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Simulation Based Evaluation of PV Brushless Direct Current Motor For Rural Irrigation Requirements

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Abstract : *Solar water pumping systems is a pro-active approach in agricultural applications. The paper presents mathematical model of Photo-voltaic(PV)panel, Maximum power point tracking(MPPT) controller considering hill climbing, perturb & observe algorithms, mathematical model of Brushless direct current (BLDC) motor simulations. PV panel connected to load with and without MPPT controllers are simulated and results are analyzed. The response of BLDC motor with changing irradiance are simulated and presented.*

Keywords - *BLDC (Brushless Direct Current) Motor, MPPT (Maximum power point tracker), PV (Photo-voltaic) cell.*

I. INTRODUCTION

Sun oriented Photovoltaic frameworks (SPV) have been in presence since numerous years. The PV frameworks as far as applications are separated into two sorts to be specific OFF-GRID (Standalone) Systems and ON (Grid-Connected system).In an OFF-Grid framework, the power produced from the PV Arrays will be used totally by the heap while in ON-Grid framework the power required for the heap is conveyed by PV board and overabundance power can be given to the Grid.

PV board's establishment is of two sorts, settled and pivoting. As a rule, control from the PV Panel isn't generally steady; it fluctuates with climatic conditions in particular irradiance and temperature. Thus, a controller circuit must be available between PV board and load to separate greatest power from the PV cluster (regardless of whether settled or pivoting) and keep up consistent voltage/current to the heap. The controller circuit for the most part utilized is charge controller. It is available between PV board yield and Load. Charge controllers are of two kinds PWM and MPPT Type. PWM write controllers is utilized as a part of long time past days.

The paper introduces an off-Grid sunlight based directing framework for horticulture applications. It manages MPPT Charge controller for a settled PV Panel .The Motors for the most part utilized for horticultural applications are AC Induction Motors [1] and Brushed DC Motors. As of late of Brushless DC Motor (BLDC) are additionally being utilized.

The methodology used in this paper is

1. Mathematical modeling of PV Panel [2].

2. MPPT Algorithm namely Hill climbing [4, 5, 6] is used for generation of gate pulses to boost converter has been implemented

3. Mathematical modeling of BLDC Motor [8, 9]

II. MATHEMATICAL MODELLING OF PHOTOVOLTIC PANEL

The solar cell is practically a silicon diode which produces voltage when light is illuminated on it. Solar cells are constant current sources and can be expressed mathematically as [2]

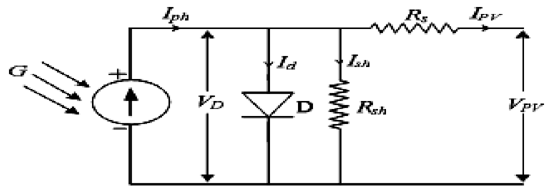

Fig1:mathematical model of PV cell

The current from PV panel is given by

$$I_{pv} = I_{ph} - I_d - I_{sh} \qquad (1)$$

Where I_{pv} = Current from PV panel

I_{ph} = Photo generated Current

I_d = Diode current

I_{sh} =Shunt current

The Photo generated current is given by

$$Iph = G \times (Isc + (K_i \times (T_{op} - T_{ref}))) \qquad (2)$$

Where G = Irradiation (w/m^2)

I_{sc} = Short circuit Current

K_i = Temp.Coefficient of I_{sc} ($2.2*10^{-23}$)

T_{op} = Operating Temperature in ^{0}/C

T_{ref} = Reference Temperature (25 ^{0}/C)

The diode current is given by

$$I_d = I_s \times (e^{(\frac{V_{pv} + I_{pv} \times Rs}{Ns \times n \times V_t \times c})} - 1) \qquad (3)$$

Where Is = Saturation Current

V_{pv} = PV Panel Output Voltage

R_s = Series resistance (0.01 Ω)

V_t =Thermal Voltage = $\left(\frac{K*Top}{q}\right)$

n = Ideality Factor (1-2)

C = Total No. of Cells

N_s = No. of cells in series

The saturation current is given by

$$I_s = I_{rs} \times \left(\frac{T_{op}}{T_{ref}} \right) \times e^{\left(\frac{1}{T_{op}} - \frac{1}{T_{ref}} \right) \times \left(\frac{E_g \times q}{K \times n} \right)} \quad (4)$$

Where the reverse saturation current is given by

$$I_{rs} = \frac{I_{sc}}{e^{\left(\frac{q \times V_{oc}}{K \times C \times T_{op} \times n} \right)} - 1} \quad (5)$$

Where E_g = Energy Gap of PV material =1.12ev

q= Charge of an electron = 1.602*10^ (-19) C

K = Boltzmann Constant = 1.38*10^ (-23)

n = Ideality factor (1-2)

$$I_{sh} = \left(\frac{V_{pv} + (I_{pv} \times R_s)}{R_{sh}} \right) \quad (6)$$

Using the above equations a PV panel is modeled [2]. The number of cells to be connected to form an array is considered by taking a practical PV Panel Electrical data [Table I].The I-V and P-V characteristics of the modeled PV panel agree with the manufacturer data.

I. TABLE1 (MANUFACTURER DATA)

Maximum Power	**252W**
Voltage at Maximum Power	**31V**
Current at Maximum Power	**8.1A**
Open Circuit Voltage , Voc	**38V**
Short Circuit Current , Isc	**8.95 A**

In any PV Panel, the manufacturer of the panel specifies about open-circuit voltage, short circuit current, voltage & current corresponding maximum power. For a particular irradiance, maximum power is obtained only at a particular point. For example, a 250w panel, for an irradiance of 1000w/m^2 and Temperature of 25^o/c the maximum power obtained is at 31V.This is called voltage at maximum power point (V_{mpp}).The V_{mpp} may vary as per irradiance. For an irradiance of 700 w/m^2 the Maximum power is 180w.The V_{mpp} may be (29-30) V.

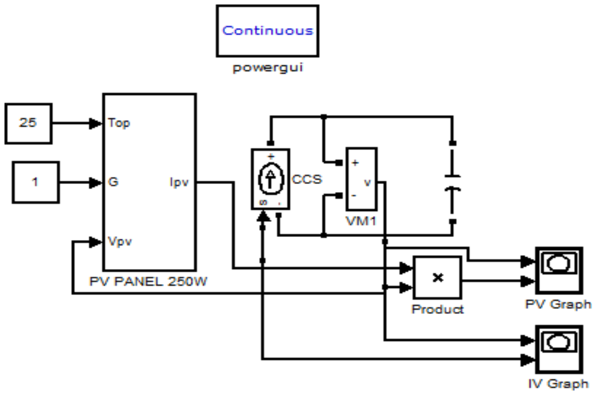

Fig 2:mathematical model of photovoltaic panel

For Irradiance=1000w/m^2 & temp = 25°/C

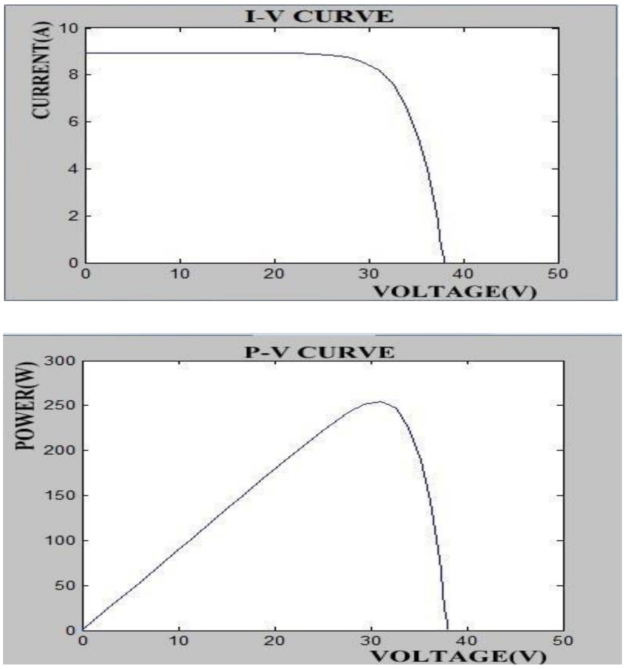

Fig3: I-V and P-V curves of a PV panel

III. MPPT CONTROLLER (MAXIMUM POWER POINT TRACKING) CONTROLLER

Mppt Controller is dc-dc converter which can increase &decrease the output power for a given input. It is analogous to a transformer in AC circuits. The voltage can be changed by varying the duty ratio given to the switch in DC-DC Converter (Buck/Boost/Buck-Boost/Sepic/Cuk converters etc).

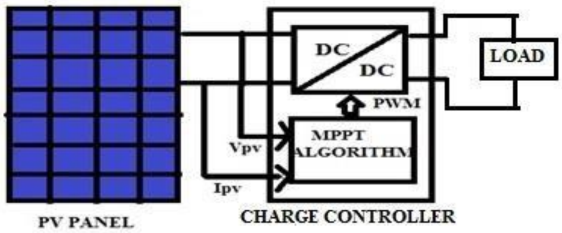

Fig4: PV Panel connected to load with charge controller

A Technique called PWM is used in the process of increase/decrease of input voltage. The output voltage of PV Panel increases with increase of irradiance and decreases with increase of temperature. For a particular irradiance, maximum power from PV panel is obtained only at a particular point. At that irradiance the voltage is set such that always V_{mpp} (voltage at maximum power point) is maintained against the panel then maximum power can always be extracted from the PV array. It is observed that from the I-V and P-V curves of a PV panel, V_{mpp} change with respect to irradiance. To maintain the voltage V_{mpp} corresponding to irradiance tracking has to be established. Once the maximum power point is known, using DC-DC converter (buck/boost etc) the voltage is increased or decreased to that point.

The process of tracking the maximum power point with respect to changing irradiance and maintaining power at that point is the key function of Maximum power point tracker. Maximum power point tracker consist an algorithm to decide the duty ratio to be given to the DC-DC converter. The algorithm takes the samples of voltage, current from PV panel at every time instant and decides the duty cycle to be given to DC-DC Converter. The most commonly used algorithms are Perturb & observe algorithm and Hill climbing algorithm [4] - [6].

The DC-DC Converter [3] considered here is a Boost Converter. The values of 'L' & 'C' are calculated based on the input voltage and required output voltage.

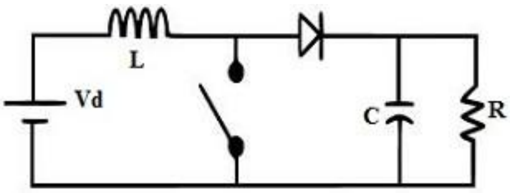

Fig5: Boost converter

For a resistive Load connected to Boost converter the value of 'L' is given by the equation

$$L = \left(\frac{T_s \times V_o}{2 \times I_{ob}} \right) \times \left(D \times (1-D) \right)^2 \qquad (7)$$

The value of 'C' considered here is very large enough to maintain constant voltage at the load.

Where

L = Inductance value

Ts = Switching frequency.

V_O = Output voltage.

D = Duty cycle/Duty ratio.

Iob= Boundary current between continuous & discontinuous which determines whether output current is continuous or not

The Value of 'L' can be varied in accordance with input, output voltage and power.

In Boost converter, inductor current is equal to output current. For any increase in load, than the maximum possible level results in increase in output current, the increase level of current cannot be provided by the source. Hence 'L' & 'C' determination is Important. From the above equation it is observed that duty cycle is required for operation of DC-DC converter. Determination of duty cycle is accomplished with MPPT algorithms.

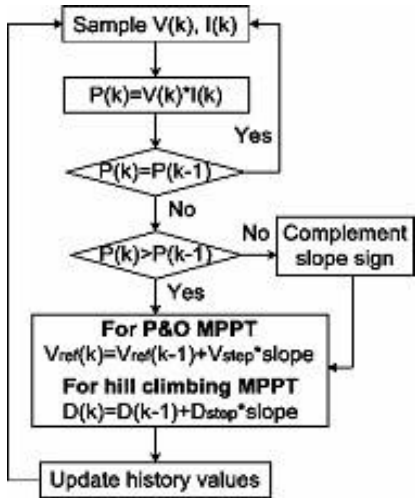

Fig6: P & O, Hill climbing MPPT algorithms

IV. SIMULINK MODEL OF HILL CLIMBING MPPT ALGORITHM

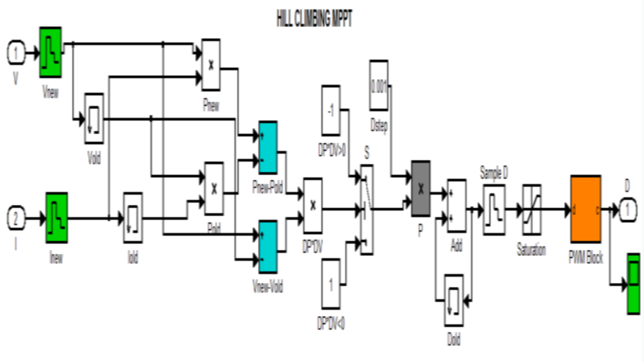

Fig7: Hill climbing MPPT algorithm simulink model

V. SIMULINK MODELS OF PV PANEL CONNECTED TO LOAD WITH AND WITHOUT MPPT

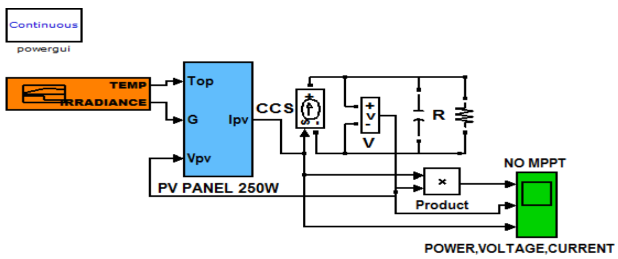

Fig8: PV Panel connected to Load

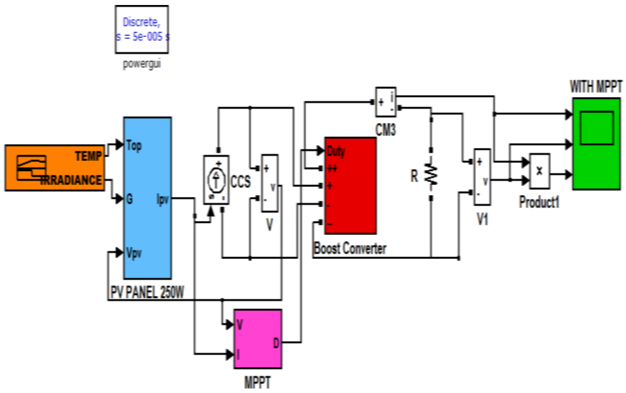

Fig9: PV Panel connected to Load with MPPT

VI. BRUSHLESS DIRECT CURRENT (BLDC) MOTOR

The most commonly used motor for pumping applications is Induction Motor, Brushed dc Motor. Because of its rugged construction Induction motor is used in many Industries, Commercial and Domestic applications. Because of its superior speed regulating techniques brushed dc motor is used in many industries [7]-[11]. The dc motors are generally used for Constant speed applications, lifts, hoists, cranes etc. The major drawback of brushed dc motor is periodical maintenance is required due to wear & Tear of the brushes. As size of the machine increases it suffers with commutation problems. The drawback of brushed dc motor has been overcome by brushless dc motor (BLDC).BLDC motor does not have brushes and has superior performance characteristics similar to Induction motor. Due to elimination of brushes it has got the advantages similar to Induction motor and performance superior to Induction motor.

The function of Commutator in a brushed dc motor is replaced by Electronic commutation with semiconductor switches. Hence BLDC Motor is also called Electronic Commutation Motor (EC Motor) .For this application a 1 HP BLDC motor is considered with Photovoltaic system through MPPT.

VI (a) *Mathematical Modeling of BLDC Motor*

$$V_a = R \times i_a + \left(L \times \frac{di_a}{dt} \right) + e_a \qquad (8)$$

$$V_b = R \times i_b + \left(L \times \frac{di_b}{dt} \right) + e_b \qquad (9)$$

$$V_c = R \times i_c + \left(L \times \frac{di_c}{dt} \right) + e_c \qquad (10)$$

Where Va, Vb &Vc are Phase Voltages

R & L are resistance (ohm) and Inductance (H)

Ia, Ib & Ic are input currents

ea, eb & ec are Back-Emf's of phases

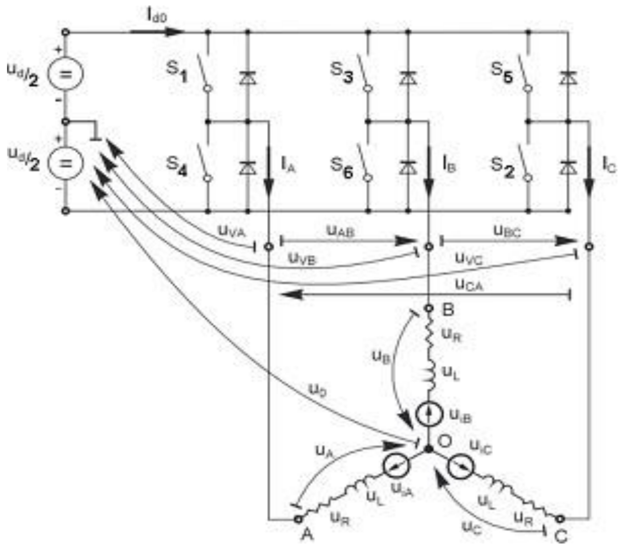

Fig10: Electronic commutation of BLDC motor

Back-emf s of the machine

$$e_a = K_w \times f(\theta_e) \times \omega \quad (11)$$

$$e_b = K_w \times f(\theta_e - \frac{2\Pi}{3}) \times \omega \quad (12)$$

$$e_c = K_w \times f(\theta_e + \frac{2\Pi}{3}) \times \omega \quad (13)$$

Where ea, eb & ec are back-emf of phase winding.

Kw = Back-emf constant of one-phase [V/rad.s^{-1}]

Θe =Electrical rotor angle. $\theta e = \frac{p}{2} * \theta m$

ω =rotor speed [rad.s^{-1}]

θm =Mechanical rotor angle

Total Torque output (Te), Nm

$$T_e = \frac{e_a \times i_a + e_b \times i_b + e_c \times i_c}{\omega} \quad (14)$$

The Mechanical part equation is

$$T_e - T_l = \left(J \times \frac{d\omega}{dt}\right) + (B \times \omega) \quad (15)$$

T_l - Load Torque, Nm

J - Inertia of rotor and coupled shaft [kgm^2]

B - Friction constant [$Nms.rad^{-1}$]

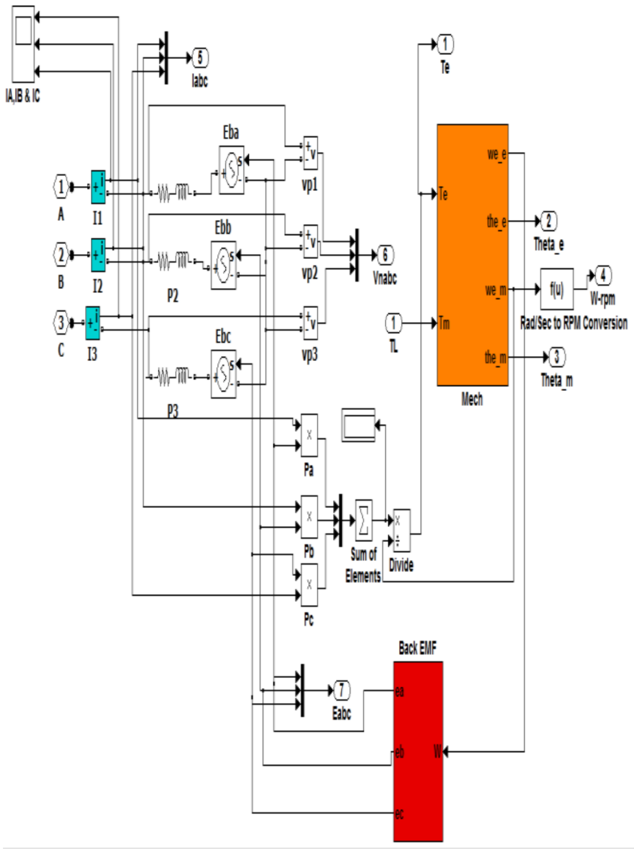

Fig11: Simulink model of BLDC motor

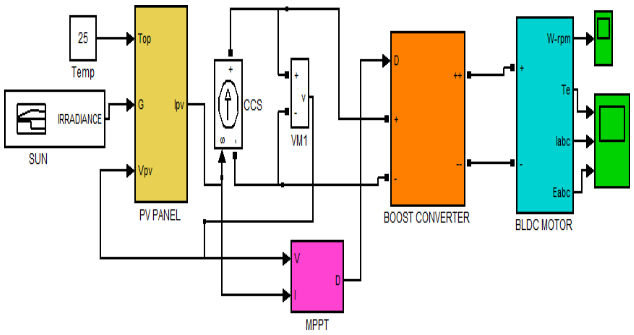

Fig12: Simulink model of system under study

III. SIMULATION RESULTS

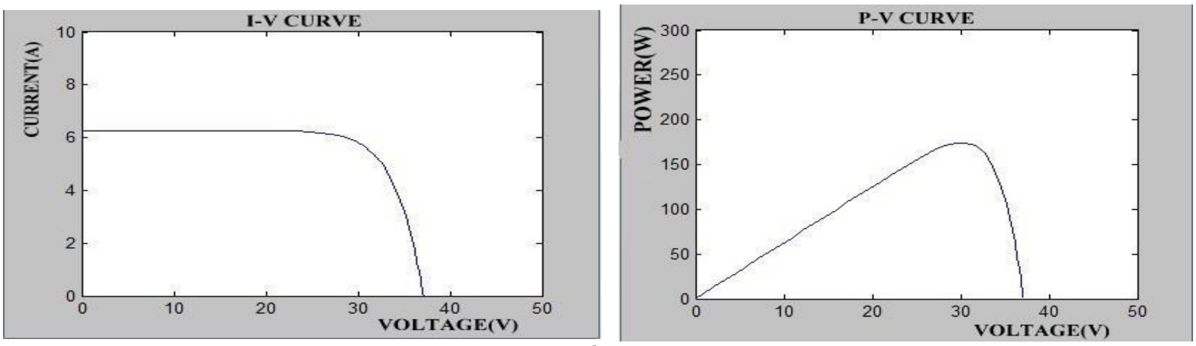

Fig13: irradiance=700w/m^2 and temp=25^o/Centigrade.

Table II Output characteristics of PV panel
With varying irradiance and temperature

Irradi-ance (w/m^2)	Tem--perature (deg/cent)	Open Circuit Voltage (V)	Short Circuit Curren-t (A)	Maxim-um Power (W)	Vmpp
1000	25	38 V	8.95 A	252 W	31 V
800	25	37.45 V	7.25A	200W	30 V
600	25	36.73 V	5.5 A	150 W	29 V
1000	40	36.2V	9 A	248 W	28 V
1000	50	35.02 V	9 A	230 W	28 V
1000	55	34.41 V	9.1 A	225 W	26 V

VII (a) CONSIDERING IRRADIANCE (W/M^2) DATA (AUGUST, VISAKHAPATNAM, ANDHRA PRADESH, INDIA

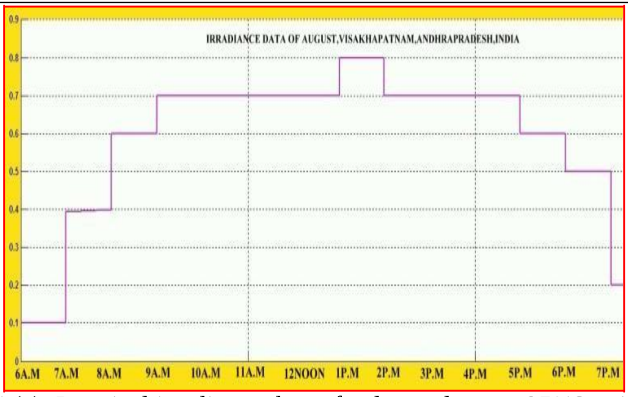

Fig14 (a): Practical irradiance data of a day and temp=25º/Centigrade

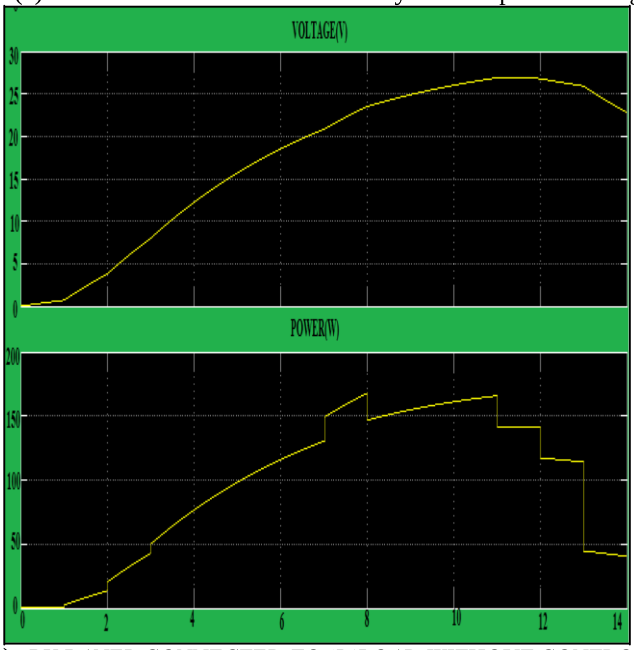

Fig14 (b): *PV PANEL CONNECTED TO 'R'LOAD WITHOUT CONTROLLER*

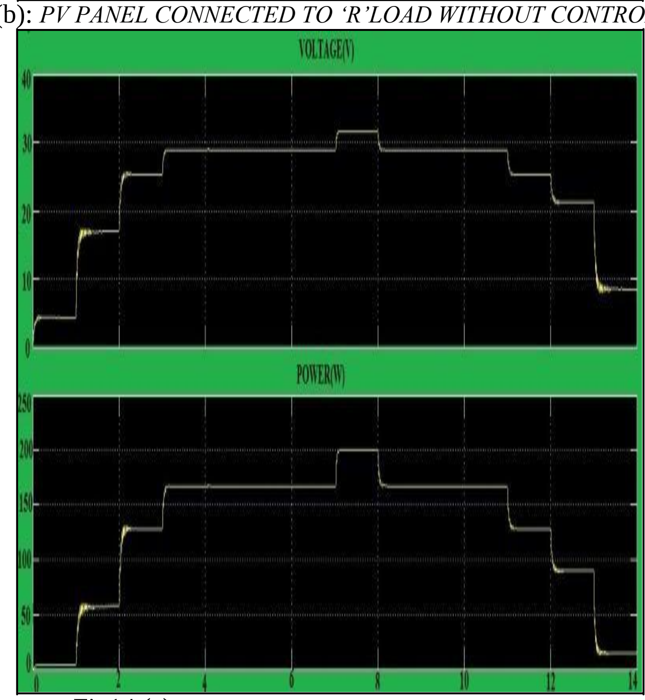

Fig14 (c): *PV PANEL CONNECTED TO 'R' LOAD WITH MPPT (HILL CLIMBING)CONTROLLER*

The simulations results state that the Maximum power point tracker is working satisfactorily. Hill climbing technique is suitable where the necessity to track rapid changes in irradiance is not prominent eg. Battery charging etc.

VII (b) COMPARISON BETWEEN HILL CLIMBING, PERTURB & OBSERVE MPPT WITH SUDDEN CHANGES IN IRRADIANCE

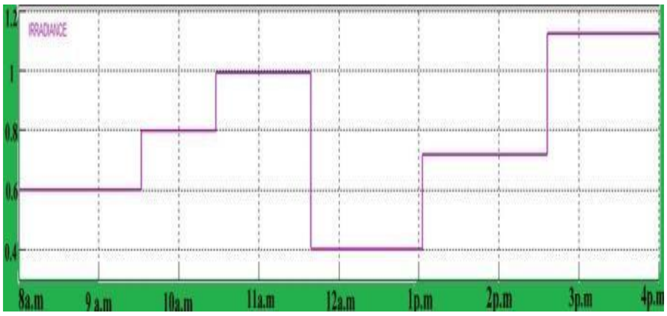

Fig15 (a): Sudden changes in irradiance and temp=25°/Centigrade

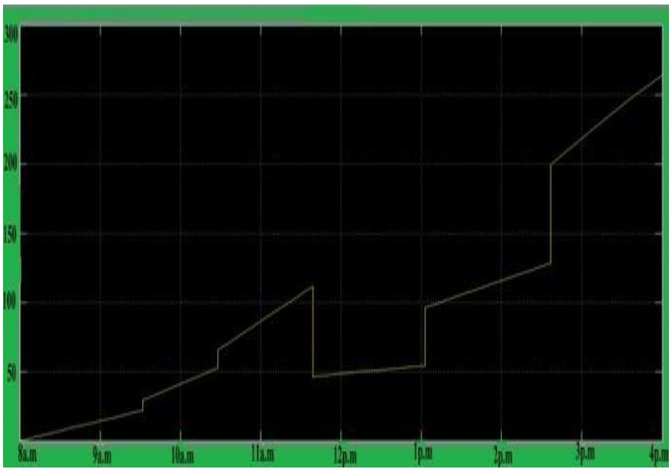

Fig15 (b): Power obtained with PV Panel connected to load

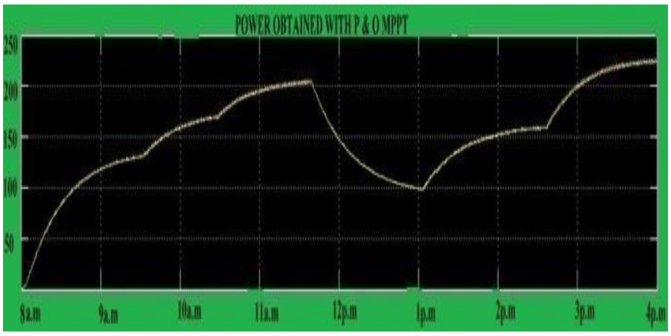

Fig15 (c): Power obtained when PV Panel connected to load

With Perturb & observe MPPT

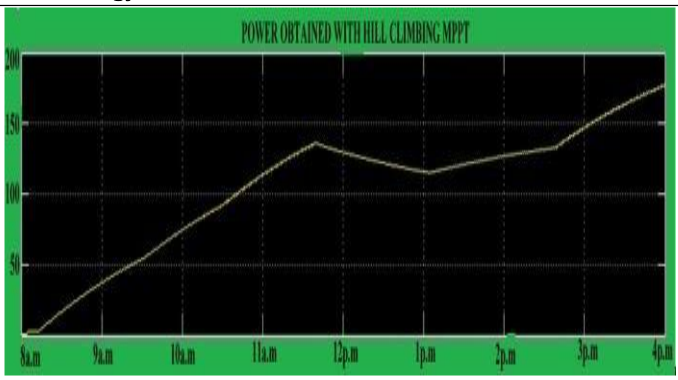

Fig15 (d): Power obtained when PV Panel connected to load

With Hill climbing MPPT

It is observed from the simulation results that whenever large changes in irradiances are present the capability to track maximum power point is minimal in Hill climbing MPPT and maximum in Perturb and observe MPPT

VIII(c) *PV PANEL CONNECTED TO BLDC MOTOR WITH MPPT*

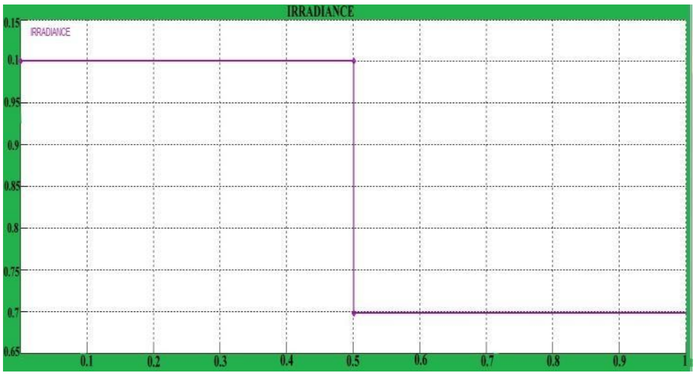

Fig 16(a): Change in Irradiance as Input to BLDC motor

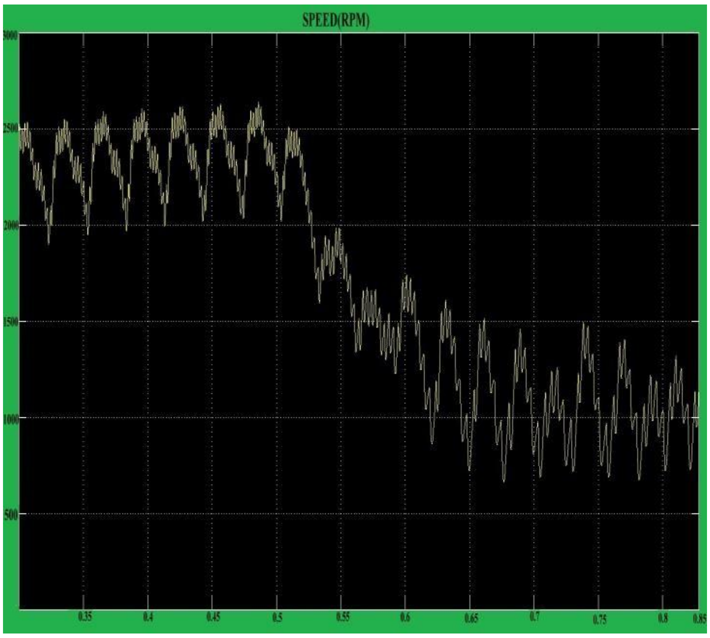

Fig 16(b): Change in SPEED (rpm) with respect to irradiance

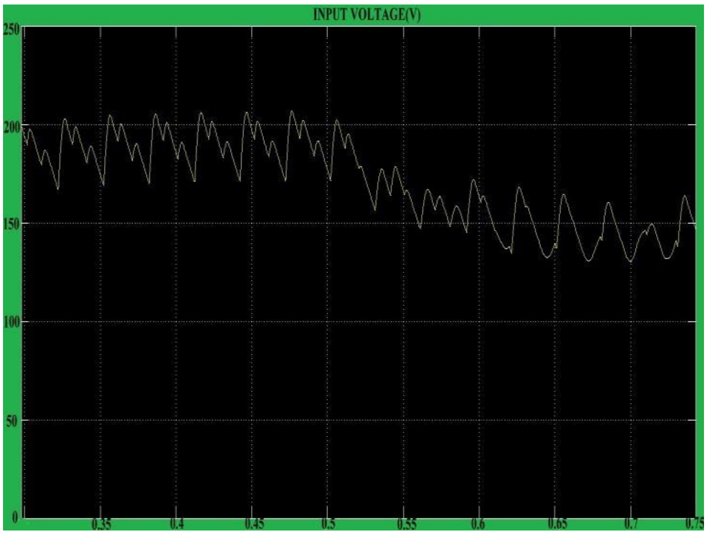

Fig 16(c): Change in VOLTAGE with respect to irradiance

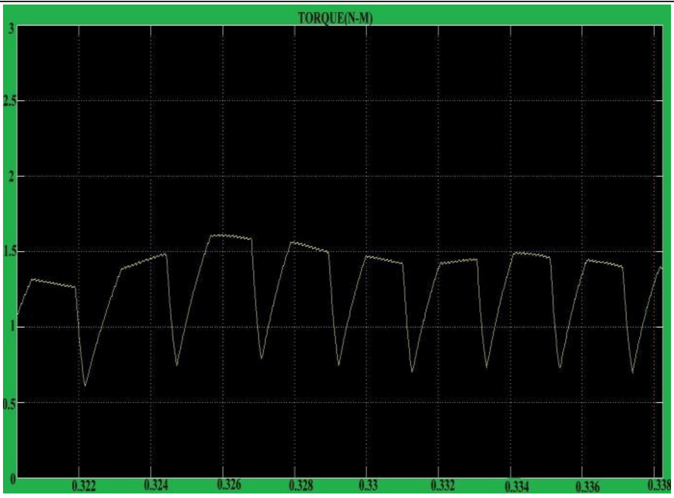

Fig 16(d): Output Torque(Newton-metre) of BLDC motor

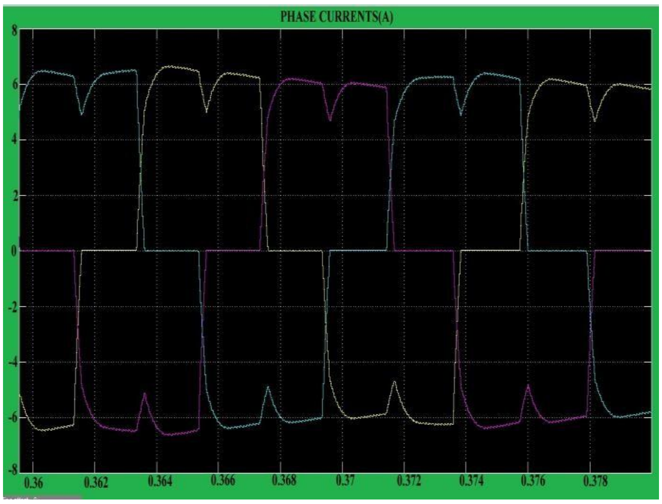

Fig 16(e): Trapezoidal shaped phase currents

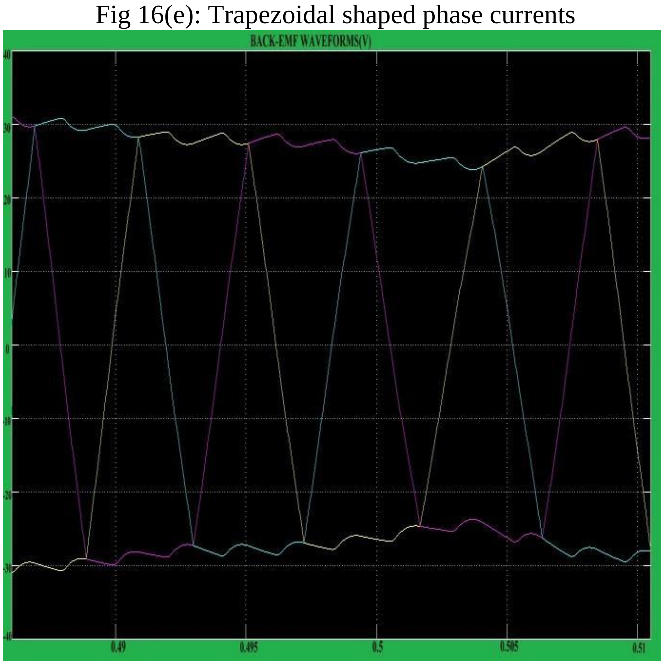

Fig 15(f): *Trapeziodal shaped Back-emfwaveforms*

Torque is not constant but pulsating due to ripples occurred during switching sequence. In order to maintain constant Torque a Hystersis Current controller can be used. Ideally the shape of the back-emf waveform must be rectangular (since on rotor the permanent magnets placed are rectangular) but because of fringing it takes a trapezoidal shape.

IV. CONCLUSION

Photovoltaic array connected to PV Panel through MPPT Controller. With changes in irradiation and Temperature the PV panel produces voltage and current on par with atmospheric conditions. Maximum power point tracking is a technique used with PV system to operate efficiently by delivering maximum power output. PV array connected to BLDC motor without battery works satisfactorily by delivering torque required to drive the pump.

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