Enhancement of wind turbine Performance using permanent magnet synchronous generator with storage system during low voltage condition

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Abstract *:*This paper presents how to improve the performance of wind turbine by using permanent magnet synchronous generator with energy storage system under low voltage condition. In this work we compare the conventional wind system model with PMSG energy storage system wind model under low voltage condition and see the advantages of PMSG model over conventional model. In this work the MATLAB simulation and graphical results has been developed for wind energy conservation system.

***Index Terms* -** Directly driven wind turbine, Energy storage system, Smoothing of output power, Low voltage ride-through

I. INTRODUCTION

More and more directly driven wind turbines with permanent magnet alternator (D-PMA) have been used in wind farms, as they have the advantages such as low mechanical consumption, high reliability, high power generating efficiency and easy maintenance, compared to the doubly-fed induction generators. The increasing wind power penetration poses significant technical problems for the electric power systems. The fluctuations in the output power of wind farms have a great impact on the power quality and stability of the host power system [1-3]. Some researchers were seeking to smooth wind power fluctuations in [4-8]. Researchers in [4] made use of the pitch control and variable speed control of the wind turbine to smooth the wind power fluctuations. Researchers in [5-6] took advantage of the energy storage system to smooth the wind power fluctuations and enhance the stability of the host power system.
High levels of wind power penetration have a significant impact on the stability of the power grid. The grid-fault conditions may cause the wind power generators to trip offline for self protection until the grid recovers. This may make the grid recover more difficult and deteriorate the grid condition. Therefore, the new grid operation codes require that the wind generators remain connected during grid fault conditions, helping the grid to resume its normal state.
In this work, a combined control strategy is proposed to smooth the power fluctuations and fulfill the LVRT requirements of D-PMA with energy storage system. Using the proposed control strategy, the output power of wind generators is smoothed by energy storage system, and the wind turbines can ride severe grid disturbances during grid side fault conditions.

II. THE PRINCIPLE OF THE SYSTEM

The topology of the system considered in this work is showed in Fig.1. The D-PMA is connected to a host AC grid network via a controlled full-scale power converter system(PCS) and a step-up transformer. The PCS comprises of a three-phase uncontrolled rectifier bridge, a filter capacitor, a boost converter at the generator side, and a pulse width modulated (PWM) three-phrase voltage source converter (VSC) at the grid side. The VSC controls the reactive power transmitted to the AC grid network and keeps the voltage of the DC bus constant, using decoupled pq current control methodology. The grid side and the generator side convertors are interconnected by a common DC bus. The energy storage system comprised of a super capacitor stack is connected to the common DC bus via a bi-directional DC/DC converter, which controls the active power transmitted to the AC grid.
In normal operating conditions, if the output power of the D-PMA P is bigger than the reference

power transferred to the grid P_{G*W}, the remaining energy is absorbed by the super capacitor stack, if the output power of the D-PMA P is smaller than the reference power transferred to the grid P_{G*W}, the super capacitor stack will release energy to the common DC bus to keep the DC voltage constant. The power transferred to the grid can be smoothed by the energy storage system.

During grid-side fault conditions, the wind turbine works normally to maintain optimized energy capture, the boost converter at the generator side will delivery as much energy as the wind generator generates, but the power transferred to the grid is much smaller than normal conditions, the redundant power will be absorbed by the ultra capacitor stack to keep the voltage of the comment bus constant, to insure that the system work normally. The ride through time scale of the system is mainly determined by the capacity of the ultra capacitors and the state of charge (SOC) of the ultra capacitors when the ride through happens. The larger the capacity of the ultra capacitors is and the lower SOC the ultra capacitors have, a longer time the system will work normally for during grid-side fault condition [16].

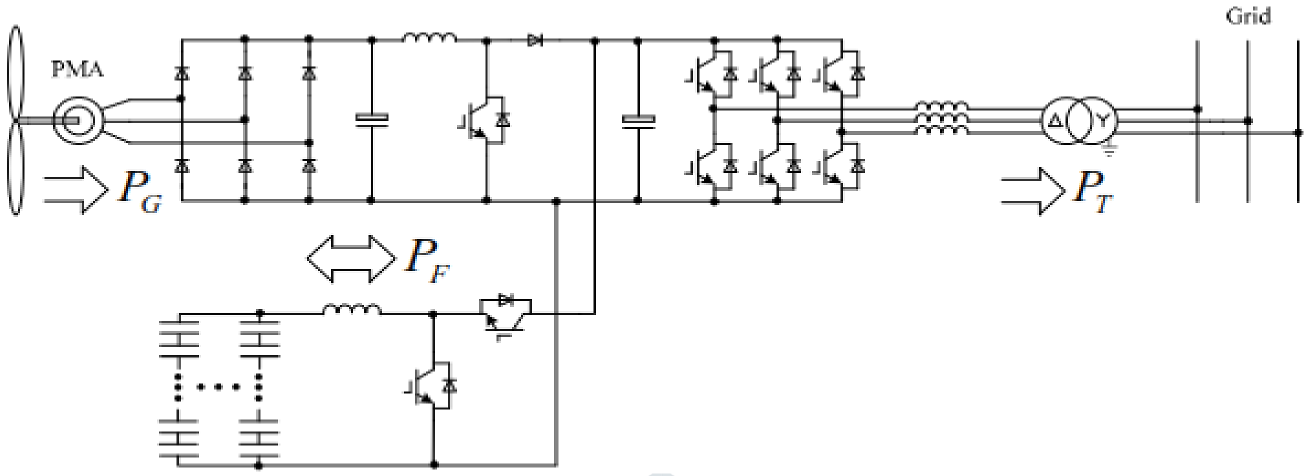
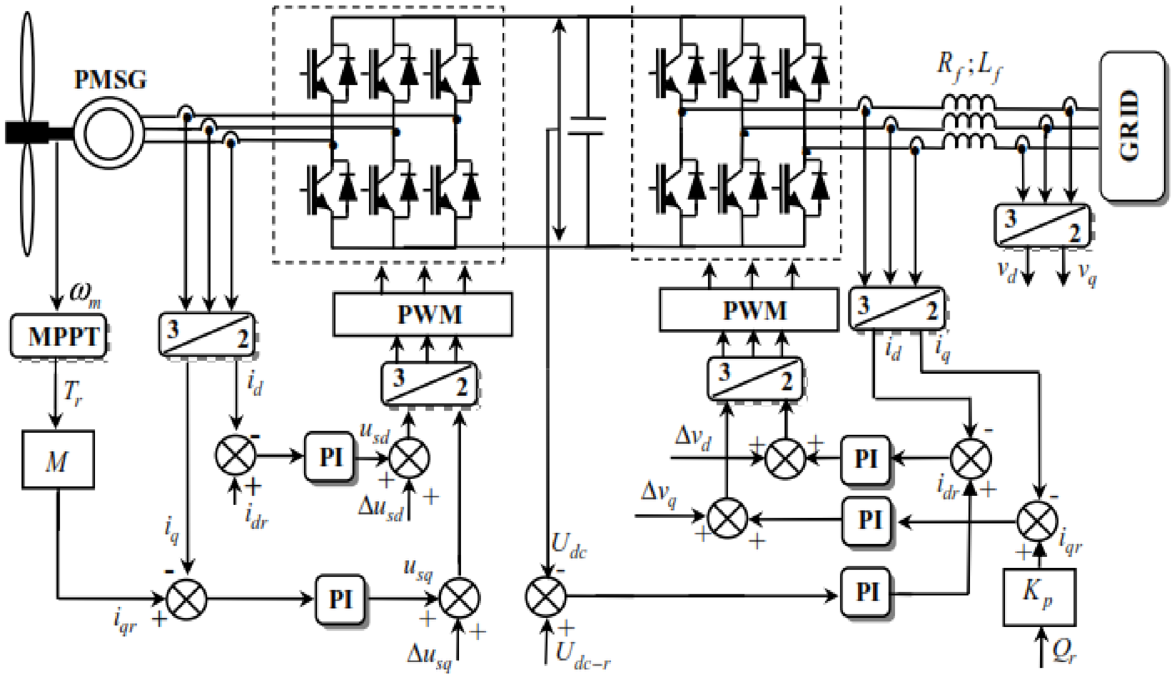


Fig.1.Direct-driven wind generation system based on the ultra capacitors

III. CONTROL STRATEGY OF THE SYSTEM

A. CONTROL STRATEGY OF THE GENERATOR SIDE CONVERTER

The generator side three-phase converter, which is used as a rectifier, uses a vector control strategy and works as a driver controlling the generator operating at optimum rotor speed w_{opt} to obtain maximum energy from wind [4]. u_{sq} is obtained by the error of i_{qr} and i_q that is delivered to a PI controller. The d axis current component i_{dr} is set to zero. Voltage feed forward compensation, Δu_{sq} and Δu_{sd} are added into control strategy to improve the dynamic response. Finally, PWM is used to produce the control signal to implement the vector control for the generator. The double closed-loop control diagram for generator-side converter is shown as Fig.2.



$$M = \frac{2}{3 p_n \psi_f} \quad ; \quad \Delta u_{sd} = L\omega_e i_q \quad ; \quad \Delta u_{sq} = \omega_e \psi_f - L\omega_e i_d \quad ; \quad K_p = \frac{2}{3V} \quad ; \quad \Delta v_d = V + L_f \omega i_q \quad ; \quad \Delta v_q = L_f \omega i_d$$

Fig.2 Schematic of control strategy for generator side and grid side converter.

B. CONTROL STRATEGY OF THE GRID SIDE CONVERTER

The grid side three-phase converter feeds generated energy into the grid, keeps the DC-link voltage constant and adjusts the amount of the active and reactive powers delivered to the grid during load transients or wind variation [4-5]. The DC-voltage PI controller stabilize the DC voltage to the reference value. PI controllers are used to regulate the output currents and voltage in the inner control loops and the DC voltage controller in the second loop. In order to compensate the cross-coupling effect due to the output filter in the rotating synchronously reference frame, the decoupling voltages are added to the current controller outputs (see in Fig.2). The vector control scheme used is based on a rotating synchronously reference frame as shown in Fig.2.

C. CONTROL STRATEGY OF THE ENERGY STORAGE SYSTEM

The proposed control is a super capacitor energy storage in the DC bus of the Back to back converter and it is used either to store or support energy which is shown in figure 3.. It is used to store the energy coming from the wind during the LVRT period since the active power deliver to the grid during LVRT is zero. The incoming power is equal to the wind turbine generated power and the delivered is almost zero so that the power will be stored in the super capacitor and lead to increases the voltage..

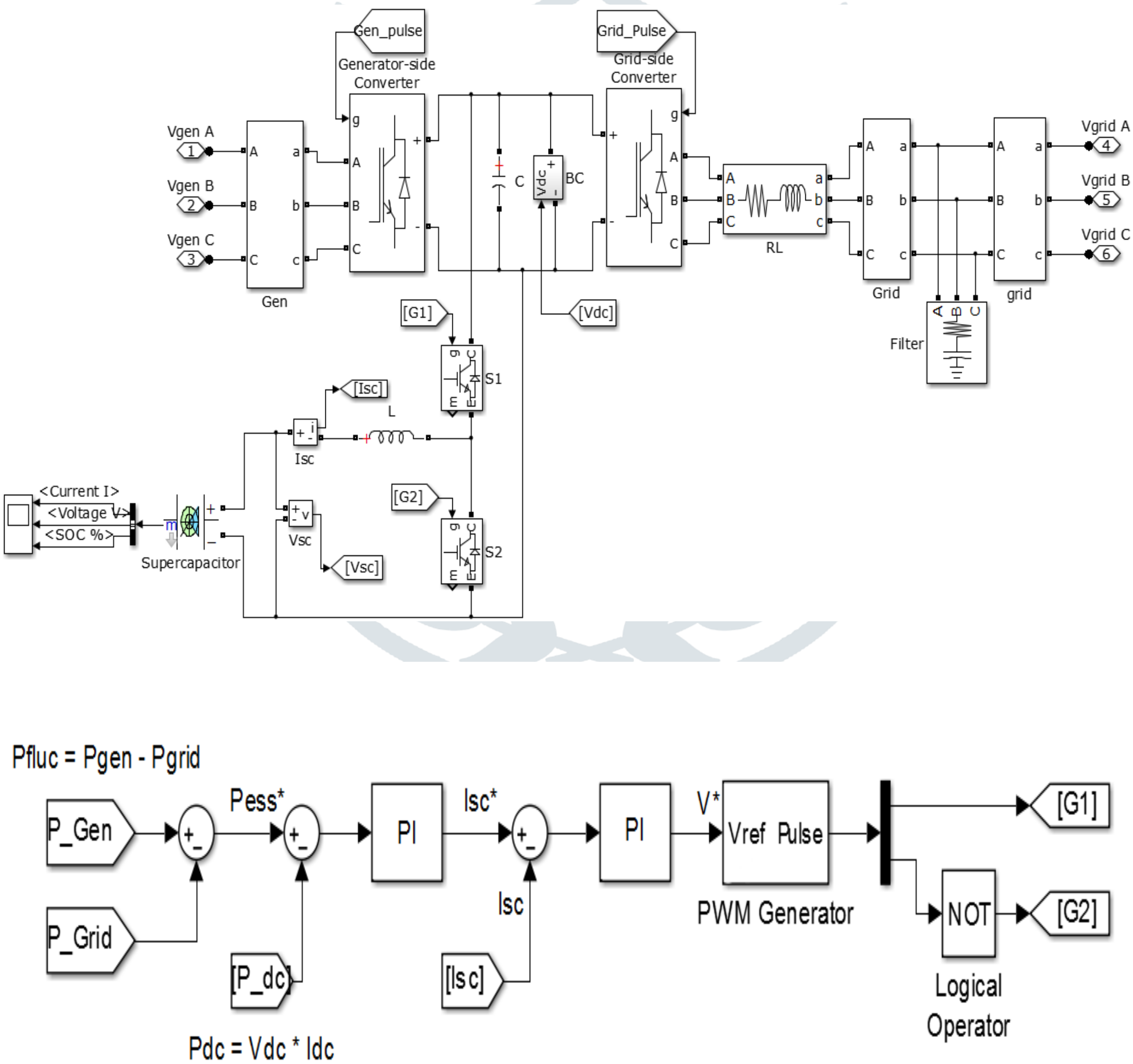


Fig.3 SIMULATION OF CONTROL OF ENERGY STORAGE SYSTEM

IV. SIMULATION PARAMETERS

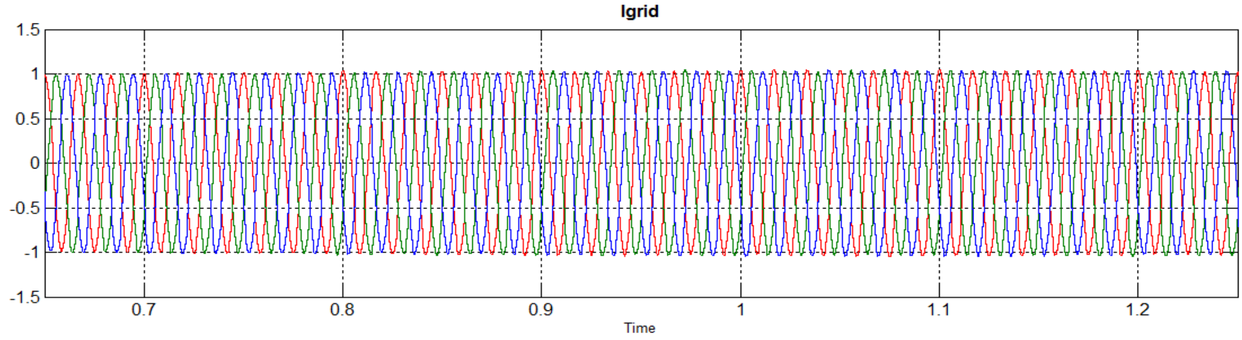
1.5MW Wind Turbine Generator Parameters	
Simulation parameter	Actual value
Rated power	1.5 MW
Rated frequency	50 Hz
Stator resistance (Rs)	0.8556 mΩ
Stator inductance	0.359 mH
Magnetic flux	1.48 Wb
No. of Pole (Np)	96
Cpmax	0.47
Wind speed	12m/s
Gride resistance	0.3 Ω
Grid side Inductance	0.003H

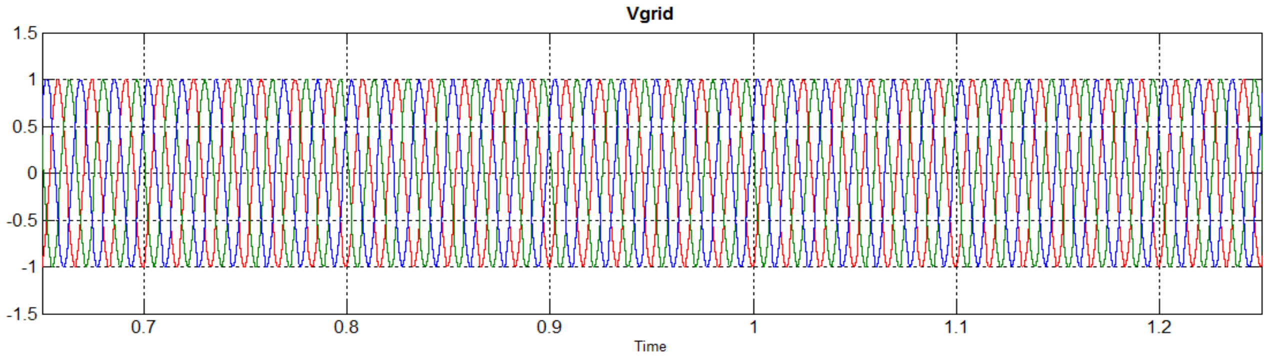
TABLE I. SIMULATION PARAMETERS OF PMSG BASED ENERGY STORAGE SYSTEM

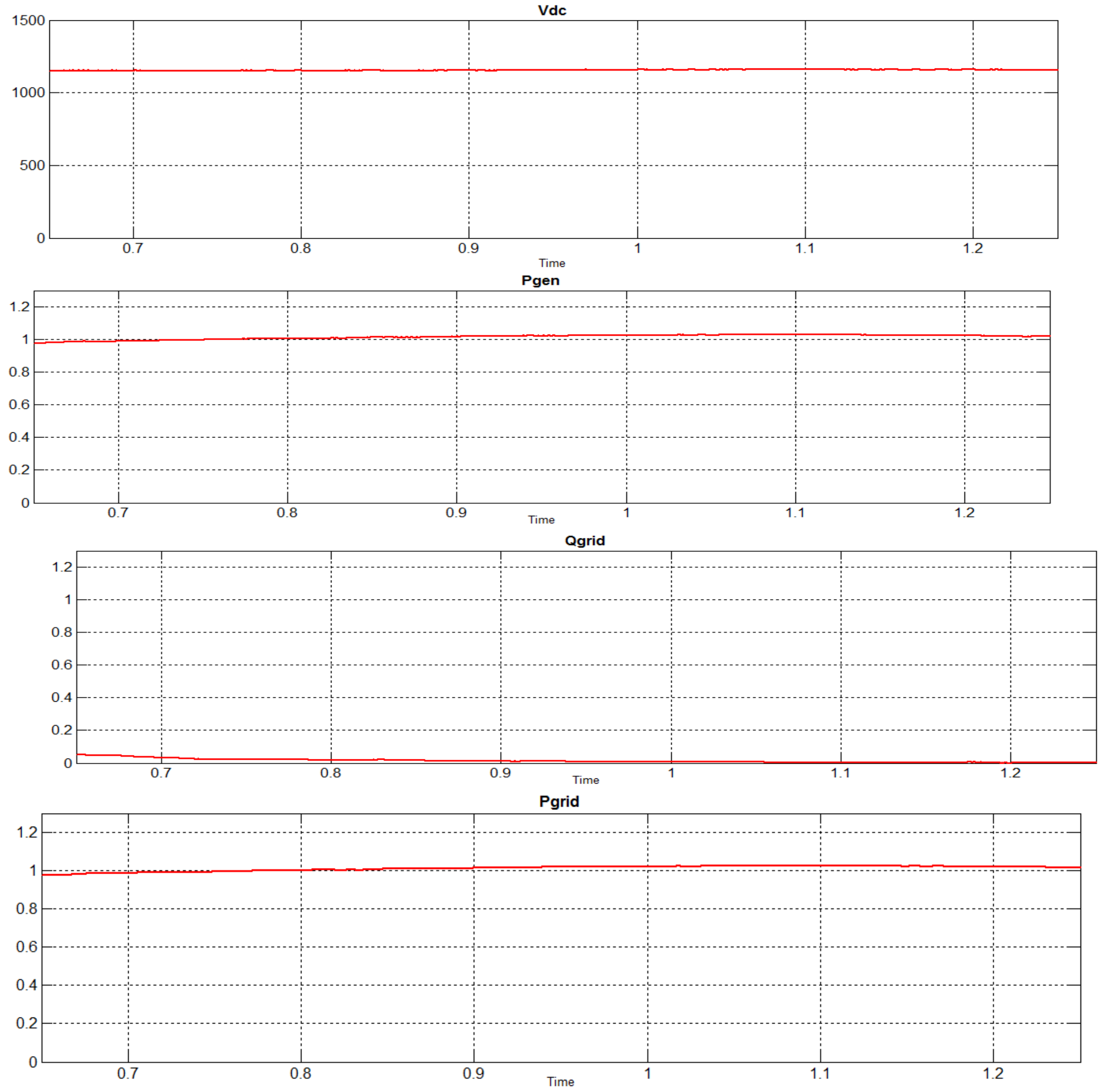
IV. SIMULATION RESULTS

- **At the wind speed = 12m/s:**

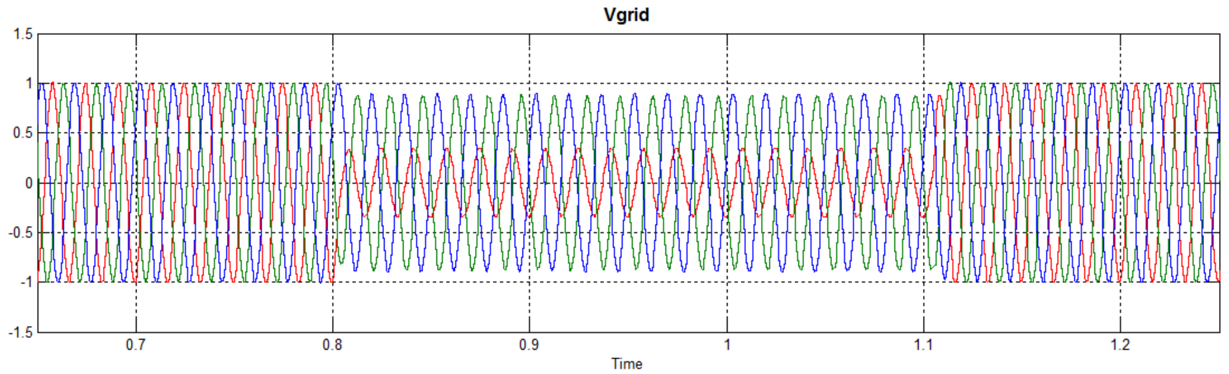
During Normal Condition:

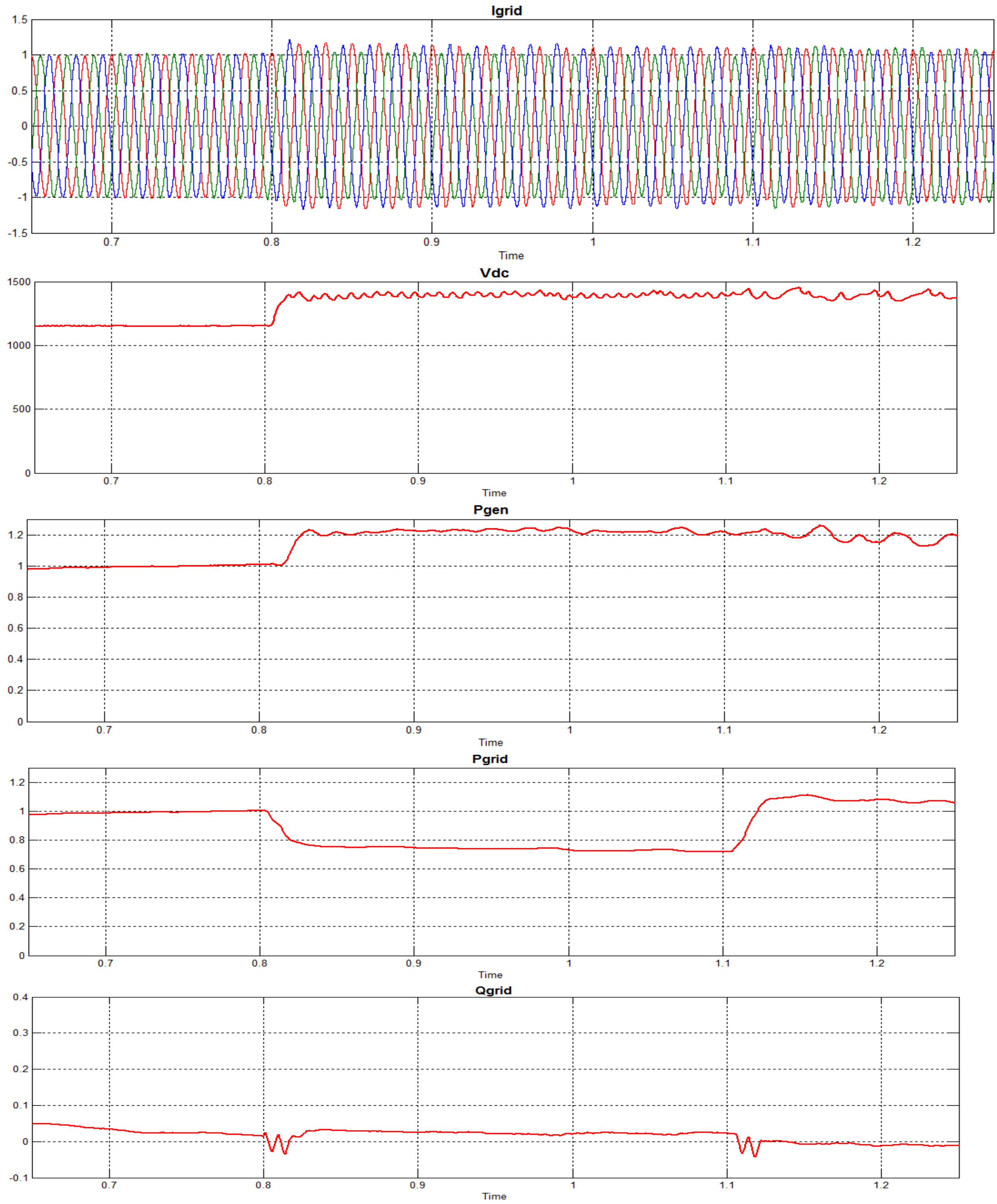




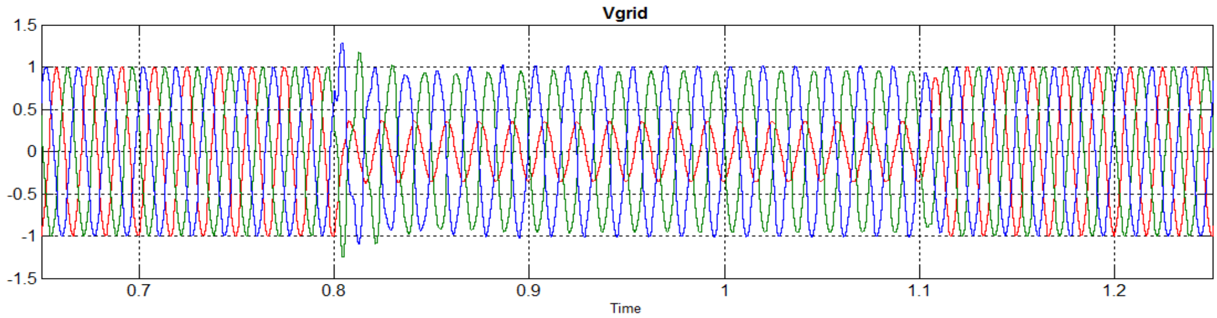


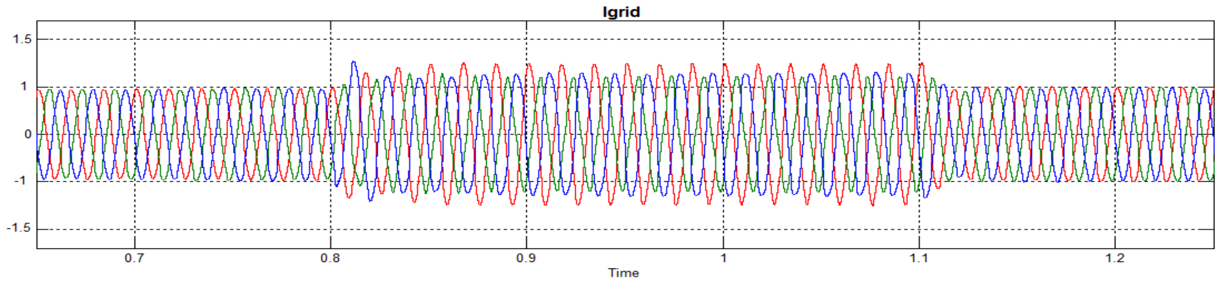
During Faulty Condition: **SLG fault:** **Fault time : 0.8 to 1 sec**

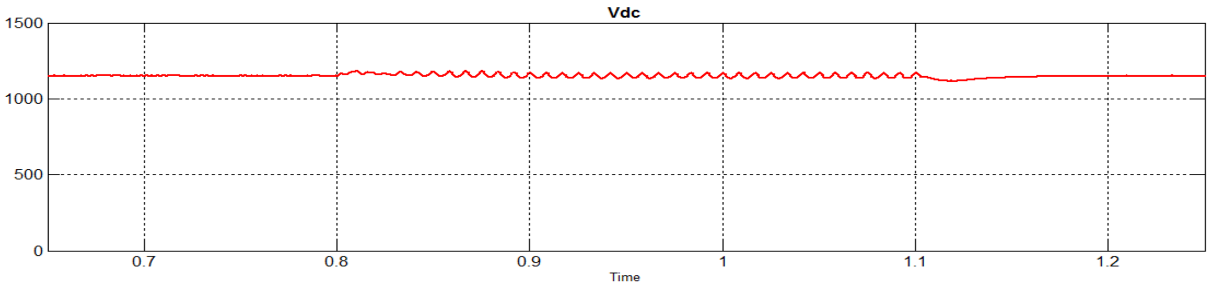


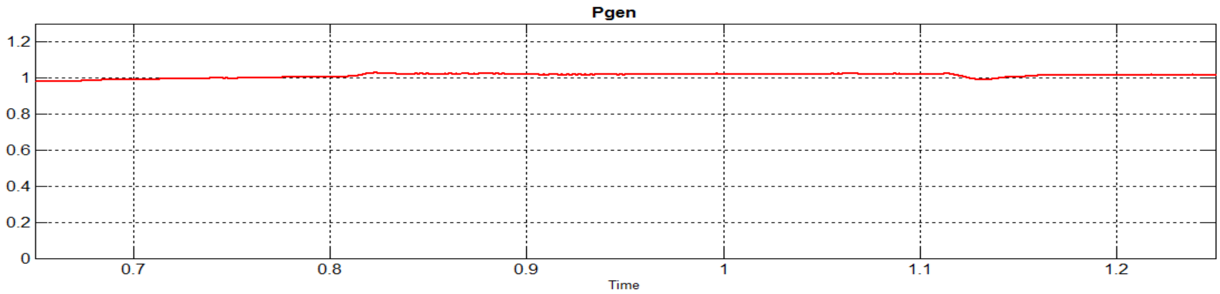


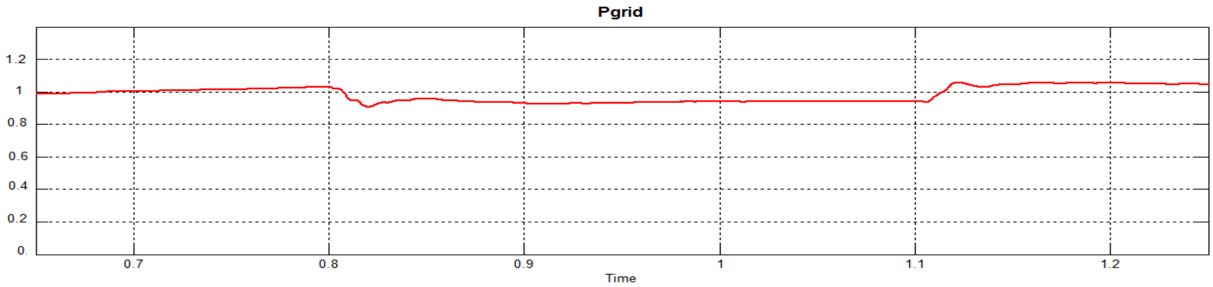
Result with Energy Storage System

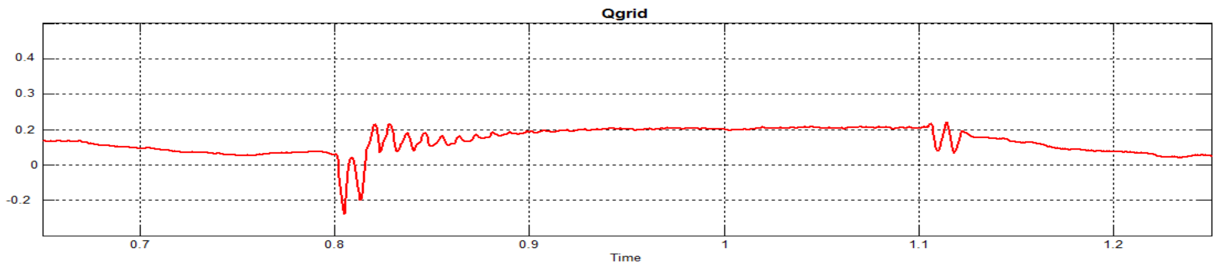












<u>Result Table</u>

Measure quantity	Normal condition	SLG Fault condition	ESS during SLG Fault
Grid voltage (pu)	1pu	0.67pu	0.7pu
Grid current(pu)	1pu	1.2pu	1.3pu
DC link Voltage (V)	1150 V	1400 V	~ 1150 V
Generator Active power(pu)	1pu	1.25pu	1.05pu
Grid Active power (pu)	1pu	0.68pu	0.95pu
Grid Reactive Power (pu)	0pu	0.05pu	0.2pu

TABLE II. SIMULATION RESULT DURING FAULT CONDITION WITH AND WITHOUT STORAGE SYSTEM

V. CONCLUSION

In this paper, a combined control strategy is proposed to smooth the power fluctuations and fulfill the LVRT requirements of D-PMA with energy storage system. The wind power quality is improved using the proposed control strategy and the energy storage system, and the wind turbine can ride-through severe grid disturbances. The simulation results have verified the correctness and effectiveness of the control strategy.

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