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Wind Turbine System with an Auxiliary Parallel Grid-Side Converter Using PMSG Wind Energy

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ABSTRACT: In this paper, based on the similarity, in structure and principle, between a grid-connected converter for a direct-driven permanent magnet synchronous generator (D-PMSG) and an active power filter (APF), a new D-PMSG-based wind turbine (WT) system configuration that includes not only an auxiliary converter in parallel with the grid-side converter, but also a coordinated control strategy, is proposed to enhance the low voltage ride through (LVRT) capability and improve power quality. During normal operation, the main grid-side converter maintains the DC-link voltage constant, whereas the auxiliary grid-side converter functions as an APF with harmonic suppression and reactive power compensation to improve the power quality. During grid faults, a hierarchical coordinated control scheme for the generator-side converter, main grid-side converter and auxiliary grid-side converter, depending on the grid voltage sags, is presented to enhance the LVRT capability of the direct-driven PMSG WT. The feasibility and the effectiveness of the proposed system's topology and hierarchical coordinated control strategy were verified using MATLAB/Simulink simulations. The PMSG is connected to a three phase resistive load through a switch mode rectifier and a voltage source inverter. Control of the generator side converter is used to achieve maximum power extraction from the available wind power.

KEYWORDS: Stand-alone variable speed wind system; permanent magnet synchronous generator; DC-link voltage; controlled output voltage

I. INTRODUCTION

Wind turbine technology has developed rapidly over the past decade into one of the most mature renewable power generation technologies. Compared to other wind turbine systems used for commercial power generation, the accelerated evolution of the direct-driven wind turbine (WT) with a permanent magnet synchronous generator (D-PMSG) can be attributed to its simple structure, low cost of maintenance, high conversion efficiency and high reliability [1]. Moreover, its decoupling control performance is much less sensitive to the parameter variations of the generator. Therefore, a high-performance variable-speed generation including high efficiency and high controllability is expected by using a PMSG for a wind generation system. The continuously growing penetration of wind power into the power grid has impacted power grid stability and power quality with increasing prominence. New grid codes [2, 3] specify that grid-connected WTs must possess low voltage ride through (LVRT) capability. With this capability, the WT system can remain connected to the grid when the voltage at the point of common coupling (PCC) drops during a power grid fault and can even provide reactive power to the power grid to support grid voltage recovery until the power grid returns to normal. . Direct drive configuration, where a generator is coupled to the rotor of a wind turbine directly, offers high reliability, low maintenance, and possibly low cost for certain turbines. Several manufacturers have opted for the direct drive configuration in the recent turbine designs. At the present time and in the near future, generators for wind turbines will be synchronous generators, permanent magnet synchronous generators, and induction generators, including the squirrel cage.

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II. RELATED WORK

- **Auxiliary GSC Control**

The control diagram for the main GSC implemented in synchronous rotating dq reference frame with its d-axis oriented with the grid voltage vector. The PI regulators with cascade control loops are employed in the GSC control scheme, in which the outer control loops are for DC-link voltage and reactive power regulation, and the inner control loops are for grid side inductor current regulation. To decouple the q-axis and d-axis current control in the GSC control loop, the feed forward compensation terms are introduced to control the d-axis component for the active current regulation and the q-axis component for the reactive current regulation.

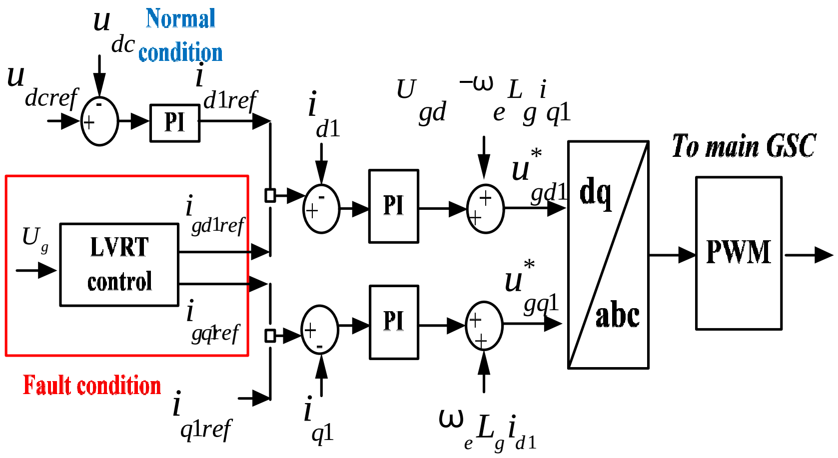

Figure 1. A control diagram for the main GSC.

Under normal conditions, dual closed-loop control is applied to the d-axis control, where the outer DC-link voltage loop outputs the reference current for the inner current loop, thereby controlling the DC-link voltage to be constant. This structure ensures that the active power output of the generator may be fed through the converter and into the grid in a timely manner. Single closed-loop control is used for the q-axis control, where the pre-set value of the reactive power determines the reactive current reference. However, under fault conditions, the active and reactive current references of the main GSC are determined by the LVRT control strategy, indicated by red dashed box in Figure 1.

Similar to the main GSC control, the auxiliary GSC control involves a feed forward compensation to decouple current control. Two control loops are used to control the active and reactive power, respectively, as shown in Figure 2 (the solid lines).

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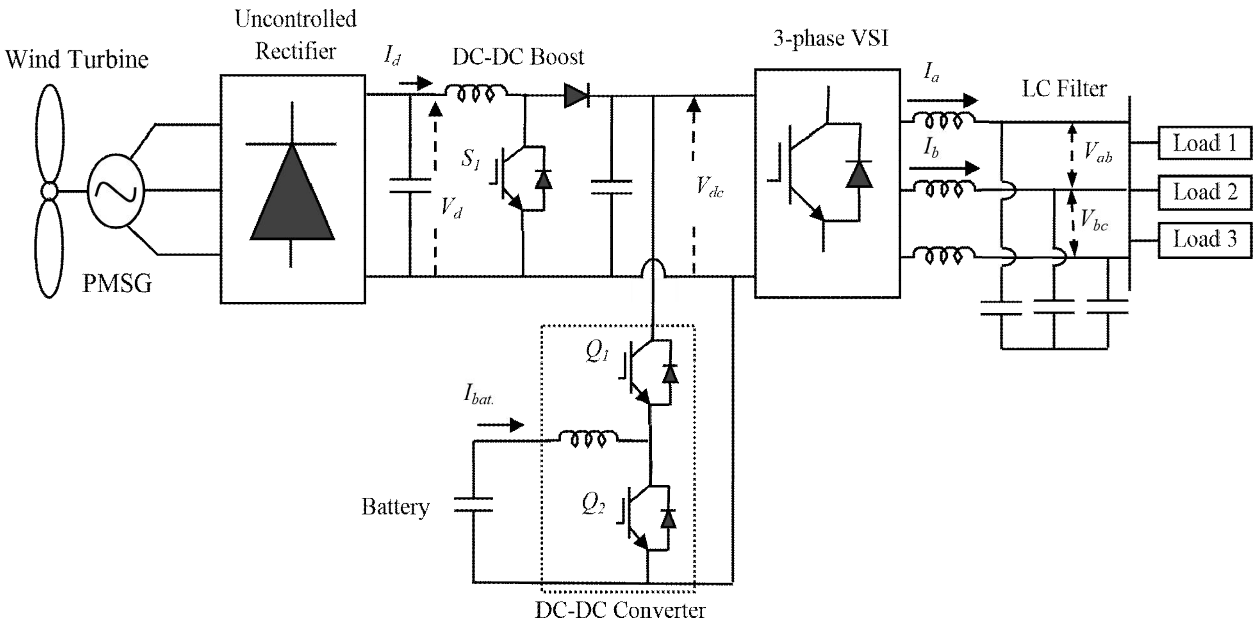

Figure 2. Generated side control diagram of the auxiliary GSC.

To describe the control function, considering Figure 2. If the PMSG operating at point “a” and wind speed increases from υ_{w1} to υ_{w2} the additional power causes the PMSG to accelerate also causes difference between reference DC current and measured DC current, this difference operate to adjust the duty cycle of DC-DC boost converter to achieve optimum speed of the PMSG ω_g which attain maximum power extraction. Finally, the generator will reach the point “c” where the difference between reference DC current and measured DC current is within the bandwidth of the hysteresis current controller. A similar situation occurs when the wind speed decreases. In this proposed strategy, there is no need to measure wind and generator speed using mechanical sensors which lead to inaccurate measurement.

III. WIND TURBINE MODEL

Wind turbine is systems that harness the kinetic energy of the wind for useful power.

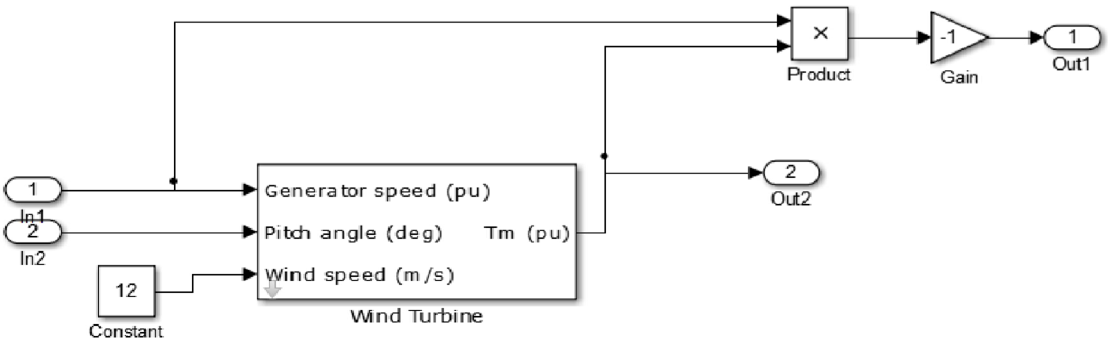

Fig.3 Simulink model of wind turbine

The aerodynamic power of wind turbine is P_m is express [3]

$$P_m = 0.5\, C_p\,(\lambda,\beta)\rho A_{v^3} \quad (1)$$

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Here ρ is the air density and A is the blades swept area

V = Wind speed
C_p = Power coefficient β = Pitch angle
λ = Tip speed ratio

$\lambda = \frac{R\,W_m}{V}$

W_m= Rotor speed of the wind speed
The power coefficient of the wind turbines indicates

$$C_p(\lambda,\beta) = C_1\left(\frac{C_2}{\lambda_i} - C_3\beta - C_4\right)e^{\frac{-C_5}{\lambda_i}} + C_6\lambda \quad (2)$$

$$\frac{1}{\lambda_i} = [\frac{1}{\lambda + 0.089} - \frac{0.035}{\beta^2 + 1}]$$

When pitch angle = 0 and bi speed ratio λ = 6.325 C_p is maximum value
C_p Of the turbine is the divided by wind power and function of the wind speed, rotational speed, pitch angle. Output of the turbine is the torque applied to the generator shaft is per unit of the generator.

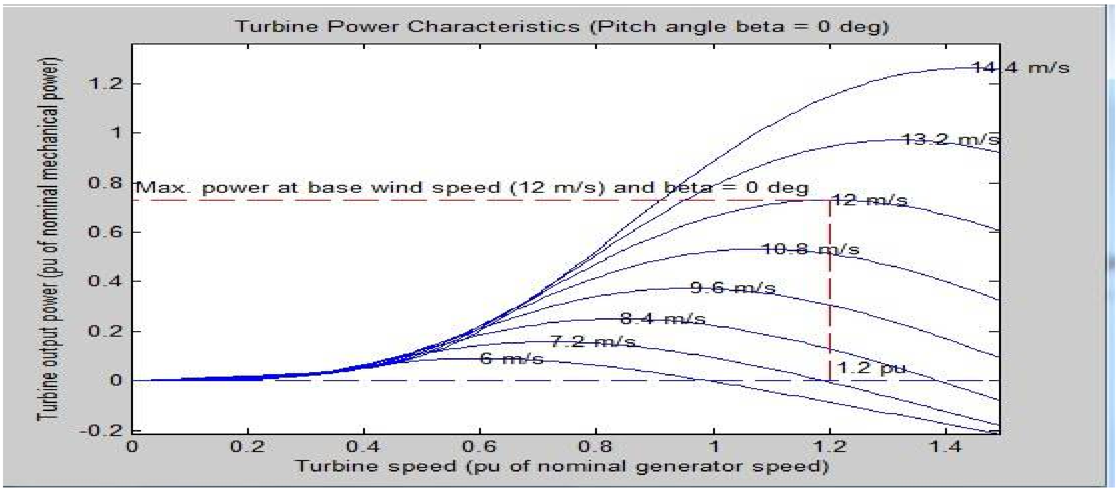

Fig 4 Characteristics of Wind turbine

- **Modeling of PMSG:**

PMSG is used in WECS because of its advantage such as better reliability, lower maintenance and more efficient [4]. The model of PMSG is established in the d-q synchronous frame as shown in fig 4

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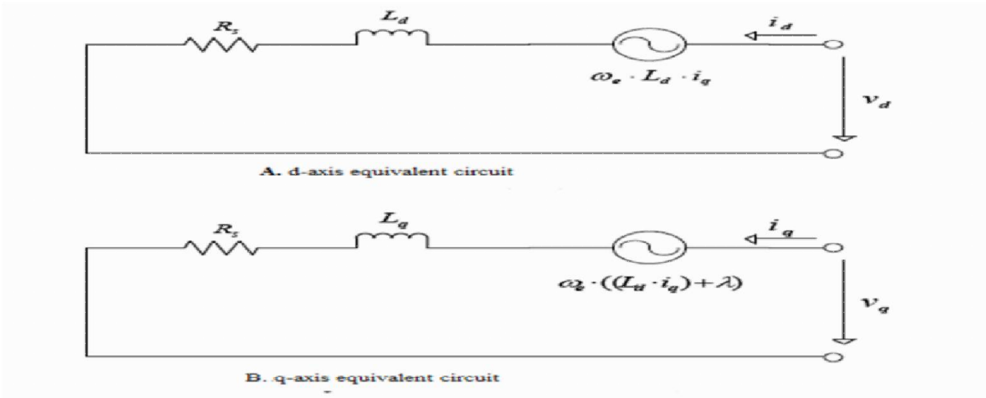

Fig .5 Equivalent Circuit of PMSG in d-q reference frame

A capacitor bank (normally stepwise controlled) is inserted in parallel with the generator in order to obtain about unity power factor. Further, to reduce the mechanical stress and to reduce the interaction between supply grid and turbine during connection and start-up of the turbine, a soft starter is used. The main advantage of this system is that it is a simple and reliable arrangement. However, capacitors need to be cut in or cutoff regularly to maintain power factor. This random switching gives rise to undesirable transients in the line currents and voltages. The fluctuations in prime mover speed are converted to torque pulsations, which cause mechanical stress. This causes breakdown of drive train and gear box. The power generated from this arrangement is sensitive to fluctuations in prime mover speed. To avoid this pitch control of rotor blades is required.

IV. RESULT AND DICUSSION

The grid voltage dropped to 0.5 p.u., and 45% $<U_g<$ 56% (a situation that corresponds to the second level of the control hierarchy). At this time, the active and reactive outputs of the two GSCs were already fluctuating as necessary.

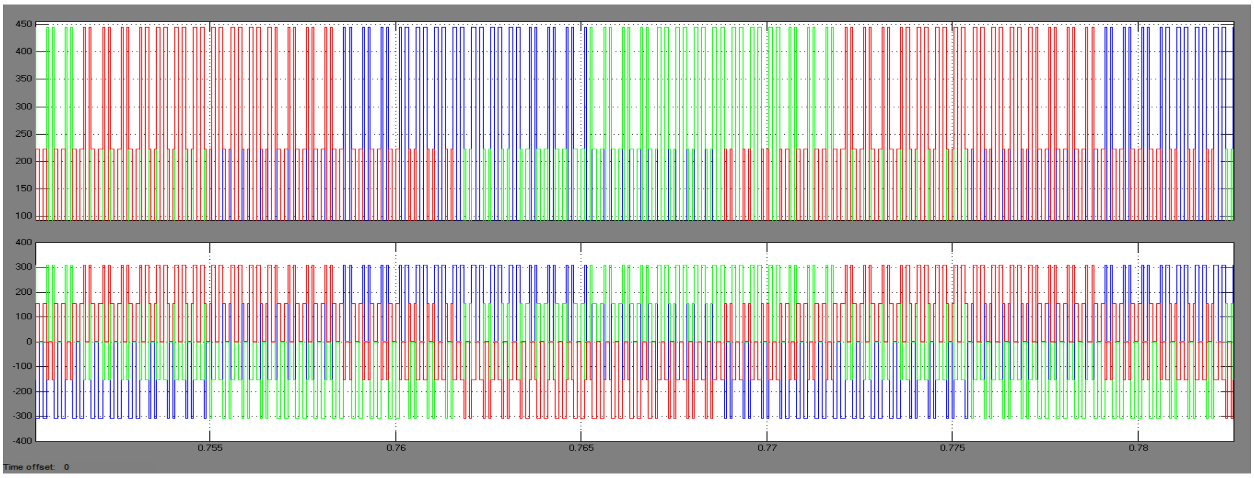

FIG: 6 Waveforms of PMSG Stator current in d-q axis

However, the reactive support had reached its upper bound, and the generator speed therefore increased to 1.34 p.u., shown in Figure 4, which reduced the output power of the generator to maintain the energy balance of the system. The WT speed responded more slowly, briefly increasing the DC-link voltage, shown in Figure 6; however, this voltage remained below 1.05 p.u., in compliance with the requirements

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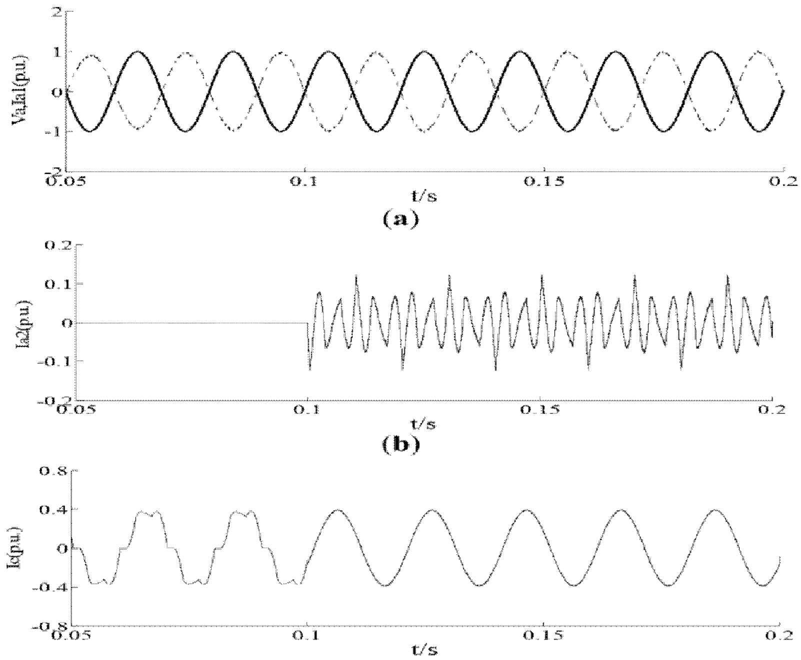

FIG: 7 Waveforms of Stator speed, angle and electromagnetic torque

V. CONCLUSION

Control strategy of a stand-alone variable speed wind energy supply system has been presented in this paper, along with a comprehensive analysis and simulation. From the simulation results, the maximum power extraction control algorithm at the generator side converter has been implemented, the DC-link voltage has been maintained at constant value; furthermore, the batteries bank has been able to store the surplus of wind energy and supply it to the load during a wind power shortage by controlling the DC-DC bidirectional buck-boost converter, which is connected between batteries bank and DC-link voltage estimating generator speed, using the relation curve between generator speed and mechanical power to adjust the generator speed operation at optimum value through a hysteresis current control for extracting maximum power from the available wind power.. Finally, it has been explained how the voltage source inverter controller uses a vector control strategy to supply controlled output voltage in terms of amplitude and frequency to the resistive load. The simulation results proved that the performance of the control strategy is satisfactory in spite of variation in wind speed and load.

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