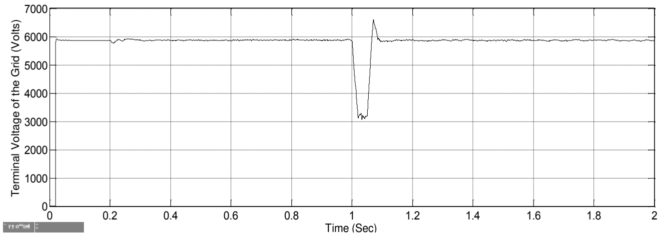

Fig. 11. Terminal Voltage of the Grid

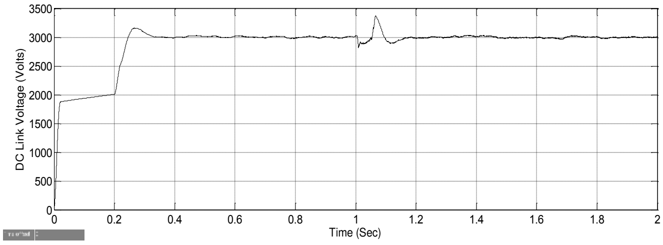

Fig. 12. DC Link Voltage

Two different cases are consider for analysis of the system and compared in following table. Result shows that converters are providing sufficient reactive power during network faults.

TABLE II. COMPARISON OF RESULTS

Parameters	Magn. = 0.4 pu Time=1.0 to 1.05Sec	Magn. = 0.8 pu Time=1.6 to 1.65Sec
Real Power (Mw)	3.142	3.134
Reactive Power (Mvar)	2.20	2.27
DC Link Voltage (V)	3007	2991
Terminal Voltage (V)	5845	5882

V. CONCLUSION

In this paper the transient stability of variable speed wind turbine driving a PMSG when a network disturbance occurs in the power system is performed. Then the control strategies for power converters are presented by using vector method and can control the active and reactive power to maintain the terminal voltage of the grid constant. In this control necessary reactive power is supplied by controlling the grid side inverter depending on the grid terminal voltage. Two different cases are considered for voltage dip magnitude & duration and transient stability is analyzed. Simulation result shows that active and reactive power control as well as DC link voltage control is obtained for two different network disturbances and therefore it can be concluded that the proposed control system can increase the low voltage ride through (LVRT) capability of VSWT-PMSG and thus wind generator disconnection from the grid can be decreased during the network disturbances.

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