Performance analysis on PMSG based Wind Energy Conversion System with Multilevel Converter

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Abstract—In response to the need for a more efficient wind energy conversion, multilevel converters have been accepted as promising options in the Medium Voltage Wind Energy Conversion System (WECS). In this paper develop a new medium voltage power converter topology that uses a diode rectifier, a Boost converter and a 5-level multilevel inverter for a wind energy conversion system based on High power permanent magnet synchronous generator. The Boost converter on the generator side tracks the maximum power point and the voltages of the DC link capacitors, while the Multilevel inverter on the network side regulates the voltage, frequency and reactive power of the CC bus of the network. A significant improvement in the power quality of the network is achieved, since the Multilevel inverter no longer controls the voltage of the neutral point of the DC link. These predictions are evaluated using two independent cost functions, and the switching states that minimize these cost functions are selected and applied directly to the generator and network side converters. To comply with the high power application, the switching frequencies of the Boost converter are minimized and kept below 1.5 kHz, respectively. Theproposed topology and control strategy are verified through the MATLAB simulation.

***Index Terms* -** grid-connected, three-level boost (TLB) converter, multilevel inverters *MLI*, permanent magnet synchronous generator(PMSG), wind energy conversion system (WECS).

I. INTRODUCTION

The large increase in the power capacity of windturbines increases the generation voltage up medium voltagesto reduce power losses, cables cost and switchgear capacity[1, 2]. The MLCs are a good solution for cost andperformance in high power systems.MLCs have been investigated for WECS of high capacity wind turbines [3].MLCs are the most promising technology for WECS of highcapacity wind turbines because (i) low THD of their outputvoltages/currents, (ii) low switching power losses insemiconducting devices (thermal stresses), (iii) capability tohandle high power voltage with low-rating devices [3] (iv)reduced voltage stress of the power electronic switches and (v)improve the power factor. There are four MLC topologies (i)DC-MLC (diode-clamped multilevel converters) [2, 3, 4,5], (ii) flying capacitor multilevel converters, (iii) cascaded H-bridgemultilevel converters [6] and (iv) Modular MultilevelConverter [7].The GSC (grid side converter) for WECS used totransfer all the generated power by the wind turbine system tothe utility-grid, regulates the DC bus voltage, synchronizesthe generated power with the utility-grid, control of activeand reactive power [28]. There are two types to control utility gridside converters of WECS; Voltage oriented control(VOC) [8, 9, 10, 11 -13] and DPC [10, 14-18].VOC for grid side converter uses current orientationon voltage vector for current control loops. This technique iscomplex and increases THD for line voltage and has a lowdynamic response [12].The classical DPC is simpler than VOC technique.Besides, it has low THD in the current and better powerfactor. The classical DPC technique with two-level converterhas the disadvantage increase THD in line voltage [11]. Theuse of DPC with MLC is to improve THD in the line voltageand improve the utility-grid power quality. In [16]. A proposed DPC strategy with a vectorproportional integrated regulator based wind power generation system. This strategy can successfully achieve thesmooth active and reactive power, but this system is complexbecause it adds an additional controller.In [18] uses DPC for utility-grid connected based onSliding mode control to improve power factor and decreasesTHD.

II. PROPOSED SYSTEM

In fig. 1.1 shows the proposed system configuration of 3KW PMSG based WECS with Multilevel converters. In wind energy conversion systems (WECS),power flow is unidirectional, that is, the power flows from the wind generator to the utilitygrid. Thus, passive (diode bridge) converters can be employed on the generator side insteadof pulse width modulated (PWM) active converters. Diode-bridge rectifiers are lessexpensive and inherently more reliable than PWM converters. In the PMSG the rotor flux is generated by permanent magnetsand rotor field excitation, respectively. Passive converters can realize generator-side powerconversion because no power is required from the utility grid to excite the PMSG.The output voltage of the diode rectifier varies according to the generator speed. Duringlow wind speeds, the generator output voltage and the diode rectifier output voltage significantlydecreases. To transfer the generated power to the grid, the DC-link voltage must behigher than the *peak* value of grid line-to-line voltage. To increase the output voltage of thediode rectifier, a boost converter is employed as an intermediate stage. The configurationbased on a diode rectifier, boost converter, and multilevel inverter, the DPC with GSC for five-level converter. This technique directly controls the reactive and activepowers of the utility-grid.

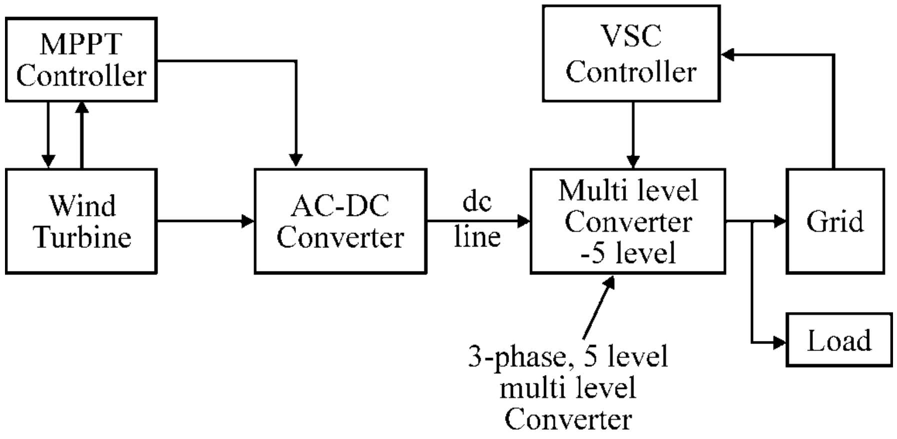


Fig. 1Proposed variable wind generation system with multilevel inverter.

III.SYSTEM MODELING

3.1. Wind turbine characteristic

The following sections explain the modeling and the control principles of the wind turbine. Wind Turbine Characteristics. The power P_{wind} (in watts) extracted from the wind is given as:

$$P_{wind} = \frac{1}{2}\rho A v^3 C_p(\lambda,\theta) \qquad (1)$$

Where T is the air density in kg/m^3, A is the area swept by the rotor blades in m^2, v is the wind velocity in m/s. C_p is called the power coefficient or the rotor efficiency and is function of tip speed ratio (TSR) and pitch angle (θ).

Tip speed ratio is defined as the ratio of velocity of rotor tip and velocity of wind. The power developed by the rotor is a function of tip speed ratio. Mathematically tip speed ratio is given as

$$\lambda = \frac{2\pi NR}{v_w} \qquad (2)$$

Where N is the rotational speed of the rotor in rpm and R is the radius of the rotor blade in meter and V is the wind speed in m/s.

The dynamic relation between the rotor and wind stream greatly affects the efficiency of rotor in power extraction. The $Cp-\lambda$ characteristic shows the rotor performance irrespective of rotor size and site parameters.The maximum rotor efficiency C_p is achieved at a particular TSR, which is specific to the aerodynamic design of a given turbine. The rotor must turn at high speed at high wind, and at low speed at low wind, to keep TSR constant at the optimum level at all times. Groups of C_p -curves with pitch angle as the parameter obtained by measurement or by computation can be represented as a nonlinear function. The following function is used.

$$C_p = C_1(C_2 - C_3\theta - C_4)\exp(-C_5) \qquad (3)$$

where θis the pitch angle.

Proper adjustment of the coefficients C_1– C_5 would result in a close simulation of a specific turbine under consideration. The values for C_1– C_5 used in this study are listed in Table-1. The $C_{p\text{-}\lambda}$ characteristic curves at different pitch angles are plotted. With an increase in the pitch angle, the range of TSR and the maximum value of power coefficient decrease considerably.

Table:1-Parameter Values for C1 – C5

C_1	0.5
C_2	116/ K_θ
C_3	0.4
C_4	5
C_5	21/ K_θ

K_θ in Table-1 used to calculate C_2 and C_5 is determined by λ and θ:

$$k_\theta = \left[\frac{1}{\lambda + 0.08\theta} - \frac{0.035}{\theta^3 + 1}\right]^{-1} \qquad (4)$$

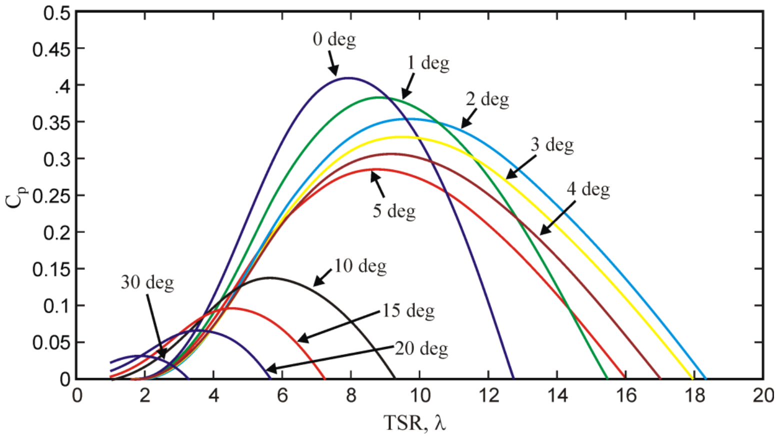


Fig. 2 C_p-λcharacteristics at different pitch angles (θ).

From Fig 2, it is clear that power coefficient increases with increase in tip speed ratio. But when tip speed ratio increases further beyond the optimized value, power coefficient starts to decline at same slope. Hence there is only one optimized point where power extraction is maximum.

3.2. Dynamic model of PMSG

The PMSG dynamic model assumes no saturation, a sinusoidal back e.m.f. and negligible eddy current and hysteresis losses. It takes into account the iron losses and the dynamic equations for the PMSG currents are:

$$\frac{di_{md}}{dt} = \frac{1}{L_d}(v_d - R_{st}i_d + \omega L_q i_{mq}), \tag{5}$$

$$\frac{di_{mq}}{dt} = \frac{1}{L_d}(v_q - R_{st}i_q + \omega L_q i_{md} - \omega\psi_{PM}), \tag{6}$$

$$i_d = \frac{1}{R_c}(L_d \frac{di_{md}}{dt} - \omega L_q i_{mq} + R_c i_{md}), \tag{7}$$

$$i_q = \frac{1}{R_c}(L_q \frac{di_{mq}}{dt} + \omega L_d i_{md} + \omega\psi_{PM} + R_c i_{mq}), \tag{8}$$

$$i_{cd} = i_d - i_{md}, \tag{9}$$

$$i_{cq} = i_q - i_{mq}, \tag{10}$$

where id, i_q are the d_q axes currents, vd' V_q are the d_q axes voltages, i_{cd}' i_{cq} are the d_q axes iron losses currents, i_{md}, i_{mq} are the d_q axes magnetizing currents, L_d, L_q are the d_q axes inductances, If/PM is the mutual flux due to magnets, OJ is the fundamental frequency of the stator currents, R_c is the iron losses resistance and $R_{st}$is the stator resistance.

The electromagnetic torque equation of the PMSG is:

$$T_e = \frac{2}{3}p\left[\psi_{PM}i_{mq} + (L_d - L_q)i_{md}i_{mq}\right] \tag{11}$$

where p is the number of pole pairs.

IV. SIMULATION AND RESULT ANALYSIS

The proposed system for 8 KW WECS is simulated by Matlab /Simulink Simscape Power Systems. In this simulation wind speed is linearly increase from 12 m/s to 7 m/s for WECS and load is kept constant. Simulation results are shown in Fig. 3.

In this response wind speed 12m/s at time period t=0 sec. and wind speed at time period t=14 sec. is 7m/s, during time interval t=0 sec. to t=16 sec. wind is linearly increase from 7m/s to 12m/s. PMSG output power is change accordingly to wind speed it is also linear increase from t=0 sec. to t=16 sec. and after t=16 sec. time period PMSG output power is constant. In fig. 3 PMSG output voltage, generator speed and PMSG output current change according to wind profile.

In Fig. 4 shows the wave form of PMSG Stator current and PMSG output voltage and zooming fig.(I) and (II) shows initial condition and steady state condition of voltage and current. In steady state condition PMSG output voltage and output current is sinusoidal.

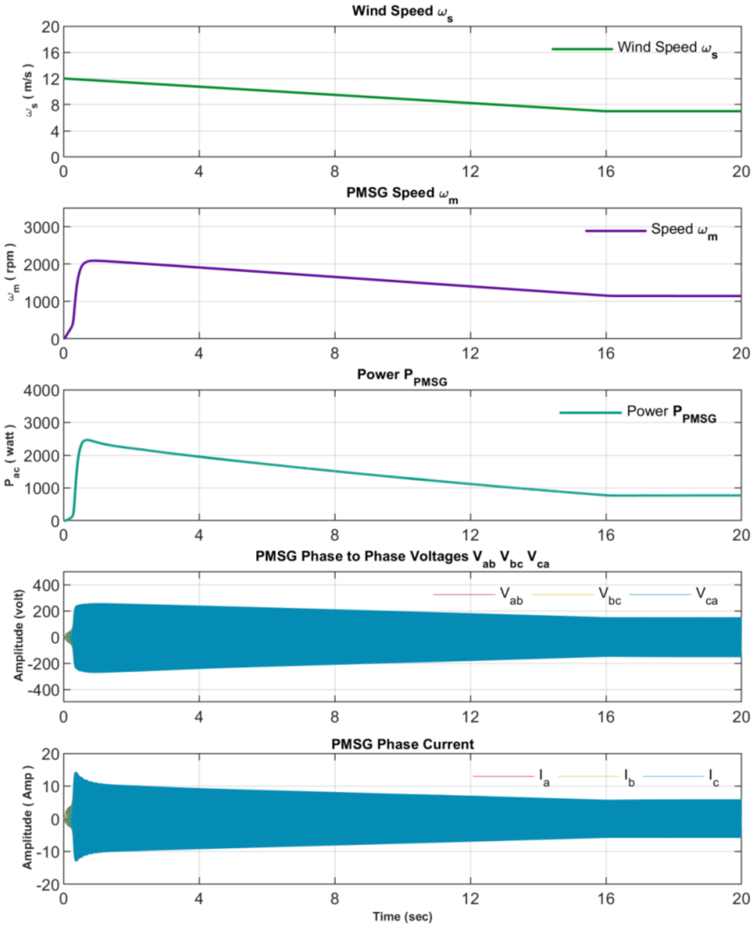
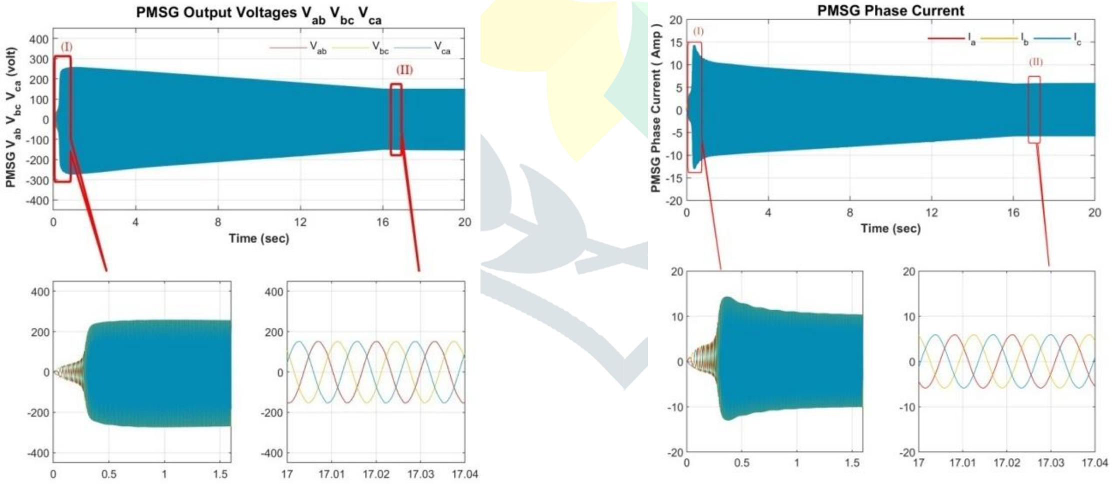
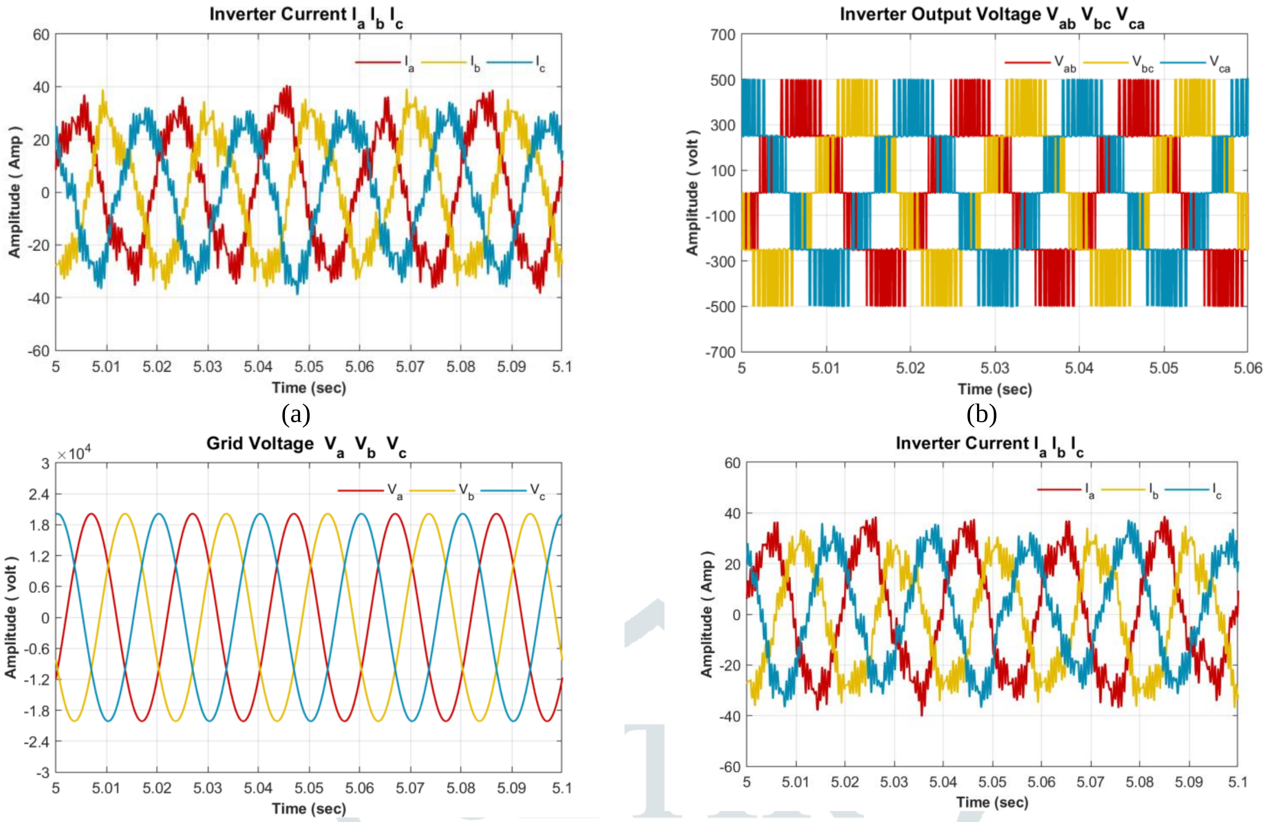


Fig. 3Simulation waveform of wind speed ω_s, PMSG speed ω_m, PMSG output power P_{PMSG}, PMSG phase to phase voltages $V_{ab}V_{bc}V_{ca}$, PMSG phase current at during wind speed linear decrease 12 m/s to 7m/s with constant load.



(A) (B)

Fig. 4Simulation waveform of (A) PMSG phase to phase voltages, (B) PMSG stator current, at during wind speed linear increase 12 m/s to 7 m/s with constant load.



(a) (b)

(c) (d)

Fig. 5. Simulation waveform (A) Inverter duty ratio (B) Inverter output voltage (C) Inverter output current during wind speed change from 12m/s to 7m/s with constant load.

Fig. 5. shows the various waveform of multilevel inverter like multilevel inverter output voltage and multilevel inverter output current in fig. 5 (a), (b),(c), (d) shows the grid voltage and grid current.

Fig. 6. shows waveform of wind speed, PMSG output power, load output power, Grid power, load frequency and grid frequency. PMSG output power varies during time period from 0 to 14 sec after this interval power is constant. In fig. 6. we can see load frequency and grid frequency are constant, so we can say system is regulated with voltage and current.

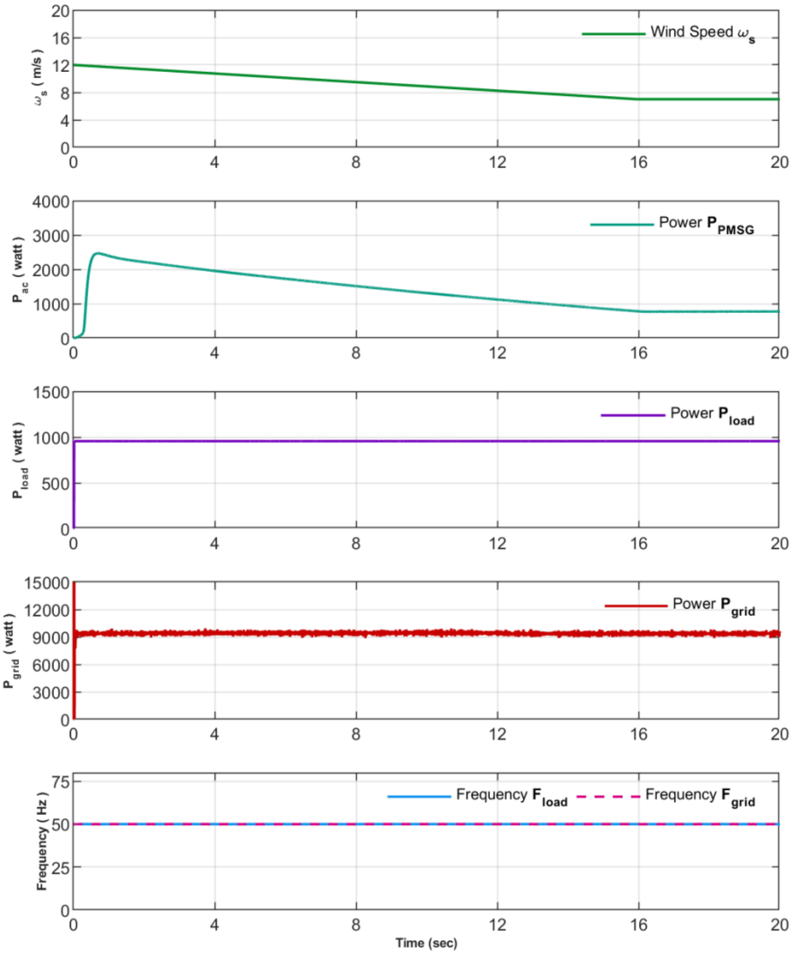


Fig. 6. Simulation results for PMSG based WECS for constant wind speed of 12m/s, Waveform of wind speed, PMSG output power, load output power, Grid power, load frequency and grid frequency.

V. CONCLUSIONS

This paper deals with a control strategy of the variable speed wind energy conversion system based onthe PMSG and connected distribution network. A8KW PMSG variable speed wind power generationsystem is simulated to demonstrate the proposed control strategy during the grid fault. The controlstrategy can implement the theory of MPPT to adjust WTG velocity according to instantaneous windspeed. Moreover, control strategy based on Pulse width modulation (PCM) theory is applied for generator converterand for inverter. As the speed of WTG vary along the wind velocity change, the rectifier is used to trackthe maximum wind power, although the inverter can deliver the energy from the PMSG to the electricgrid with unity power factor.Besides, Direct Power Control (DPC) of three phases multilevel inverter isadopted and Grid-side reactive and active power decoupling method is applied. The employed controlstrategy can regulate both the reactive and active power independently. The performance of system has been demonstrated under varying wind conditions and the grid fault conditions. It is finally shown that the results proved the effectiveness of the employed control strategies.

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