Maximum Power Point Tracking Methods for Wind and Solar Conversion Systems for Standalone Generation PSIM based Perturb and Observe Method

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Abstract:- Among all the renewable resources, wind and solar are the most popular resources due to its ease of availability and its ease conversion into electricity. Each renewable resource uses DC/DC boost converter separately with MPPT control to generate power. To increase the efficiency of photovoltaic (PV) system and wind energy system, the maximum power point tracking (MPPT) technology is employed. Perturb and Observe MPPT technique is used for PV system in which dc voltage is used as perturbation variable. While in wind energy system, perturbation variable as a dc current is used in modified perturb and observe MPPT algorithm. Modified perturb and observe algorithm is stable and tracks fast for sudden wind speed change conditions. Maximum Power Point Tracking (MPPT) technique used with boost converter extracts maximum power from the source when it is available. Simulation of both the renewable energy sources is carried out separately in PSIM 9.0 with different MPPT types of techniques.

Keywords:- MPPT, Wind energy conversion system, Solar energy conversion system, Boost Converter, Simulation.

I. INTRODUCTION

Sources like coal, thermal are non-renewable type sources which are used to generate electricity but it leads to global warming and other environmental issues. Thus to meet the energy demand requirements renewable energy sources can also be used to generate electricity. Though these sources are intermittent in nature, but once it is installed and maintained properly its lifespan increases. Renewable sources like wind, solar, hydro have the substantial capabilities to compensate for the increasing energy demands.[1]

There are several MPPT technique types for PV and wind energy system. MPPT techniques for PV system like constant-voltage tracing, advanced intelligent, incremental conductance (INC) and perturbation and observation (P&O). The constant-voltage method tracks MPP rapidly but its accuracy is poor. P&O method has been widely used due to its simplicity and easy implementation, but its convergence is too slow. The INC technique improves the tracking accuracy but its tracking speed is also very slow [7]. MPPT techniques for wind energy system like TSR (tip speed ratio), perturb and observe (P&O) control, and optimum-relation-based (ORB) control. TSR algorithm relies on the accuracy of the wind speed measurement to maintain optimal tip speed ratio and ORB technique prior knowledge of accurate system parameters are required that can vary from one system to another. Since these MPP requires accurately knowing these parameters, continuous monitoring is needed to increase its efficiency. P&O algorithms has system variables as control inputs for the MPPT like the dc-link voltage and the duty cycle which reduces system cost and increases reliability by removing the need for shaft speed sensing [6].

In this paper, simulation of solar energy system and wind energy system with MPPT technique is done separately. MPPT technique is employed with DC/DC converter to turn on/off the controlled switch of the boost converter. Simulation is carried out in PSIM 9.0. MPPT algorithm used for the PV system is perturb and observe algorithm which is adopted from PSIM renewable examples while MPPT algorithm for wind energy system was programmed in visual C++ from the proposed modified perturb and observe algorithm in [6]. Results are compared by changing input conditions of sources like for PV system- irradiance and for wind system- wind speed, and output is observed. With different input conditions, power generated from these sources must be equal to power delivered to the load which is shown in simulation results.

II. MODELLING OF SOLAR ENERGY SYSTEM

Solar energy is a renewable energy resource which can be converted into the electrical power using PV cells. There are two factors-radiations and temperature which can affect the output of PV panels. If irradiance increases then current increases but variation in voltage is very less. If temperature increases, open circuit voltage decreases while if intensity of solar radiation increases, short circuit current increases. Thus I-V and P-V curve changes with change in temperature and irradiance, which also changes maximum power point.

The power output from a solar photovoltaic system mainly depends on the nature of the connected load because of non-linear I-V characteristics [8]. The schematic diagram of solar system to which MPPT technique will be applied is shown in Fig.1. When PV panel is directly connected to the varying load its voltage keeps on fluctuating and thus voltage and current must be tracked continuously to achieve maximum power using MPPT technique. MPPT technique is used with boost converter to track maximum power and by extracting maximum power from the PV array using MPPT technique efficiency of the system can be increased.

III. MODELING OF WIND ENERGY SYSTEM

Electric generator is used with wind turbine which converts mechanical energy into the electrical energy. Electrical energy production mainly depends on the availability of wind. With variation in wind speed, electric energy production can be increased or decreased. So selection of area for wind energy system installation is important.

The mechanical power that is generated by the wind is given by:

$$P = 0.5 \times \rho \times A \times C_p(\lambda, \beta) \times v_w^3 \qquad (1)$$

Where P= Power
ρ=Air density
A=Area perpendicular to the flow of wind
v_w^3 =Wind velocity
$C_p(\lambda,\beta)$ = Power Coefficient
λ = tip speed ratio;
β = blade pitch angle.
The tip speed ratio λ is defined as

$$\lambda = \frac{R\Omega}{v_W} \qquad (2)$$

The maximum value of C_p is 0.48 at β = 0 and λ = 0.16. So we cannot convert all the wind energy into

electrical energy; we can only convert 48%, according to Betz limit.

The schematic of the wind energy system to which the MPPT applied is shown in Fig.2. Generator used is of permanent magnet synchronous generator type which is directly coupled to turbine due to its advantages like no need of gear box, small size, very less maintenance cost, no requirement of excitation current[6]. Instead of using three-phase controlled rectifier, diode bridge rectifier is used which converts the AC to a DC by rectifying voltage at constant level using boost converter.

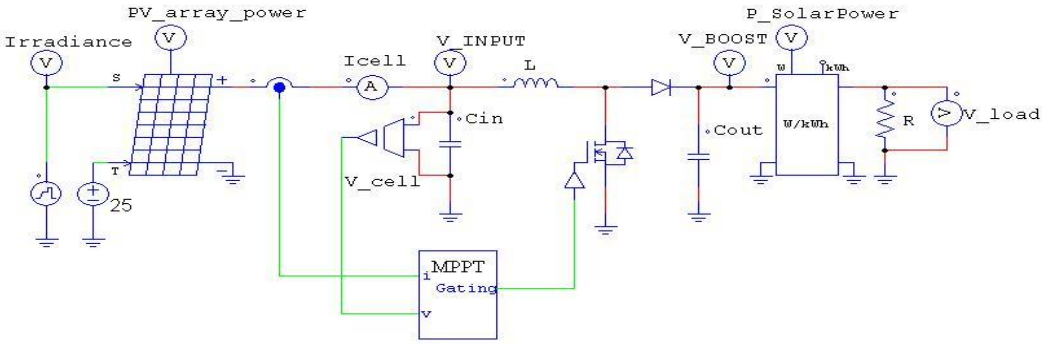

Fig.1: Solar energy system

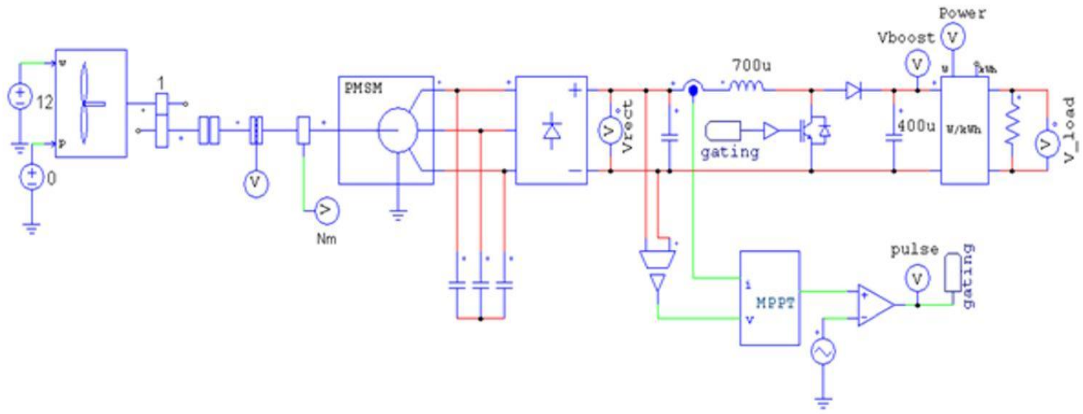

Fig. 2: Wind energy system

IV. MPPT CONTROLLER

A. Perturb and Observe algorithm for solar energy system

The Perturb & Observe MPPT (maximum power point tracking) algorithm is shown in Fig. 3. There exists different MPP for different condition of temperature and irradiation which is tracked by MPPT technique and can be delivered to load. The P&O MPPT technique algorithm calculates the power P(t) by measuring the instant voltage V(t) and current I(t) and then compares it with last calculated power P(t-1). The algorithm continuously perturbs the system if the operating point variation is positive; otherwise the direction of perturbation is changed if the operating point variation is positive. [8] The duty cycle of the DC/DC converter is varied till it reaches the maximum power point. [5] With higher step size of perturbation, system may oscillate around MPP which results into wastage of energy.

Perturb and Observe MPPT technique which is adopted from PSIM software is shown in Fig. 4. Voltage V_cell and current I_cell are measured from solar array to calculate power, P_O . Block dv/dt compares

the present value of power with previous value. If increment in power is positive then perturbation variable voltage is incremented by predefined step size. Output voltage of solar panel is compared with this varied voltage value and steady state error obtained is eliminated by PI controller. To avoid over saturation, a limiter should be placed at the output of PI controller which is compared with carrier wave to generate pulse for controlled switch IGBT of DC/DC boost converter.

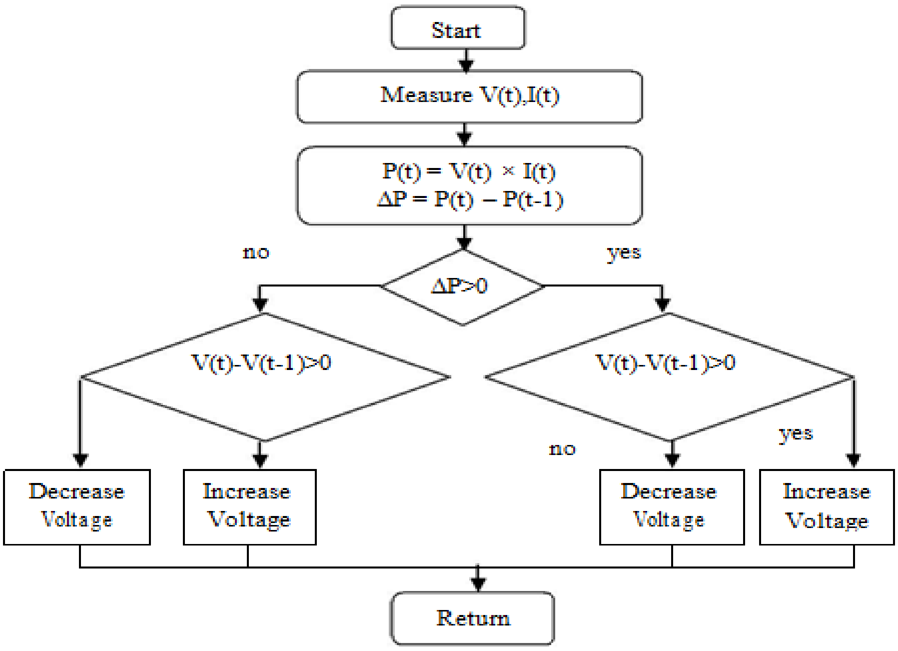

Fig. 3: Flowchart of P&O MPPT Technique [8]

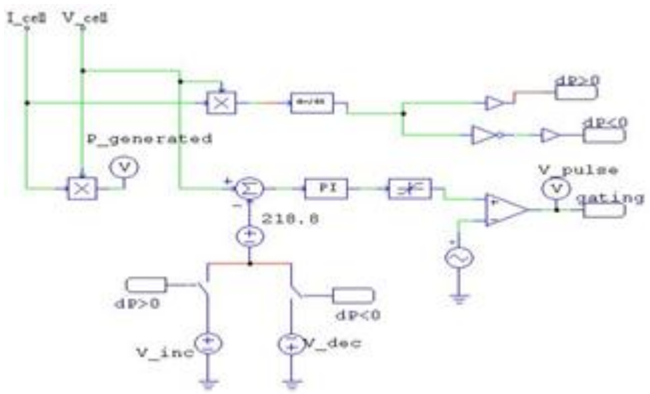

Fig. 4: P&O MPPT technique in PSIM

B. Modified Perturb and Observe algorithm for wind energy system

The flowchart for the proposed algorithm is shown in Fig. 5. The wind speed change detection through the dc-link voltage slope described earlier will be used to differentiate between the two modes. First, the system variables are initialized and samples from the dc-link voltage and the inductor current are taken. The samples of the voltage and current (and hence the power) are taken at a rate that depends on the system response time.

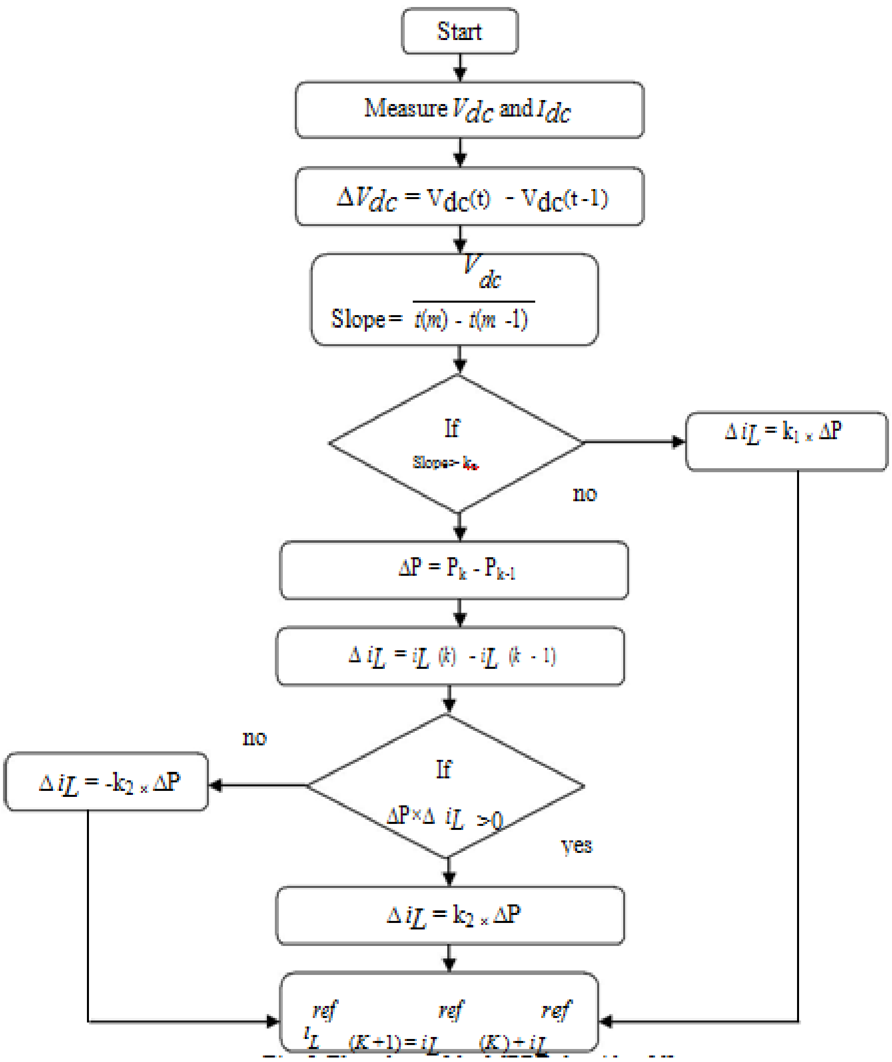

Fig. 5: Flowchart of the MPPT algorithm [6]

When the MPPT algorithm decides to increase the current command the system decelerates and reaches a new operating point. The rectified dc-link voltage will change according to the change of the speed [6]. Slope variation of the dc-link voltage is continuously monitored to adjust the current as it varies with change in wind speed. A very steep slope will be observed, if there is sudden change in the wind speed algorithm will go into prediction mode with generation of interrupt during which dc-link voltage slope will be higher than threshold value k_o and change in current Δi_L^{ref} =k_2 × slope is introduced to compensate change in wind velocity; where Δi_L^{ref} is the reference inductor current step and slope will determine the increment or decrement in the inductor current, k_2 is determined based on the system characteristics by tuning its value.

When the slope of the dc-link voltage is less than threshold value k_o, the normal P&O technique is employed. In normal mode value of power at present state is compared with the previous value which is expresses as follow: $\Delta P = P_k - P_{k-1}$, then the reference inductor current of the current cycle is compared with the previous one $\Delta i_L = i_L(K) - i_L(K-1)$.To proceed further in algorithm comparison of $P \times \Delta i_L$ is done. When $P \times \Delta i_L$ is greater than zero current is increased by step size $\Delta i_L = k_1 \times \Delta P$ and when less than zero it is decreased by step size $\Delta i_L = -k_1 \times \Delta P$. In the implementation, value of k_2=0.05 is selected such that resulting step size avoids the stalling. The desired value of the scaling factor k_1 will not be the same for different wind speed range. [6]

After running the algorithm from normal P&O or prediction mode, inductor current changes by $\Delta i_L^{ref}(K+1) = \Delta i_L^{ref}(K) + \Delta i_L^{ref}$. Thus the MPPT algorithm will run in normal prediction mode in normal wind speed and it will run in prediction mode in sudden wind speed change.

V. SIMULATION RESULTS FOR SOLAR ENERGY SYSTEM

MPPT control of PV array with boost converter is modelled using PSIM software. Four Solar modules of Sun Power E19 of 320 W are connected in series, and a combined block is formed. Such type of two solar arrays are formed and connected in parallel. When panels are connected in series voltage increases and when panels are connected in parallel current increases. Parameters of PV array are shown in Table I.

A. Simulation of Boost Converter

The simulation of boost converter with P&O MPPT control of solar array as input is taken and the input and output waveforms for voltage obtained are shown in Fig. 6. Parameters of boost converter are shown in Table I. The first step is to determine the duty cycle, D which is as follow [4]:

Maximum Duty Cycle: $$D = 1 - \frac{V_{out} \times \eta}{V_{in}} \quad (3)$$

Where, V_{in} = minimum input voltage, V_{out} = output voltage, η = efficiency of the converter

Inductor Selection: By selecting appropriate value of inductor current, current ripple can be reduced.[4]

$$L = \frac{V_{in} \times (V_{out} - V_{in})}{I_L \times f_S \times V_{out}} \quad (4)$$

Where, V_{in} = Input voltage, V_{out} = required output voltage, f_S = switching frequency, ΔI_L = inductor ripple current = (0.2 to 0.4) × $I_{out(max)} \times \frac{V_{out}}{V_{in}}$

Capacitor Selection: Equations can be used to adjust the output capacitor values for a desired output voltage ripple[4]:

$$C_{out(min)} = \frac{I_{out(max)} \times D}{f_S \times V_{out}} \quad (5)$$

Where, $C_{out(min)}$ = output capacitance. From (3)-(5), D =43.9% , L = 2.92 mH with switching frequency 5 kHz and C_{out} = 10 μF is obtained .

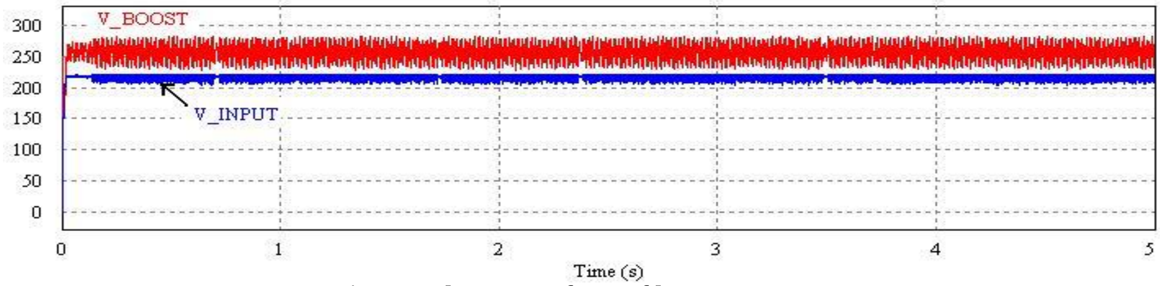

Fig. 6: Voltage waveform of boost converter

Table I: Parameters of Solar System

Parameters of solar array		**Parameters of Boost Converter**	
Parameters	**Value**	**Parameters**	**Value**
Number of cells N_S	384	Input Voltage, V_{in}	218.8 V
Maximum power P_{max}	2560 W	Output Voltage, V_{out}	260 V
Voltage at P_{max}	218.8 V	Output Capacitor, C_{out}	10 µF
Current at P_{max}	11.72 A	Inductor L	2.92 mH
Open-circuit voltage V_{oc}	259.2 V	Switching Frequency f_S	5 kHz
Short-circuit current I_{sc}	12.48 A		
Temperature coefficient of V_{OC}	0.38 %/^{0}C		
Temperature coefficient of I_{SC}	0.65 %/^{0}C		

B. MPPT tracking for different values of resistance

MPPT technique which tracks the power generated from solar panel for different resistance is shown in Fig. 7. For R=20 ohm, MPPT technique works efficiently as shown in results but for R=10 ohm MPPT tracking is inaccurate. Thus minimum value of resistance should be 20 ohm to track maximum power. For higher values of resistance i.e. more than 20 ohm MPPT tracking works efficiently. Power flowing through load with different resistance values is shown in Table II. As resistance increases power varies by small amount nearly 5-10%.

C. Effect of Variation of Solar Irradiance

The irradiation changes at fixed interval of time keeping load resistance constant at 30 Ω and the ambient temperature constant at 25 ^{0}C. The following results are shown with varying irradiation levels in Fig. 8. With decrease in solar radiation, but with constant load power generated by solar panel also decreases. So MPPT technique transfers maximum power generated by solar panel to the load. With constant resistance and decrease in irradiance, output quantities like Current, Voltage, and Power decreases. It can be seen from the simulation results that the maximum power produced by solar panel is transferred to the load with change in irradiance or load using MPPT technique perturb and observe.

Table II: Variation in output Power with Resistance

Sr. No.	**Resistor (in Ω)**	**Power (in Watt)**	**Sr. No.**	**Resistor (in Ω)**	**Power (in Watt)**
1	10	1261.8 W	5	50	2232.6 W
2	20	2246.5 W	6	60	2231.2 W
3	30	2246.7 W	7	70	2228.9 W
4	40	2239.03 W	8	80	2227.6 W

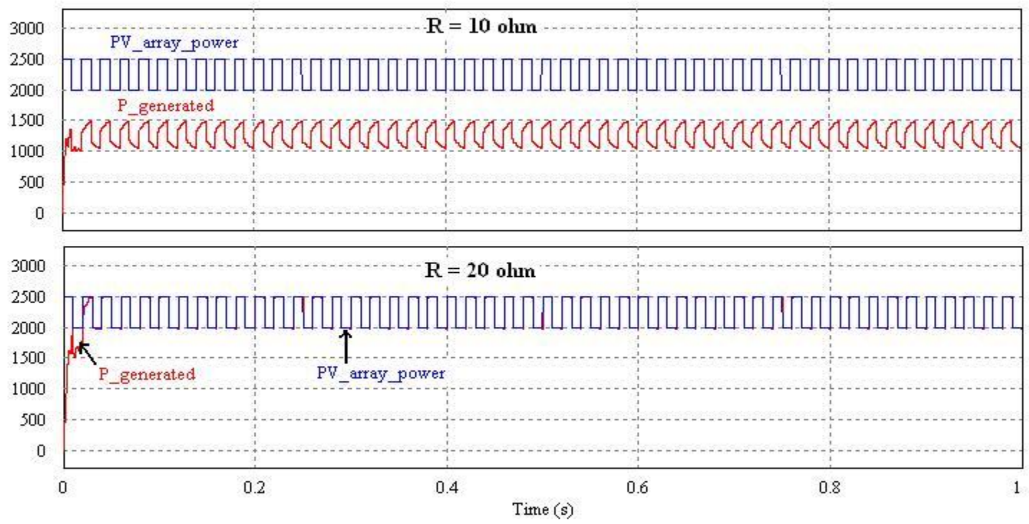

Fig. 7: MPPT tracking for 10 ohm and 20 ohm

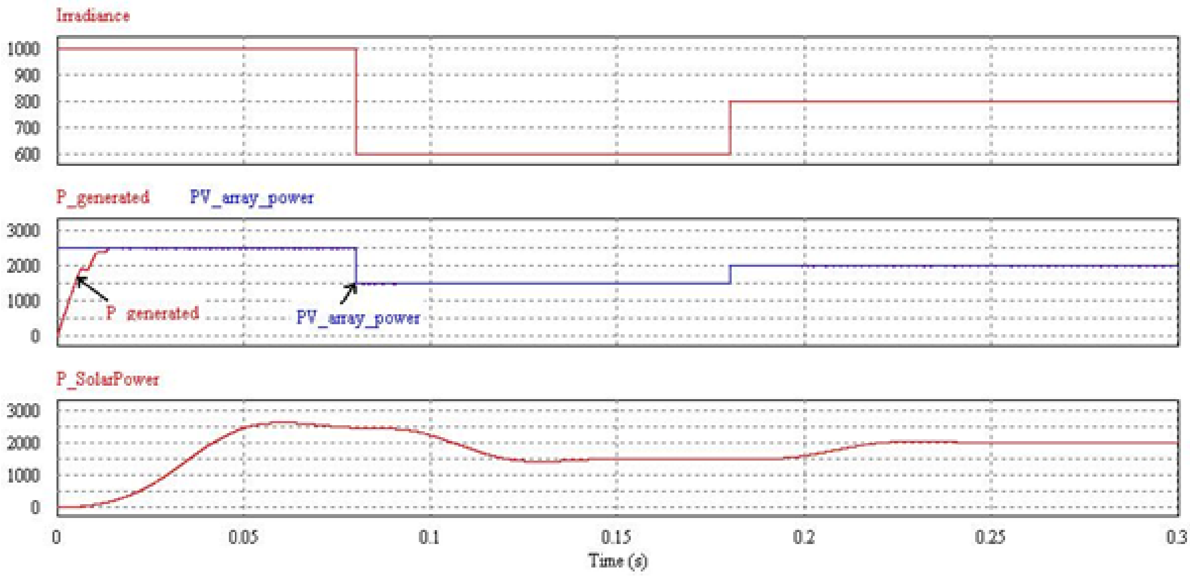

Fig. 8: (i) Solar irradiance varying 1000 W/ m^2, 600 W/ m^2, 800 W/ m^2 with fix interval 0.2 seconds (ii) MPPT tracking and (iii) Output Power at load side (Scale:X-axis:1 cm = 0.05 s and Y-axis: (i)1 cm = 100 W/ m^2 (ii)1 cm = 500 W (iii)1 cm = 500 W)

VI. SIMULATION RESULTS FOR WIND ENERGY SYSTEM

MPPT control of wind turbine with boost converter is modelled using PSIM software. Simulation results from PSIM 9.0 are given for simulation of wind energy system with MPPT technique which is programmed using visual C++ 6.0 and linked to PSIM using DLL block. The DLL block receives values from PSIM as inputs and sends results back to PSIM by performing the calculations with program visual C++. The parameters are given in Table 3.

A. Simulation Results of Boost Converter

The simulation of boost converter with modified P&O MPPT control is shown in Fig. 9 by considering wind speed constant at 12 m/s and its wind pitch angle constant at 0^0. Input voltage waveform is obtained from the 3-phase diode bridge rectifier. Parameters of boost converter are shown in Table III which can also be obtained from equations (3)-(6).

B. MPPT tracking for varying wind speed

Fig. 10 shows variation in different parameters like power, voltage and current with change in wind speed. The system starts with 8 m/s wind speed at which power starts increasing and achieves MPP and becomes constant. Also load current and load voltage starts increasing as shown in Fig.10. Then wind starts increasing and its speed becomes constant 12 m/s after some time. During this sudden change in wind speed, dc voltage increases which leads to the algorithm in prediction mode where it proceeds by increasing current with larger steps. After sometime wind speed becomes constant which leads to the algorithm into normal perturb and observe algorithm. This mode is active till wind speed starts decreasing slowly from 12 to 9 m/s. The algorithm starts decreasing the current command with steps that are scaled by the measured slope.

Table III: Parameters of Wind Energy System[6]

Wind Generator		Wind Turbine		Boost Converter	
Parameters	**Value**	**Parameters**	**Value**	**Parameters**	**Value**
Power Rating	30 kW	Power rating	28 Kw	Input Voltage, V_{in}	8.74 V
Poles	8	Radius	1 m	Output Voltage, V_{out}	151 V
R_s	56 mΩ	Gear Ratio	1:1	Output Capacitor, C_{out}	400 µF
L_d	1.6 mH	Base rotational speed	180 rpm	Inductor	700 mH
L_d	1.6 mH	P	1.205 kg/ m^2	Switching Frequency	5 kHz
Moment of inertia	0.02 kg. m^2	Moment of inertia	0.025 kg. m^2		

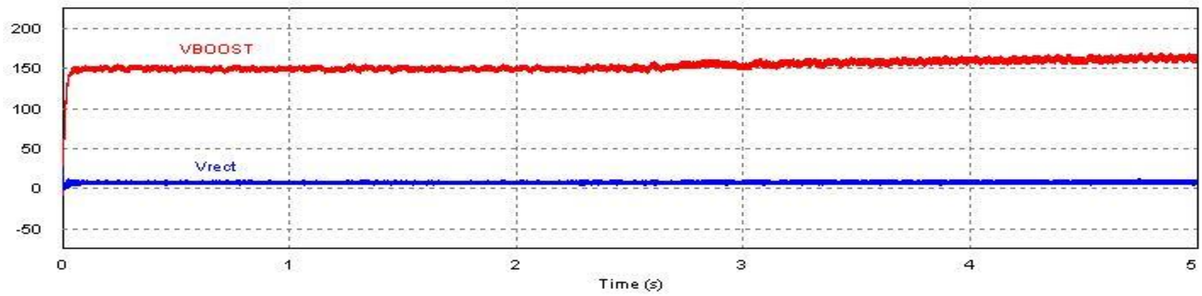

Fig. 9: Voltage waveform of boost converter

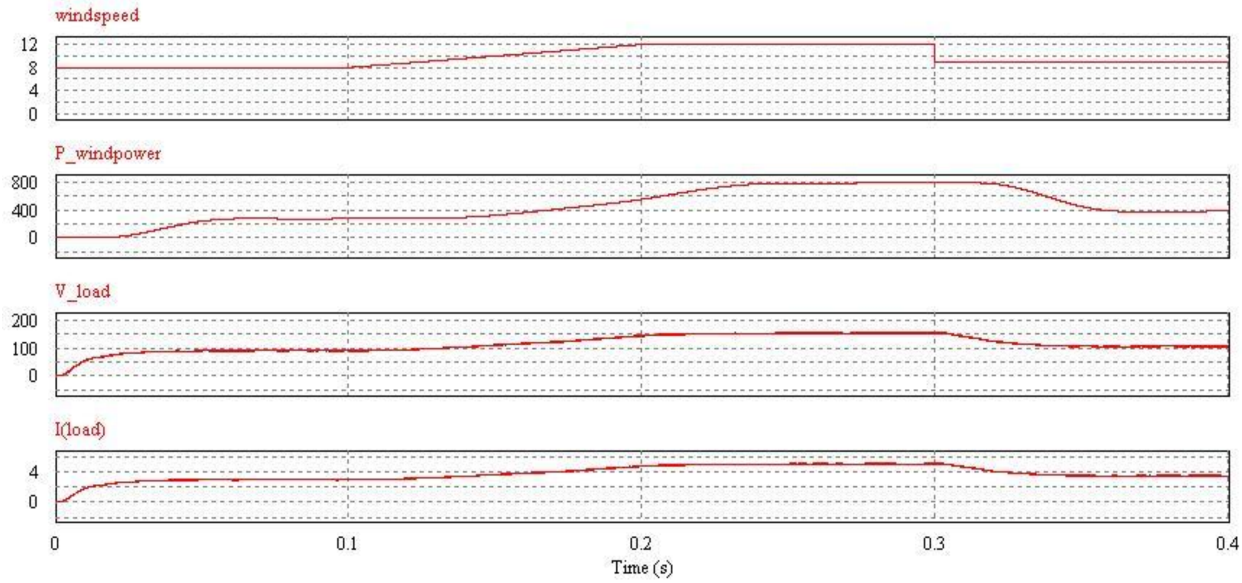

Fig. 10: Variation of different parameters with sudden wind speed change (i) wind speed with 8m/s, 12m/s, 9 m/s (ii) Output Power (iii) Output Voltage (iv) Output Current(Scale:X-axis:1cm =0.1 s, Y-axis: (i)1cm=2 m/s, (ii)1cm=200 W, (iii)1cm=50 V, (iv)1cm =2 A)

When the wind speed settles again at 9 m/s, the normal P&O mode is activated again by small variation in voltage slope. The current will vary with normal P&O mode during slow wind variation and will abruptly change to prediction mode when there is sudden change in wind speed. From the results proposed algorithm shows fast tracking performance with change in wind speed with minimum calculation and simple implementation. Under fast wind speed change, the proposed algorithm prevents the generator from stalling by comparing slope with threshold value which indirectly detects change in wind speed.

VII. CONCLUSIONS

The simulation of the MPPT technique achieves the maximum power point for wind energy system as well PV system. For a particular irradiance level, maximum power generated by wind generator/PV system is delivered by using MPPT technique at the load. For PV system, perturb and observe MPPT technique is used which works efficiently. For wind energy system, modified perturb and technique adopted from IEEE transactions on energy conversion [6] is used in which with normal wind speed conventional perturb and observe technique is employed and with rapidly wind speed conditions prediction mode is employed. Under rapid wind speed condition, conventional P&O has the direction misleading problems while prediction mode reaches MPP faster.

The features of this simulation circuit are: 1) Both renewable sources are stepped up using boost converter; 2) Different MPPT technique is employed for each source; 3) individual operations are supported. Simulation results are presented in this paper.

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