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Simulation and Modeling of Wind Turbine, Permanent Magnet Synchronous Generator System and Five Level Diode Clamped Multilevel Inverter

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Abstract
In the wind vitality preservation framework, the wind turbine catches the wind vitality. At that point the generator transforms it to the electrical power. Wind turbines are characterized into two sorts as settled speed wind turbine and variable speed wind turbine. Variable speed wind turbines yield more vitality than the settled speed wind turbines, decrease control changes. This paper presents the model and the control schemes of a variable speed wind turbine with permanent magnet synchronous generator. This model includes a PMSG model, a wind turbine model, drive train model, three phase diode rectifier, a dc to dc boost converter and three phase diode clamped inverter. The power conversion system topology is explained and electrical model of each component is presented. Based on this electrical model, a simulation model of the system has done. The simulation was implemented in power system simulation tools in MATLAB SIMULINK.

Keywords: diode clamped multilevel inverter, PMSG, renewable energy, variable speed wind turbine, wind energy conversion system

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INTRODUCTION

As we all know that due to environment concern the Wind based systems are mostly used in the field of power generation. Hence, a vast Research is going on to increase the power and efficiency of the wind power plant and decrease the cost and losses of the system. Wind power mainly depends on weather and geographic conditions and varies from time to time. Hence it is necessary to construct a system that can generate maximum power for all the operating conditions Modern wind turbines are very advanced machine they can generate power for all the operating conditions. Two configurations used for the wind energy conversion system: (i) standalone system, (ii) grid connected systems. In standalone systems direct load is supplied it is mainly used in the remote areas and in the grid connected systems power is fed to the grid and then distributed to the load. Utility system guarantees a backup power in situations where wind availability is insufficient.[1,2]

As the infiltration of wind power expands, incorporating extensive twist ranches to power matrices and the significant impacts on the host networks should be precisely explored. Along these lines, exact and solid model of variable speed wind turbine generators are critically required for power framework reenactment investigation. In order to achieve variable speed operation, a power electronic converter interface is used to connect the generator to the grid as illustrated in Figure 1. The modeled system consists of PMSG model, Wind turbine model and drive train model and the Conversion system consists of an uncontrolled 3-phase diode rectifier, DC to DC boost converter, a three phase diode clamped multilevel inverter. DC to DC boost converter are used to maximize the generated power. The control schemes include a speed control of the generator. The aim of this paper is to investigate the performance of permanent magnet wind generator and to predict the output. It predicts the power output, the current and the output voltage at a certain average wind speed.[3]

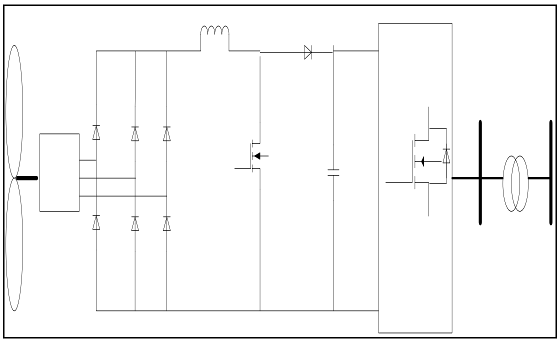


Fig. 1. *Wind Power Conversion System.*

WIND TURBINE MODELLING

The power is captured from wind by wind turbines by means of its aerodynamically designed blades and convert it into rotating mechanical power. Maximum power output that can be extracted from a wind turbine is limited by the coefficient of power C_p which is a function of tip speed ratio λ. C_p never exceeds the Betz limit. This rotating Mechanical power is used to drive generator, which will produce electrical power. The amount of power extracted from wind turbine is given by equation[4–7]:

$$Pm = \frac{1}{2}\rho A C_p V w^3 \qquad (1)$$

The mechanical torque in (N-m) is given by[7]

$$T_m = P_m / W_m \qquad (2)$$

where A is the wind turbine rotor swept area in m^3, V_W is the speed of the wind in (m/s), W_M is the mechanical speed of the wind turbine in (rad/s), C_P is the turbine power coefficient and ρ is the air density in kg/m^3 (Figure 2).

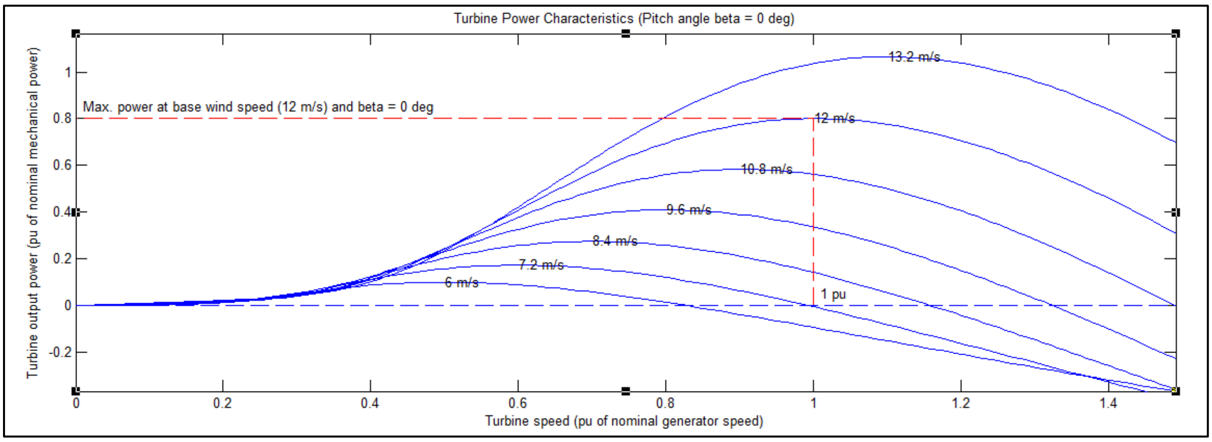


Fig. 2. *Characteristics of Wind Turbine.*

GENERATOR MODELING

The dynamic model of PMSG is gotten from the two-stage synchronous reference outline in which the q-hub is 90° in front of the d-pivot as for the heading of turn. The synchronization between the dq-pivoting reference outline and the abc-three stage casing is kept up by a stage bolted circle (PLL). The electrical model of PMSG in the synchronous reference casing is given by

$$V_{ds} = -R_s i_{ds} - \omega_r L_q i_{qs} + L_d p i_{ds} \qquad (3)$$

$$V_{qs} = -R_s i_{qs} - \omega_r L_d i_{ds} - L_q p i_{qs} + \omega_r \lambda_r \quad (4)$$

where subscripts '*d*' and '*q*' refer to the physical quantities that have been transformed into the *dq*-synchronous rotating reference frame; *Ra* is the armature resistance; w_r is the electrical rotating speed which is related to the mechanical rotating speed of the generator as $w_r = n_p w_g$ where n_p is the number of pole pairs; λ_r is the permanent magnetic flux. Figure 3 shows a simplified model for the synchronous generators which is based on Equations 3 and 4.[8–11]

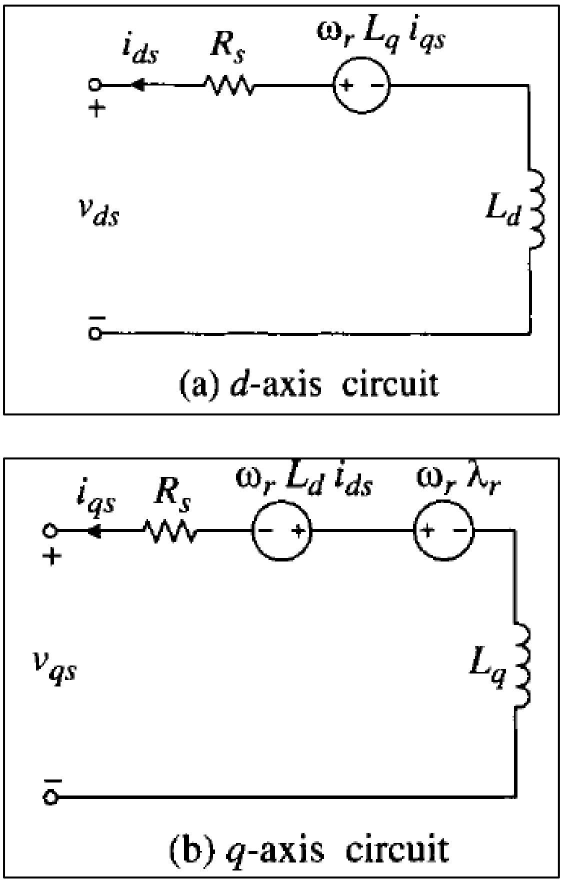


Fig. 3. *Equivalent Circuit of PMSG in the Synchronous Frame.*

The electromagnetic torque produced by synchronous generator can be calculated by

$$Te = 1.5p(i_{qs}\lambda_r - (L_d - L_q) i_{ds} i_{qs}) \quad (5)$$

The rotor Speed $_r$ is given by equation

$$\omega_r = p(T_e - T_m)/JS \quad (6)$$

THREE PHASE DIODE BRIDGE RECTIFIER

The diode rectifier is the most commonly used topology in converting AC to DC output voltage. The circuit is shown in Figure 3. The power generated from the generator is converted in to DC power through diode bridge rectifier circuits (Figure 4).

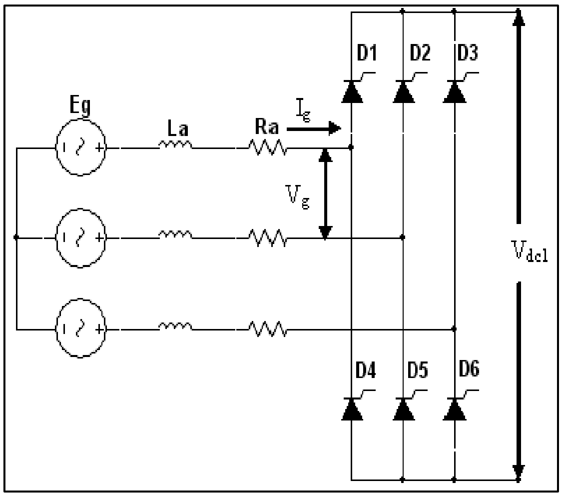


Fig. 4. *Diode Bridge Rectifier Circuit.*

DC TO DC BOOST CONVERTER

A boost converter consists of a voltage source V_{dc1}, an inductor L, which is used for energy storage and connected to the voltage source in series, a switching device M, a diode D, a filter capacitor C and a load.

Energy from voltage source is stored in the inductor *L* when the switching device *M* is conducting. The current through the inductor increases linearly, the diode *D* is reverse biased and the capacitor provides voltage for the load during that time.

When the switching device *M* is opened, the diode *D* conducting the current through the inductor *L*, and diode *D* offers power for the load and the charging of the capacitor *C*. The circuit of DC–DC boost converter is shown in Figure 4 (Figure 5).

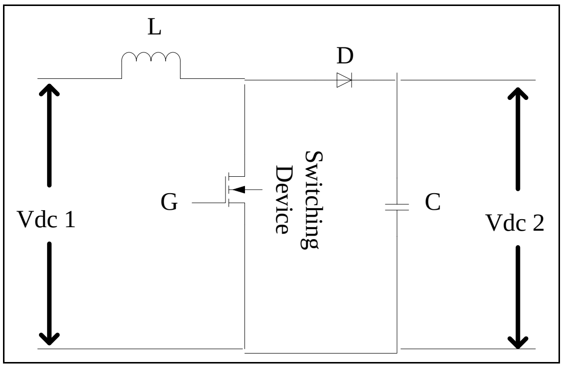


Fig. 5. *Circuit of DC–DC Boost Converter.*

DIODE CLAMPED MULTILEVEL INVERTER

It is the most commonly used multilevel inverter topology, in which diode is used as a clamping device to clamp DC bus voltage so that output voltage can be achieved in steps. These diodes are used in this circuit to limit voltage stress on power devices. An n-level inverter needs (n-1) voltage sources, 2(n-1) switching devices and (n-1) (n-2) diodes. If the no. of voltage levels are increased the quality of output voltage is improved and the output waveform becomes close to sinusoidal waveform.

The circuit diagram for the five level diode clamped multilevel inverter is shown in Figure 6 in which dc bus consists of four capacitors C1,C2,C3,C4. For the dc bus voltage of V_{dc}, the voltage across each capacitor is $V_{dc}/4$ through the clamping diodes. The switches for phase A are Sa1, Sa2, Sa3, Sa4, Sa1', Sa2', Sa3', Sa4'.

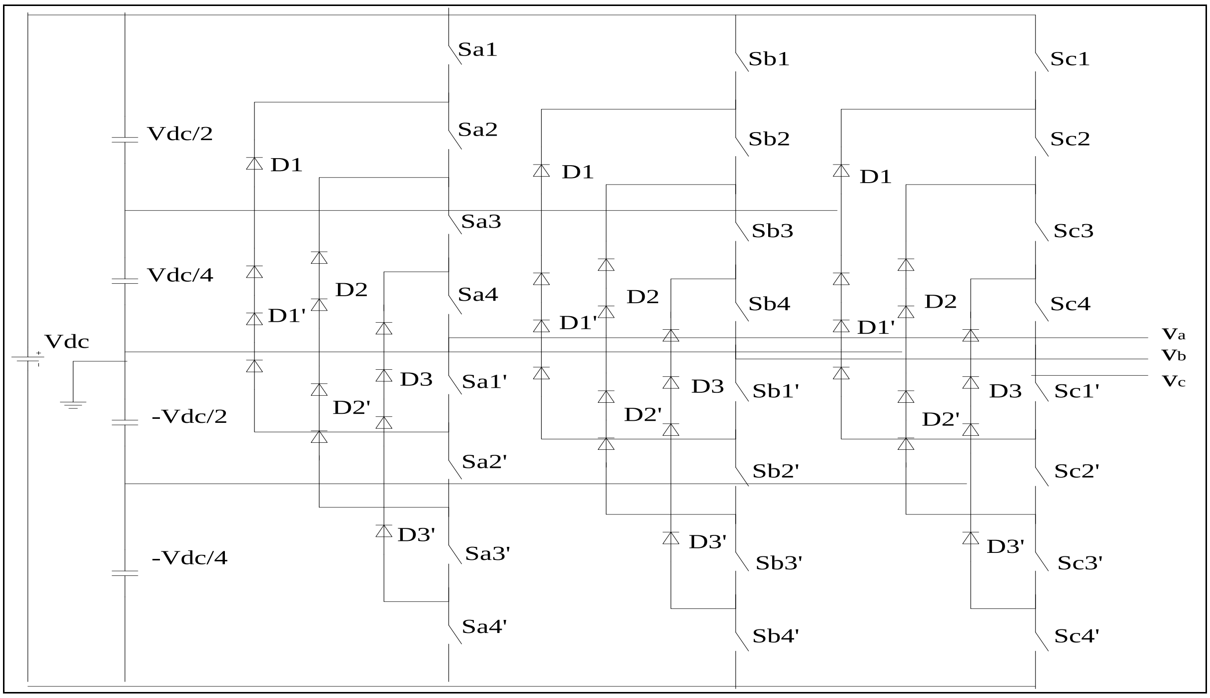


Fig. 6. *Five Level Diode Clamped Multilevel Inverter.*

Table 1 shows the output voltage levels and the corresponding switching states for one phase of the chosen five levels DCMLI.

Switching sequence is given in Table 1. State 1 means ON and State 0 means OFF.

Table 1. *Switching State of Diode Clamped Multilevel Inverter.*

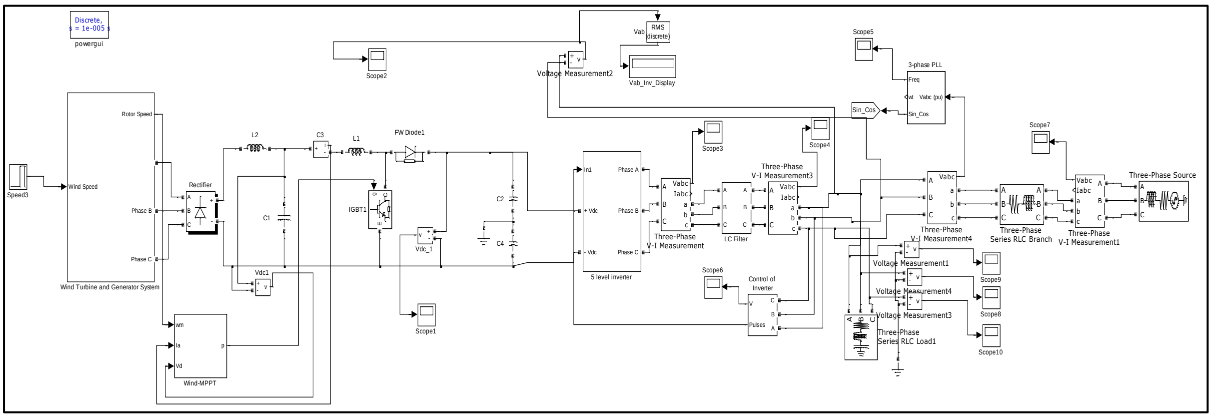
V_o	S_{a1}	S_{a2}	S_{a3}	S_{a4}	S_{a1}'	S_{a2}'	S_{a3}'	S_{a4}'
$V_{dc/2}$	1	1	1	1	0	0	0	0
$V_{dc/4}$	0	1	1	1	1	0	0	0
0	0	0	1	1	1	1	0	0
$-V_{dc/2}$	0	0	0	1	1	1	1	0
$-V_{dc/}$	0	0	0	0	1	1	1	1

4									

SIMULINK MODEL

The proposed model of the variable speed twist turbine with PMSG is developed with MATLAB/Simulink. This Paragraph presents the output of the simulation diagram. In this model wind turbine shaft is mechanically connected with permanent magnet generator's shaft which is connected to load through back to back converters. The Simulink model is presented in Figure 6.

The rectifier piece actualizes an extension of chose power hardware gadgets. Arrangement RC snubber circuits are associated in parallel with every switch gadget. The output of the PMSG is rectified to have a dc voltage output. The dc voltage is boosted using the designed Simulink dc-dc boost converter. The duty cycle of the gate driver in dc–dc converter is adjusted in order to step up the voltage to a certain level. The DC output power is converted to AC for electric utility connection. The diode clamped multilevel inverter uses IGBT power electronic devices. This inverter is used to convert this dc voltage to a comparable ac utility voltage. The controller is used to achieve the optimal operating by keeping the output voltage more or less constant by controlling modulation index of diode clamped multilevel inverter and duty ratio of the boost converter to utilize completely the available wind energy. The LC filter is connected between inverter and load to have a smooth ac output voltage. Scopes are added to monitor and plot the output waveform at different points in the wind turbine power system.



SIMULATION RESULTS

The detailed modeling of the wind turbine, PM alternator, the rectifier, the DC–DC converter and the inverter is very important in obtaining the accurate picture of all the system waveforms (voltages, currents, power).

Simulation results for steady state operating conditions are shown in Figure 8 which are composed of load voltage and current. In the simulation, the three input parameters used were; 1.0 pu generator speed, zero (0) pitch angle and 12 m/s for the wind speed (Figures 7–11).

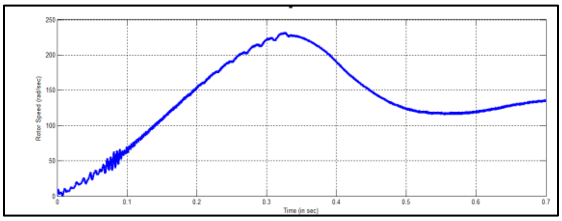


Fig. 7. *Rotor Speed in rad/sec.*

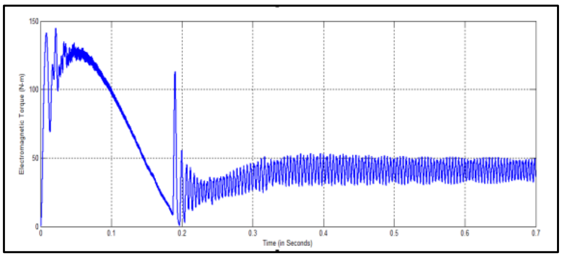


Fig. 8. *Electromagnetic Torque.*

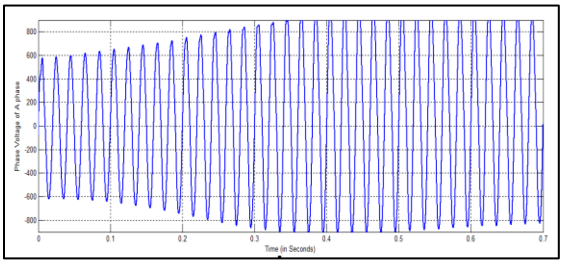


Fig. 9. *Output Phase Voltage.*

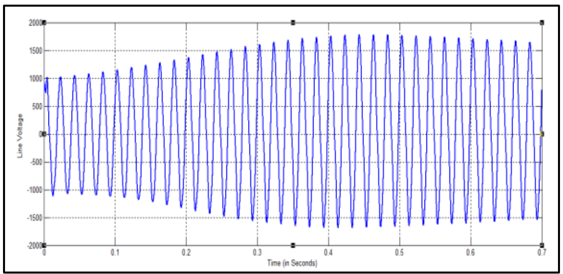


Fig. 10. *Output Line Voltage.*

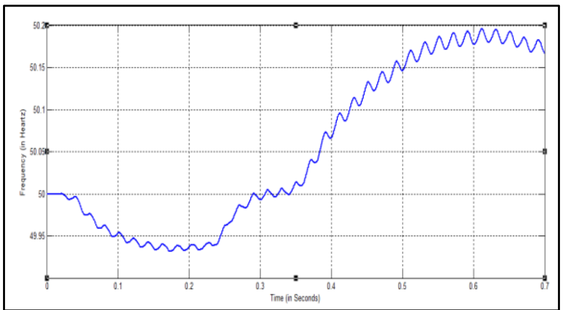


Fig. 11. *Change in Grid Frequency.*

CONCLUSION

This paper describes the configuration and operation of power electronic converter used for connection of permanent magnet generator for variable speed wind turbine. Simulation results visualize the basic operation of the power converter. The steady state analysis performed using this simulation confirms the validity of the model. The PC reenactment instrument turned out to be a significant apparatus in foreseeing the framework conduct, selecting certain segments, planning a controller, and deciding the yield era of wind turbine. The connection of power electronic converter to the grid may inject harmonic current into the grid and cause reduction in power quality. Today multilevel inverter technology has been developed and it can manage to control the power level associates with the commercial wind turbines.

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