ISSN No.: 2454- 2024 (online)

International Journal of Technical Research & Science

MODELING AND DESIGN OF MAXIMUM POWER POINT TRACKING SYSTEM CONTROL ALGORITHM FOR PMSG BASED GRID CONNECTED WIND POWER GENERATING UNIT

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Abstract: Over recent decades because of many drawbacks of conventional energy sources like higher fossil fuel prices, harmful environmental damage, shortage of sources and increasing pollution the need to use renewable sources of energy has grown over recent decade. Seeing the needs of future generations, in recent decades, non-conventional energy resources are the core center of research investigative work. Among all other non-conventional energy sources wind energy conversion system is come out to be the most cost effective and the preferred alternative for power generation. As the wind has arbitrary and unpredictable nature, it is important that few kind of control strategy has to be introduced to obtain maximum power from the generated power from PMSG. Therefore, to obtain maximum power as possible from wind during uneven wind speed or wind speed variation, tracking controller for maximum power point tracking is employed. This paper represents a system model for a grid connected 3KW PMSG wind turbine system along AC-DC-AC conversion stages. Major object is to extract the maximum energy from the wind which confirms a highest efficiency of proposed work. First, mathematical modeling of wind turbine and PMSG are illustrated in this thesis. Among numerous methods available, the most competent technique of maximum power point tracking is Perturbation and observation (P&O) that has its own qualities. Complete system modeling is carried out by MATLAB & Simulink. Proposed system simulation evaluation is performed to ensure operation of maximum power point tracking and effectively extract maximum power generated throughout the variation in wind speed. Wind speed variation, causes disturbance in system frequency and voltage that results in generation losses. So to decrease significant variation in the system frequency and voltage, a voltage & frequency controller is also used to operate with voltage source converter (VSC). The implementation of the given system is evaluated for various profile of wind speed. A grid connected permanent magnet synchronous generator based WESC is designed, modeled & simulated with MATLAB & SIMULINK.
Keywords: Maximum Power Point Tracking, MPPT Algorithm,WECS

1. INTRODUCTION

The depletion in the reserves of fossil fuels considered as traditional sources of power generation at an alarming rate coupled with the level of environmental pollution associated with them have shifted the focus towards harvesting non-conventional energy sources such as wind and solar energy for power generation. Wind energy is environment friendly and the cleanest source of energy. The foremost benefits of wind energy are wind-generated electrical energy does not cause air or soil & water pollution. Among many countries India is one which has the highest generation of power from nonconventional resources. In the power market, nonconventional power contribution is approx. 34.4% of the gross power generated. Nearly 73.36 Gigawatt of total nonconventional power capability have been put within India as on Oct. 2018 out of all nonconventional power resources that incorporate approx. 34.97 Gigawatt by wind, 24.34 Gigawatt by solar, 4.5 Gigawatt by little hydro power & 9.55 Gigawatt by bio power. In addition 46.74 Gigawatt capabilities are in progress. The authority has acknowledged the mechanical phenomenon of installing sixty Gigawatt capability of solar energy & twenty Gigawatt capability of wind power until year 2020. As on March 31, 2018 wind power capacity was 34,046 MW. India is at fifth place for overall put in renewable energy capability fourth place for wind energy and fifth place for solar energy.

Wind energy conversion systems convert the kinetic energy associated with wind velocity into electrical energy for feeding power to grid. The wind energy is captured by the blades of wind turbines whose shaft is coupled to the rotor of electric generators. The wind power rotates the blades of turbine which in turn run the electric generators this generate electrical power at the output of machine. The power output from such wind energy conversion systems depend on the wind speed and the pitch angle of the turbine blades. The wind generation systems using permanent magnet synchronous generators (PMSGs) represent a further advancement in this area. Flexible speed wind energy systems are particularly suitable to draw maximum power from wind energy & are more efficient than

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flat speed systems. Several maximum power point tracking schemes are implemented to harness total energy from wind at various wind speeds and blade pitch angle values. However, for low speed systems typically using PMSGs pitch angle control is rarely used. The power extracted from wind needs to be fed to the AC grid. Several power electronic converters are employed to achieve this goal and they considerably improve the power quality before supply power to the grid. The grid side converters (inverters) play an important role in meeting the strict voltage and frequency requirements of AC grid. Although wind power is in abundant but this changes continuously as speed of wind varies all over the whole day. Total power output of wind energy conversion system depends mainly on precision due to which maximum power point is tracked using the MPPT controller of the wind energy conversion system which doesn't depend on the type of generator used. The peak power extraction algorithm which was invented can be classified into 3 important control mechanisms: (i) Tip Speed Ratio Control (TSR) (ii) Power Signal Feedback Control (PSF) & (iii) Hill-Climb Search Control (HCS) or perturbation and observation (P&O).

2. MATERIALS AND METHODS

2.1 Wind Turbine Dynamic Model

It gives control principles & modeling of wind turbine i.e
Characteristics of wind turbine. Wind power (P_{wind}) is obtained from the wind is given as:

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

Here ρ = air density in kg/m^3

A = cross sectional area of the rotor blades in m^2

V = wind speed in m/s.

C_p= Rotor efficiency or power coefficient and it is the function of tip speed ratio (TSR) and pitch angle (θ).

Peak rotor efficiency C_p is realized at a specific value of TSR, This depends upon aerodynamic design of the turbine. To keep TSR fixed at the particular level all the time the rotor must move at high speed for high wind and at low speed for less wind. Wind turbines having high tip speed ratios are chosen for function over a large span of wind speeds.

A group of C_p – curves including pitch angle as the main consideration, achieved by computation or measurement may be presented as a nonlinear function.

The function is as follows.

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

Here θ = Pitch angle.

If coefficients $C_1 – C_5$ are properly adjusted then better simulation results are obtained for given turbine.

Purpose of PMSG to transform the mechanical power of turbine into electrical power, it is more preferred for this purpose, because of its more favorable properties such as absence of gearbox, high power density, small size, reduced weight and external excitation.

This dynamic model considers a back e.m.f. of sinusoidal nature, no saturation, and minor iron losses. It assumes the iron (hysteresis & eddy current) losses and the dynamic equations of permanent magnet synchronous generator (PMSG) currents are:

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

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

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

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

$$i_{cd} = i_d - i_{md},$$

$$i_{cq} = i_q - i_{mq},$$

here i_q& i_d, are d_q axes currents, V_q &V_d, 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 axis inductances, If$\Psi_{pm}$is the mutual flux of magnets, ω is the

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ISSN No.: 2454- 2024 (online)

International Journal of Technical Research & Science

fundamental frequency of the stator currents, R_c is resistance of the iron losses &$R_{st}$is the resistance of stator.
The electromagnetic torque equation of permanent magnet synchronous generator is:

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

here p = number of pole pairs

3. MPPT FOR WIND ENERGY CONVERSION SYSTEM

The MPPT technique is implemented to obtain the maximum power from the available wind speed. MPPT is implemented into the system to track the voltage operating close to the maximum power during varying condition. MPPT is also used for maintaining the stable voltage through operation thus making it grid capable.

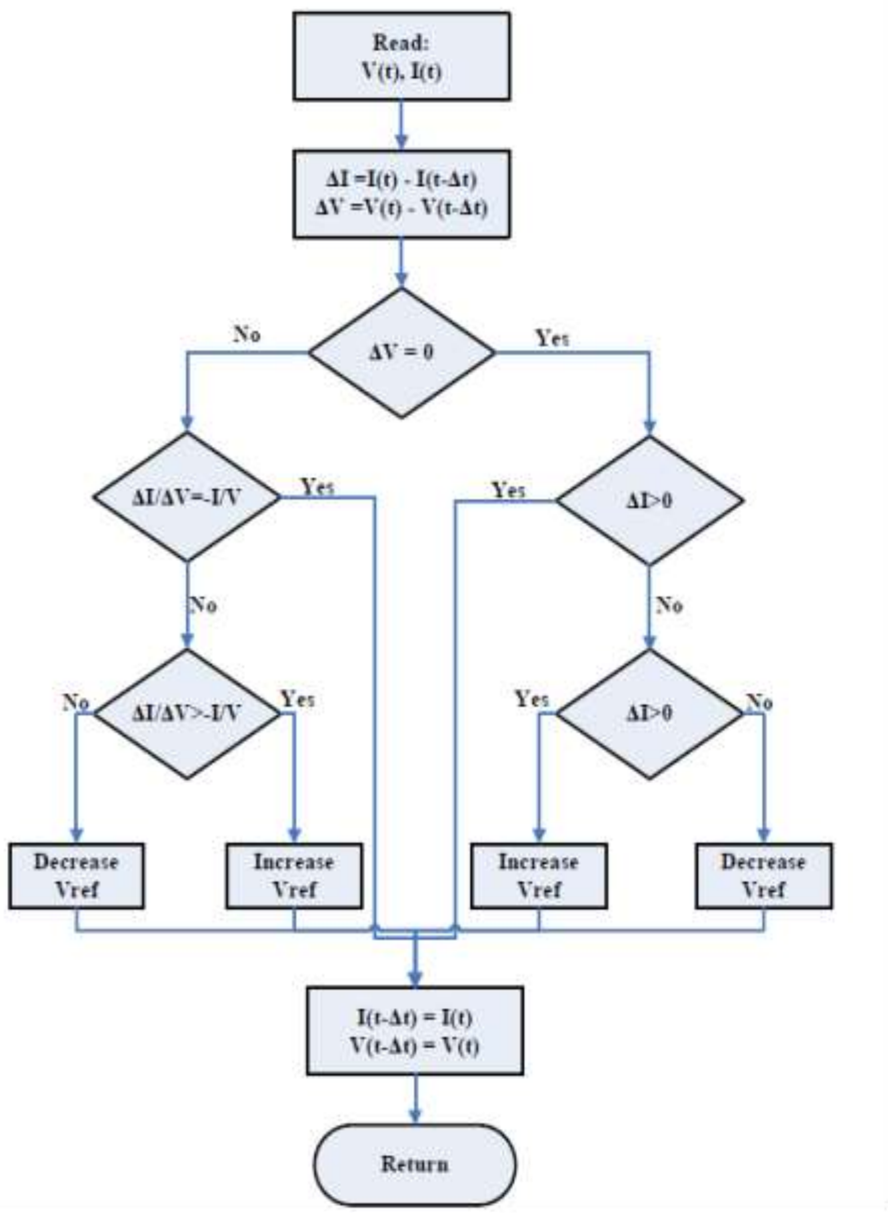

Fig. 3.1Flowchart of MPPT Algorithm

P&O method is most common MPPT algorithm which is used extensively in small WECS. It periodically monitors and compare the output power or voltage of the system to the previous value and thus perform the perturb operation. If the difference between observed value and the previous value is positive, then the perturbation is performed in positive direction. If the variation tends to negative then the perturbation is reversed as shown in Fig. 3.1 This process is continued until the maximum power is achieved. The oscillation in the system depends on the size of the perturbation. In this paper, variable step method is used to search the MPP where the step length is adjusted

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according to the distance to the MPP. The duty cycle of P&O is generated through voltage and power relationship of wind system. The main drawback of the P&O algorithm is tradeoff between the oscillation and the response around the MPP during non-linear condition. P&O fails to track the MPP when there is large and rapid variation in wind speed. Figure 1.1 shows the MPPT control scheme for controlling the output voltage level by adjusting the duty ratio of the boost converter.

4. GRID SYNCHRONIZATION OF THREE-PHASE INVERTER

To connect grid &power plant the output inverter voltage should be of same frequency as of utility grid this is achieved by current controller with PLL. Fig. 4.1 shows inverter with current control controller for grid synchronization. This is achieved by the conversion of 3-phase current &voltage into rotating reference frame (dq0) by using Park's transformation, then again convert them into three-phase reference quantities. We used Park's transformation to converter abc components into three constant DC quantities as direct, quadrature and zero component. These constant DC quantities can be easily controlled by PI regulator. By using below equation abc to dq0 transformation is done.

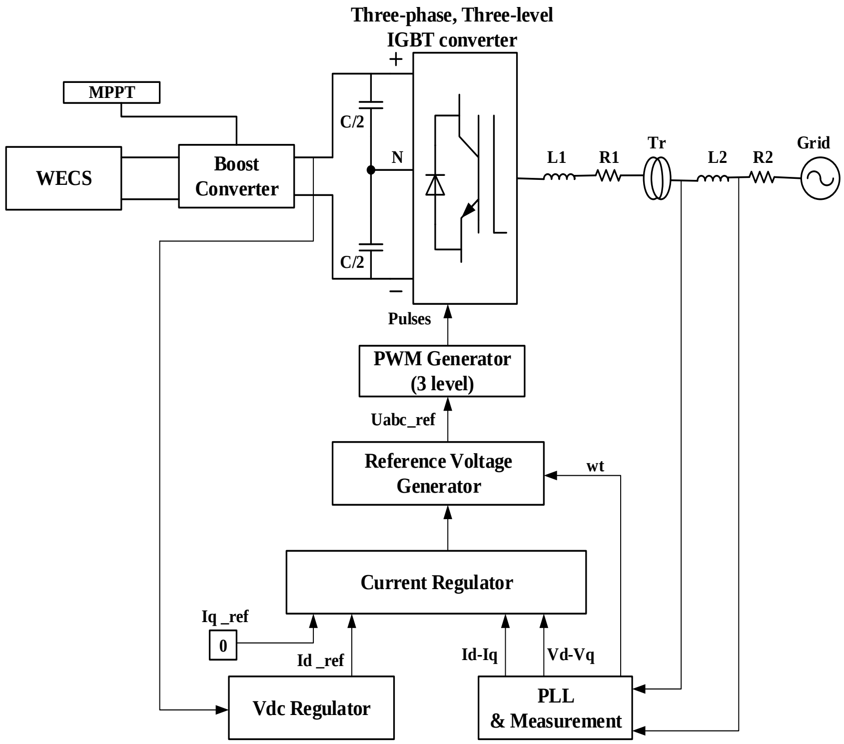

Fig. 4.1 Grid Synchronization of Three-Phase Inverter

$$\begin{bmatrix} U_d \\ U_q \\ U_0 \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos wt & \cos(wt - {}^{2\pi}/_{3}) & \cos(wt - {}^{2\pi}/_{3}) \\ -\sin wt & -\sin(wt - {}^{2\pi}/_{3}) & -\sin(wt - {}^{2\pi}/_{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} U_a \\ U_b \\ U_c \end{bmatrix}$$

Grid voltage and current are uncontrolled quantities, most feasible approach of controlling the operation is by Iq and Id control. Figure shows controller used for voltage and current of inverter.

$$e_d = I_{d\_ref} - I_d$$

Similarly the output of another controller is

$$e_q = I_{q\_ref} - I_q$$

Both error signal e_d and e_q are processed by PI regulator. Constant of PI regulator are chosen such as

$$K_p = {}^{L}/_{\tau_i}$$
$$K_i = {}^{R}/_{\tau_i}$$

Here, L and R represent the inductance and capacitance of distribution system. τ_i is time constant of current control loop. PLL is a feedback system with PI regulator used to track phase angle of utility grid

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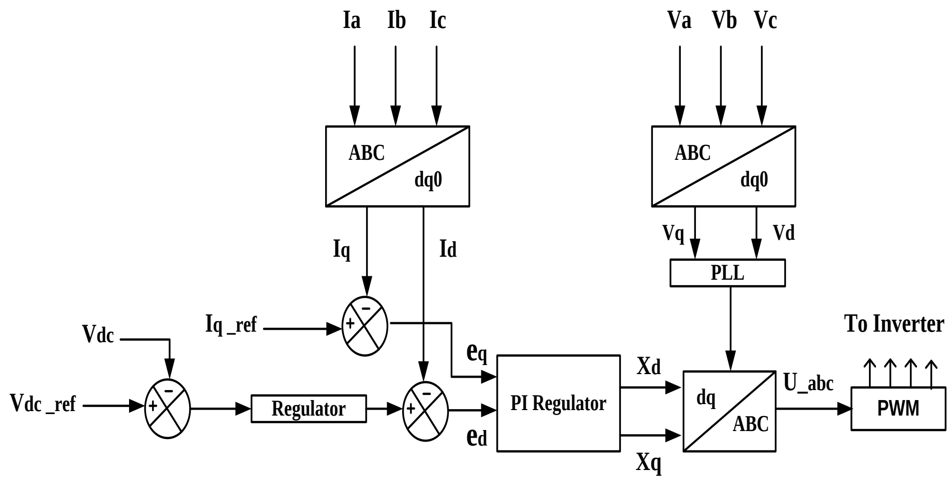

Fig. 4.2 Current Controller of Inverter with PLL

5. UTILITY GRID

Electric grids are the backbone of social and economic development. It takes power generated by various generating station (both conventional and renewable) transmits it over a certain distance and distribute it among end users. In the modeling of 50-kW grid connected solar system we are using 25-kV distribution feeder. Fig. 5.1 shows major components of utility grid:

- It consists of two generating units one is 50 kW solar systems and another is 120-kV generating system.
- Coupling transformers are used for step up and down the generating voltage as per the requirement. Two transformer are used:47-MVA, 120-kV/25-kV to connect 120-kV generating station to 25-kV line.
- Grounding transformer is used to provide low impedance ground path for fault current. As we can see from figure, there is no KVA ratting, because grounding transformer doesn't work as power source.
- 15-km transmission line.
- 2-MW resistive load and 30-MW, 2-Mvar inductive load

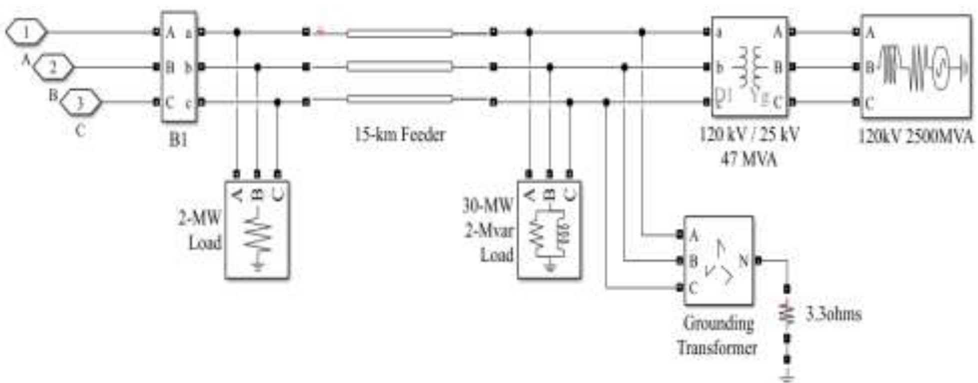

Fig. 5.1 Simulink Model of Utility Grid

System modeling is developed together with wind energy conversion system modeling, Converter circuits as dc to ac, dc to dc & ac to dc converters, MPPT with WECS. The chapter represents active model of WECS, averaged model of boost converter &state space model of PWM DC/AC converter.

6. RESULTS &DISCUSSIONS

6.1 PMSG Based WECS Simulation without MPPT

The MATLAB & Simulink model block of wind turbine model is illustrated in Fig. 5.1 & 6.1 illustrate complete model for PMSG based WECS. During the wind model simulation, the wind speed as the wind turbine input was set to different wind speed at 12m/s, 11m/sec, 10m/sec, 9m/sec, 8m/sec, 7m/sec, 6m/sec and 5m/sec.

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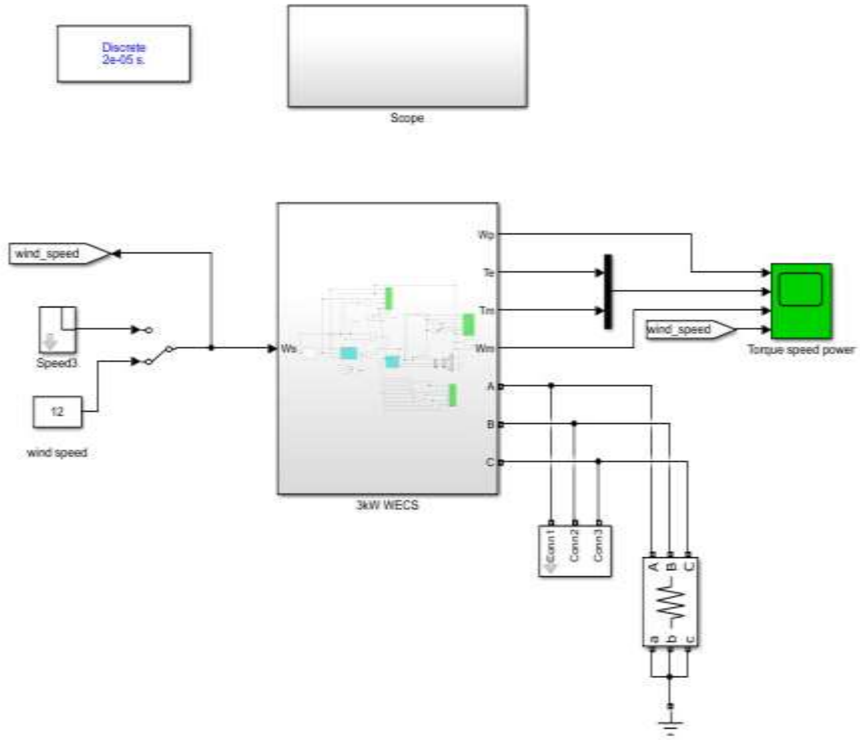

Fig. 6.1 Wind Turbine Model Block

The output power, output voltage, output current, output speed, input wind speed, electromagnetic torque, mechanical torque, quadrature and direct axis component of voltage and quadrature and direct axis component of current without using MPPT at speed 12m/s, 10m/s, 8m/s and 6m/s respectively are given in the below figures.

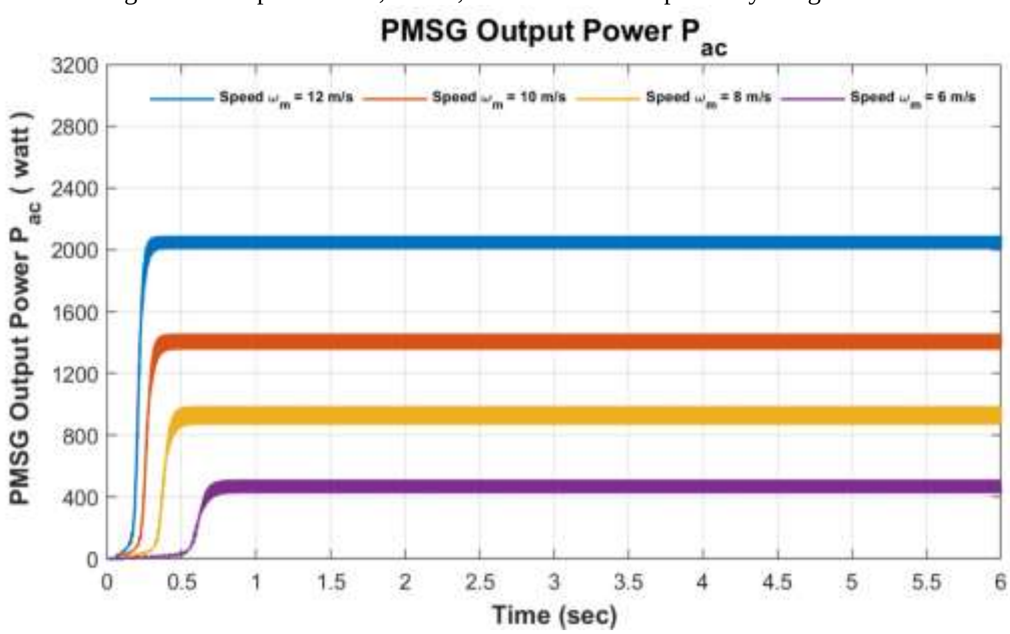

Fig. 6.2 Power Output Without Employing MPPT at 12m/s, 10m/s, 8m/s and 6m/s

Case-1:Mechanical torque without employing MPPT at 12m/s, 10m/s, 8m/s and 6m/s

Fig. 6.3 shows the various parameter output waveform when system runs at a constant input wind speed of 12m/s. Fig. 6.3 (a) shows the power output, Fig. 6.3 (b) shows the PMSG output phase to phase voltages, Fig. 6.3 (c) shows the PMSG stator current, Fig. 6.3 (d) shows the PMSG speed ω_m, Fig. 6.3 (e) shows the input speed ω_s, Fig. 6.3 (f) shows the PMSG electromagnetic torque T_e and mechanical torque T_m, Fig. 6.3 (g) shows the PMSG d-q component of voltage V_d and V_q, Fig. 6.3 (h) shows the PMSG d-q component of current I_d and I_q.

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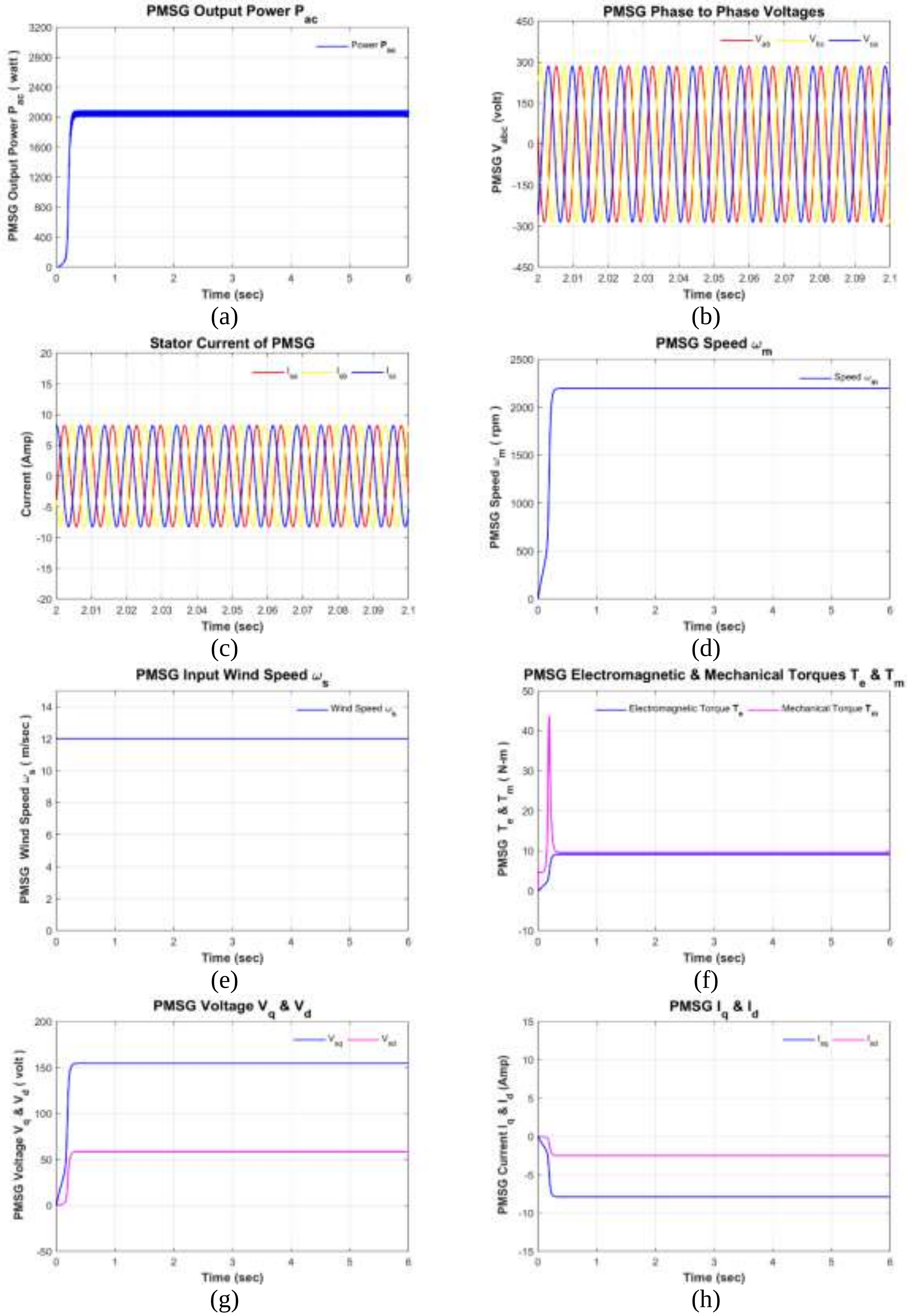

Fig. 6.3 Simulation Results at Wind Speed 12m/s Without MPPT (a) Output Power (b) Output Voltage (c) Output Current (d) Output Speed (e) Input Wind Speed (f) Electromagnetic and Mechanical Torque (g) d-q Component of Voltage (h) d-q Component of Current

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When developed system runs at input speed of 12m/s as shown in Fig. 6.3 power output is 2073 watt rms phase to phase voltage is 186 volt and current is 5.85 amp generator speed is 2195 rpm.

Case-2: When System is simulated at Varying Wind Speed of 8 to 10, 10 to 12 and 12 to 8 m/s

To evaluate the robustness of the designed maximum power point tracking technique an input wind signal is made using the signal builder block. This block represents the varying wind speed from 8 to 10, 10 to 12 and 12 to 8m/s.

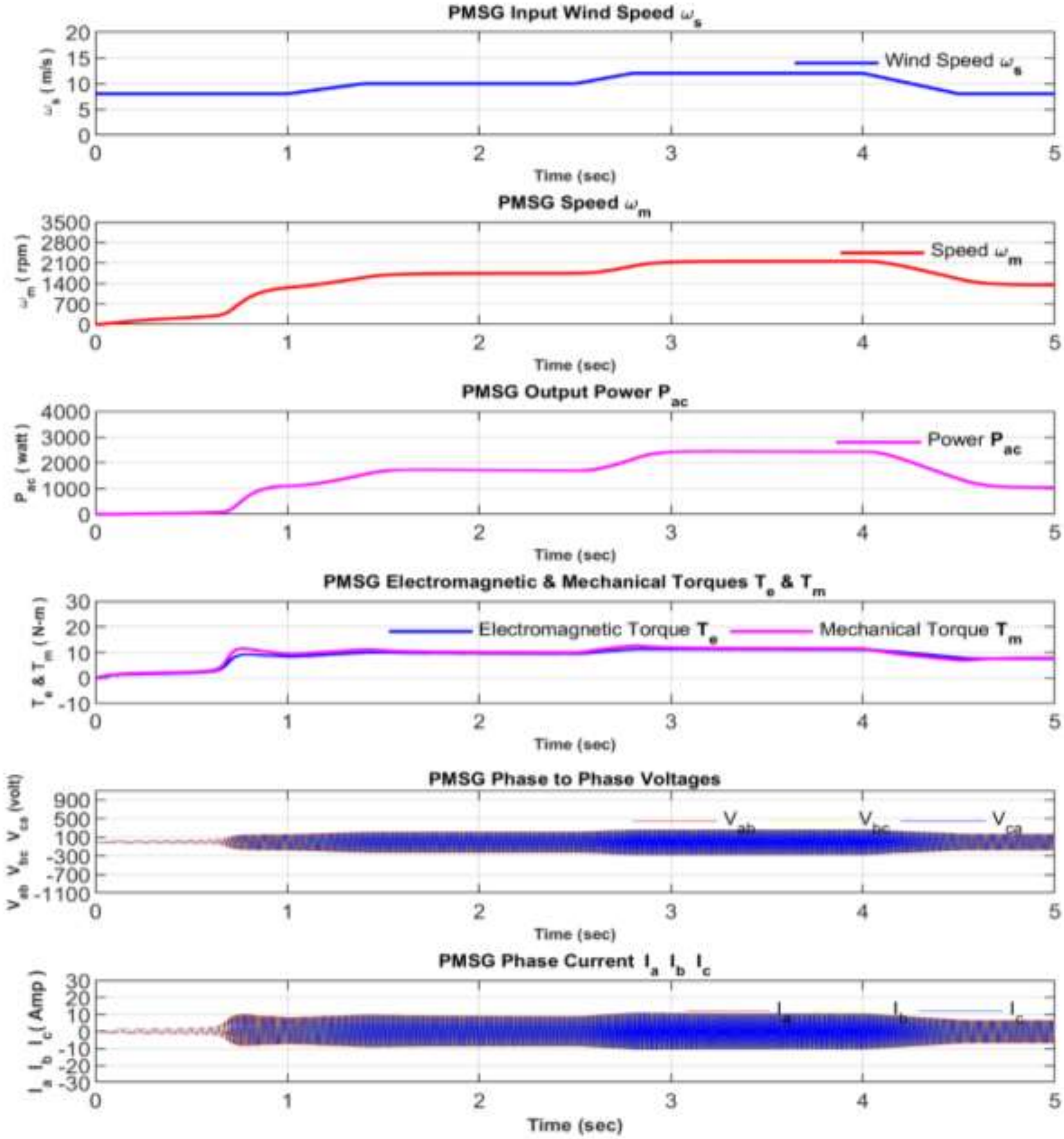

Fig. 6.4 Simulation Results at Input Wind Speed Varying 8 to 10, 10 to 12, 12 to 8 m/s with MPPT, Waveform of Input Wind Speed ω_s, PMSG Speed ω_m, PMSG Output Power P_{ac}, Electromagnetic & Mechanical torque T_e&T_m, PMSG phase to phase voltages $V_{ab}V_{bc}V_{ca}$, PMSG phase current $I_aI_bI_c$

Fig. 6.4 shows the simulation results at PMSG system. This figure demonstrate the combined plot of the input wind speed ω_s, PMSG speed ω_m, PMSG output power P_{ac}, Electromagnetic & mechanical torque T_e&T_m, PMSG phase to phase voltages $V_{ab}V_{bc}V_{ca}$, PMSG phase current $I_aI_bI_c$. As seen from the waveform PMSG with MPPT system gives better dynamic performance with wind speed change compared to without MPPT. Torque response is also improved. Fig. 6.4 (a) shows the zoomed waveform of PMSG phase to phase voltages$V_{ab}V_{bc}V_{ca}$, Fig.6.4 (b) shows the zoomed waveform PMSG phase current$I_aI_bI_c$.

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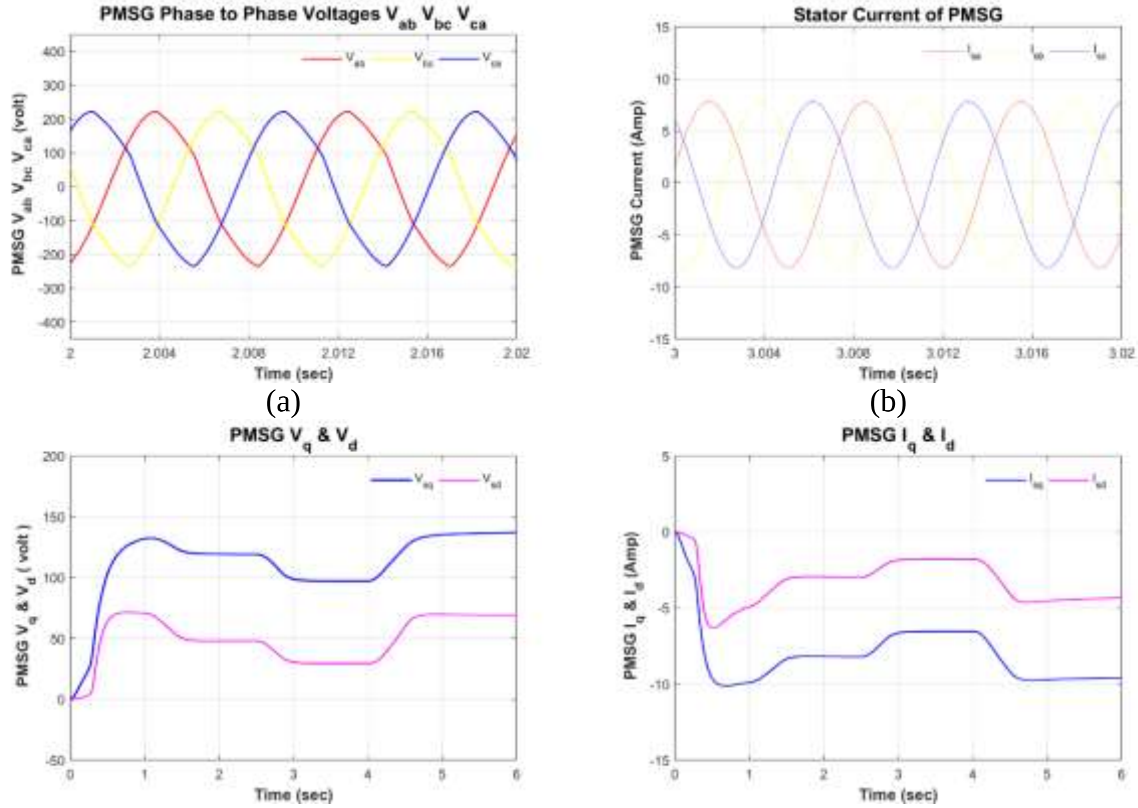
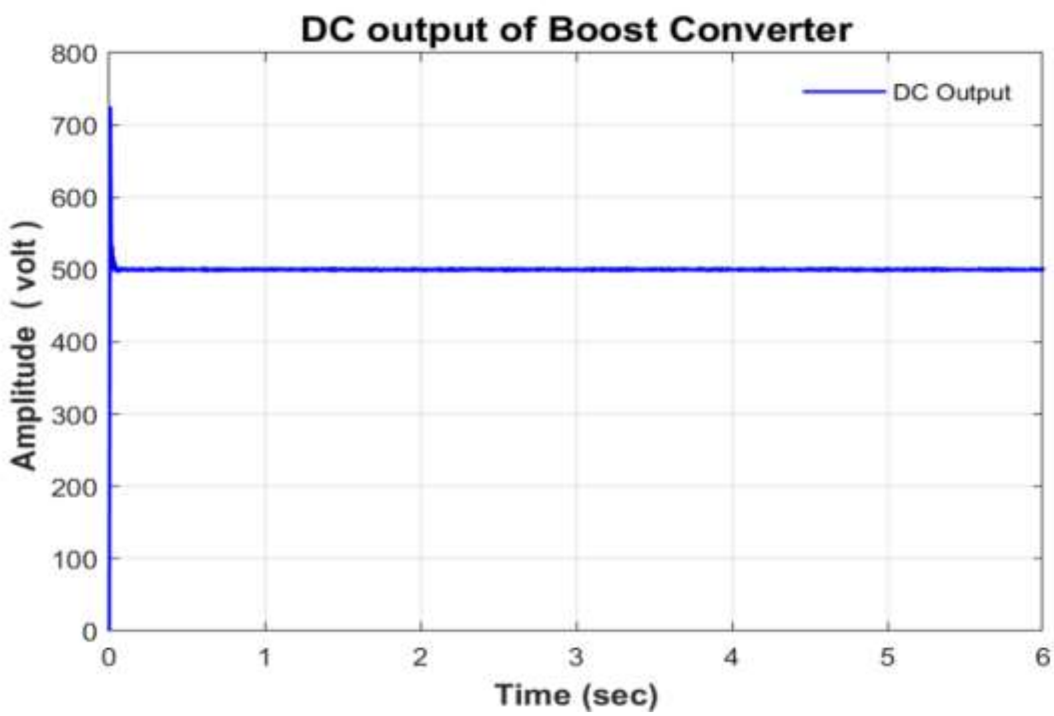


(a) (b)

(c) (d)

Fig. 6.5 Simulation Results at Input Wind Speed Varying 8 to 10, 10 to 12, 12 to 8 m/s with MPPT, (a) Zoomed PMSG Phase to Phase Voltages $V_{ab}V_{bc}V_{ca}$ (b) Zoomed PMSG Phase Current $I_aI_bI_c$(c) d-q Component of Voltage V_qV_d (d) d-q Component of Current I_qI_d

Fig.6.5 (c) shows the waveform of PMSG d-q component of voltage V_qV_d, Fig. 6.5 (d) shows the waveform of PMSG d-q component of current I_qI_d.



(a)

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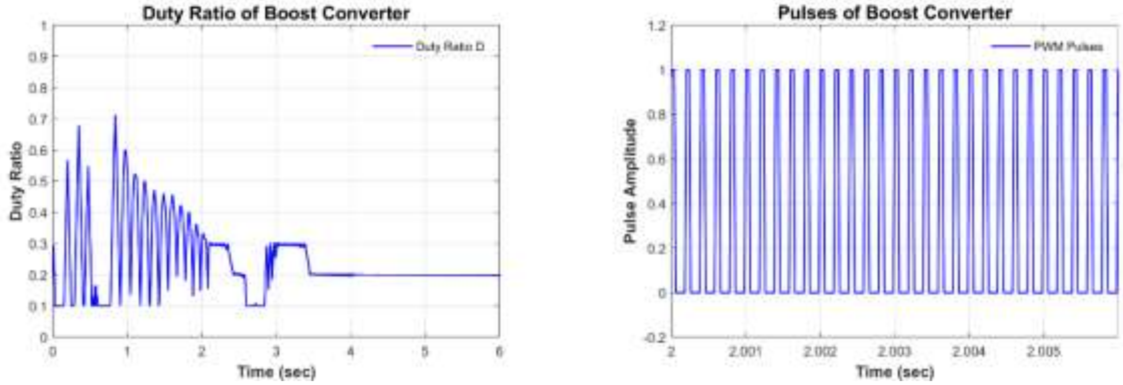

(b) (c)

Fig. 6.6 Simulation Results of DC DC Converter at Input Wind Speed Varying 8 to 10, 10 to 12, 12 to 8 m/s with MPPT (a) DC Output Voltage (b) Duty Ratio Change (c) Pulses for DC DC Converter Switch

Fig. 6.6 (a) shows the output DC voltage of DC DC converter which is maintaned at 500V. Fig. 6.6 (b) shows the change in duty ratio and Fig. 6.6 (c) shows the the generated PWM pulses for the switch. As the duty change, pulse width change accordingly. In this simulation 5kHz PWM is generated. Duty ratio value is updated at every 2msec.
DC output from the DC DC converter is fed to dc link capacitors whose main purpose is to maintain the DC voltage at the input of the inverter. Fig. 6.7 (a) illustrates the inverter phase to phase voltages $V_{ab}V_{bc}V_{ca}$, Fig. 6.7 (b) illustrates the inverter phase current $I_aI_bI_c$, Fig. 6.7 (c) illustrates the inverter phase to phase voltage V_{ab}, Fig. 6.7 (d) illustrates the duty ration of inverter.

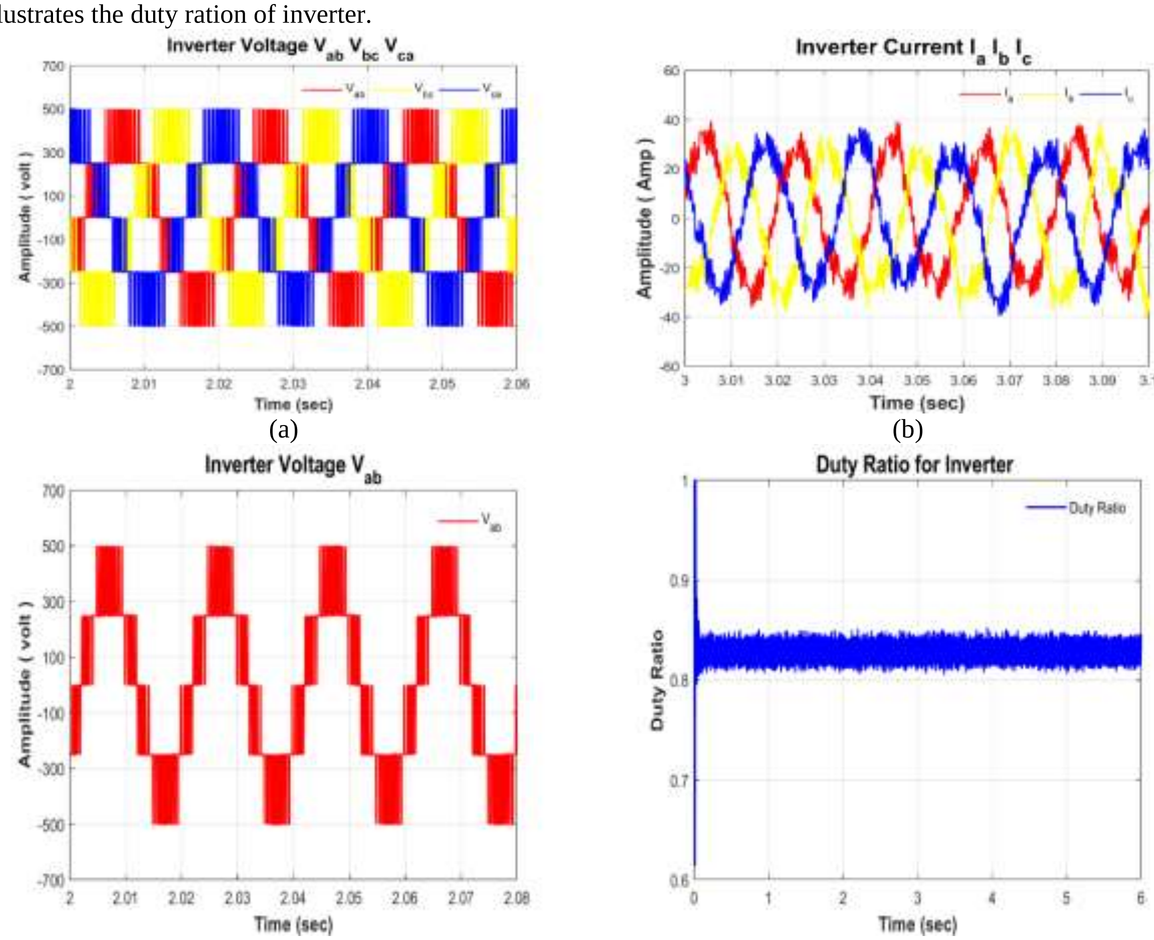

Fig. 6.7 Simulation results of multilevel inverter at input wind speed varying 8 to 10, 10 to 12, 12 to 8 m/s with MPPT (a) Inverter phase to phase voltages $V_{ab}V_{bc}V_{ca}$ (b) Inverter phase current $I_aI_bI_c$ (c) Inverter phase to phase voltage V_{ab} (d) Duty ration of inverter.

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Table-6.1 Comparision Study

Input wind speed (m/s)	Power (watt)		Voltage RMS (volt)		Current RMS (Amp)	
	Without MPPT	With MPPT	Without MPPT	With MPPT	Without MPPT	With MPPT
12	2073	2510	186	196	5.85	7.9
10	1400	1680	168	174	4.8	6.2
8	920	1033	130	138	4.15	4.8

CONCLUSION

The object of given work is to introduce maximum power point tracking algorithm for wind energy system & simulate the structure which associate the PMSG based wind model & grid connected structure using AC-DC-AC conversion. Modeling & simulation of WECS using PMSG was performed by Matlab and Simulink. The overall scheme with & without MPPT were tested with variable speed of wind. According to the simulations outcome& the response investigation carried out following points can be concluded:

- The given algorithm was examined for various wind situations together with stable wind speed, rapidly changing wind speed, and arbitrarily changing wind speed. In all the schemes, the power withdrawal by the turbine was at the maximum point on the wind curves for the turbine. The improved efficiency & minimum ripple in power are the major achievements of proposed MPPT.
- In proposed MPPT technique dc link current &voltage are used as inputs. Duty ratio for boost converter is controlled by calculating the ratio of current & voltage and by evaluating the variation in sign. This method is simple in terms of implementation as there is no requirement for wind speed measurements or system characteristics.

FUTURE SCOPE

With reference to literature survey and proposed scope of this work, following fields can be additionally worked to design a well-organized and almost executable wind system:

- Further to test the execution of the proposed control algorithm, an experimental study must be done in upcoming research projects.
- Hydropower, biomass, geothermal energy, and other nonconventional sources have to be studied; few of them are efficiently feasible for installation in remote communities for Hybrid system.
- To study the execution of PMSG based system with artificial intelligence technique for WECS to take out highest power from the complete system.
- Experiments could observe the algorithms for working the hybrid system along with the aim of optimizing the schemeby each environmentally &economically.

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