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Performance Evaluation of Photo-Voltaic fed Brushless Direct Current Motor for Agricultural applications

B.V.A.S.S.R.Krishna*, K.Narasimha Rao** & Basam venkata Rao***
*Department of Electrical & Electronics Engineering, GVPCOE, JNTUK University, Visakhapatnam, India
**Department of Electrical & Electronics Engineering, GVPCOE, JNTUK University, Visakhapatnam, India
***Naval Science & Technological Laboratory, NSTL), DRDO, Visakhapatnam, Andhra Pradesh, India

ABSTRACT
This work presents an effective approach towards reduction of steps in power conversion from solar photovoltaic system to load. When a Photovoltaic system is fed to an induction motor, it requires MPPT controller and an Inverter circuit in first and second stages since Induction motor works with a.c supply. By eliminating the Inverter circuit and employing a BLDC motor the efficiency of the system can be improved. The BLDC motor works under Electronic commutation principle with VSI embedded in the motor. A PV Panel fed to the "R" load with Hill Climbing MPPT is considered along with practical irradiance data. Simulation is carried out by formulating the mathematical model for the photovoltaic source, MPPT, Motor. System performance's are investigated under different levels of solar insolation.
Keywords - BLDC (Brushless Direct Current) Motor, MPPT (Maximum Power Point Tracker), PV (Photo-voltaic) cell, VSI (Voltage Source Inverter)

I. Introduction

Solar Photovoltaic systems (SPV) have been in existence since many years. The PV systems are divided into two types namely OFF-GRID (Stand alone) Systems and ON-GRID (Grid-Connected system) based on application. There are two kinds of installation of PV panel namely fixed and rotating. Generally power from the PV Panel is not constant always; it varies with atmospheric conditions viz., irradiance and temperature. Hence, to extract maximum power from the PV array and supply it to the load, a controller circuit has to be present between PV panel and load. Generally the controller circuit used is charge controller. Practically these Charge controllers are of two types namely PWM and MPPT Type [5].

This paper presents an off-Grid solar pumping system with BLDC motor for agriculture applications. It deals PV Panel connected to "R" load and motor with MPPT. The Motors generally used for agricultural applications are AC Induction Motors [1] and Conventional DC Motors. In recent years with exploration of new permanent magnet materials there is a sharp decline in their cost, which results in increased availability of BLDC motor. Hence Brushless DC Motors (BLDC) is also being used for domestic, commercial and agricultural applications.

The methodology used in this paper is
1. Modeling of PV Panel [2-4].
2. PV Panel connected to sensitive load with and without MPPT [5-7]
3. PV Panel connected to BLDC motor with MPPT [8-12].

II. Modeling of Photovoltaic Panel

The solar cell can be modeled as a silicon diode which produces voltage when light is illuminated on it. Solar cells are constant current sources and can be represented as shown in the Fig1

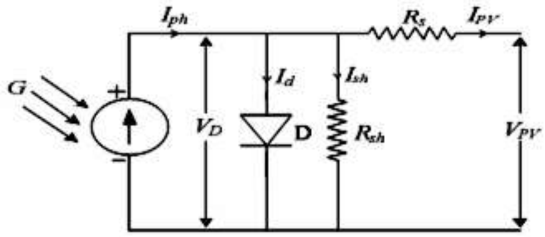

Fig1:mathematical model of PV cell

PV panel is modelled using mathematical equations (1)-(6) as given below[2]

The current from PV panel is given by

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

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

$$I_{ph} = G \times (Isc + (K_i \times (T_{op} - T_{ref}))) \quad \text{------ (2)}$$

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

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

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
Q = Charge of an electron = $1.602*10^{-19}$ C
K = Boltzmann Constant = $1.38*10^{-23}$

The saturation current is given by

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

Where the reverse saturation current is given by

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

Where E_g = Energy Gap of PV material =1.12ev
The shunt current is given by

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

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 conform to the manufacturer data.

Table I (Manufacturer Electrical 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

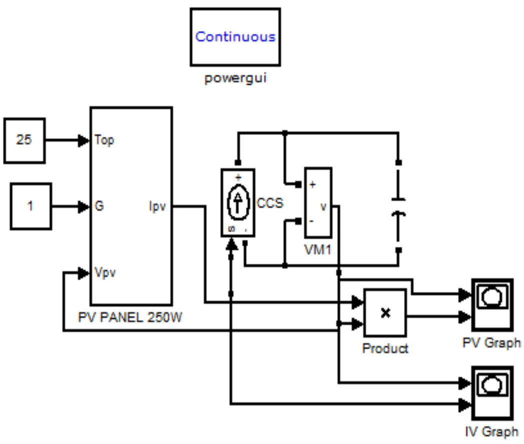

Fig2:simulink model of photovoltaic panel

For instance, for a 250w PV panel as shown in the fig2. The I-V and P-V characteristics of the Panel for an Irradiance=1000w/m^2 & temp = 25°C is shown in the fig3.

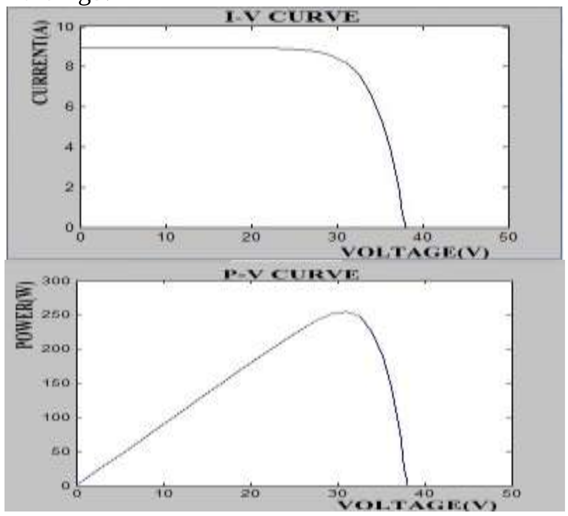

Fig3: I-V and P-V curves of a PV panel

The specification of PV panel generally include open-circuit voltage (V_{oc}), short circuit current (I_{sc}), voltage corresponding maximum power (V_{mpp}).

For a particular irradiance, maximum power is obtained only at one value. As an example, for a 250w panel with irradiance of 1000w/m^2 and Temperature of 25°/c the maximum power obtained is at 31V as shown in the fig3. This is called voltage at maximum power point (V_{mpp}).TABLE II shows variation of V_{mpp} with changing irradiance.

III. MPPT(Maximum Power Point Tracking)Controller

MPPT Controller is dc-dc converter which can increase or decrease the output power for a given input as shown in the fig4. 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)

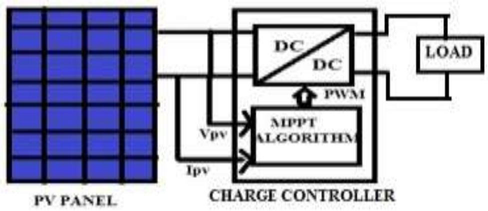

Fig4: PV Panel connected to load with charge controller

It is observed that from the I-V and P-V curves of a PV panel, V_{mpp} change with respect to irradiance. Tracking is essential to ensure constant voltage for constant irradiance. The DC-DC Converter [4] as shown in the fig5 considered here is a Boost

Converter. The values of 'L' & 'C' are calculated based on the input voltage and required output voltage. The process of tracking the maximum power point with respect to changing irradiance and maintaining power at that point is the primary function of maximum power point tracker. Maximum power point tracker consist an algorithm to fix the duty ratio to be given to the DC-DC converter. As shown in the fig6 the algorithms take the samples of voltage, current from PV panel at instant and determine the duty cycle to be given to DC-DC Converter.

The most commonly used algorithms are Perturb & observe algorithm and Hill climbing algorithm. [4-7]. The simulink model of Hill climbing MPPT algorithm is shown in the fig7. Fig 8 & Fig9 gives the simulink model of PV panel connected to 'R' load with and without MPPT controller.

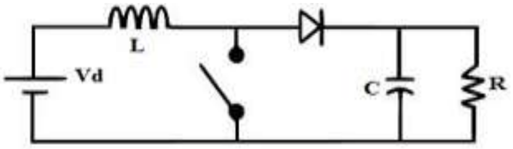

Fig5: Boost converter

The value of 'C' considered here is very large enough to maintain constant voltage at the load. The Value of 'L' can be varied in accordance with input, output voltage and power

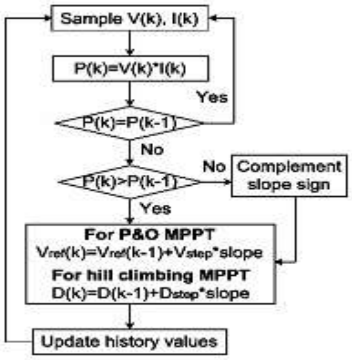

Fig6: P & O, Hill climbing MPPT algorithms

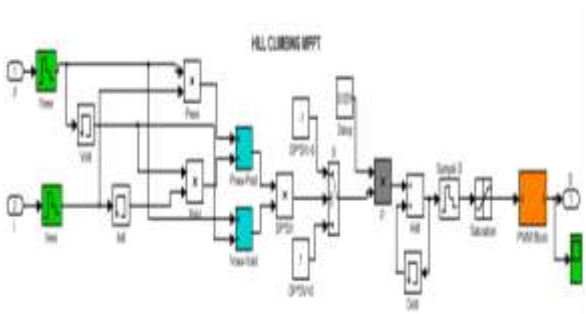

Fig7: Hill climbing MPPT algorithm simulink model

3.1..Simulink models of PV Panel Connected to Load with and without MPPT

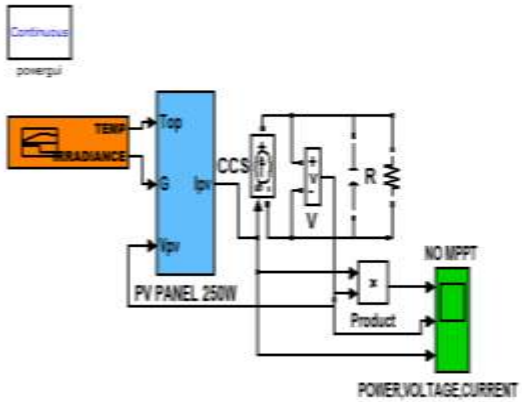

Fig8: PV Panel connected directly to Load

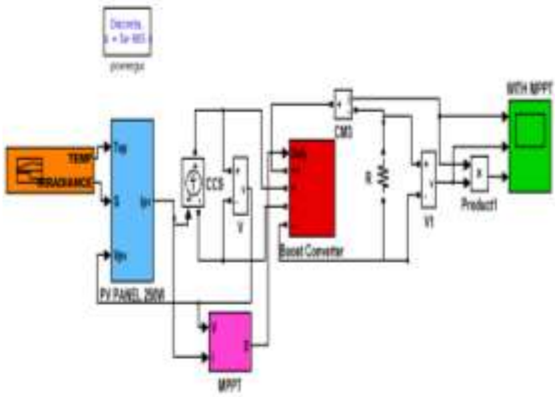

Fig9: PV Panel connected to Load with MPPT controller

IV. Brushless Direct current (BLDC) Motor

The most commonly used motor for pumping applications is induction Motor or Conventional dc Motor. The major drawback of brushed dc motor is periodical maintenance due to wear & tear of the brushes & commutation problems. The drawback of conventional 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.

The function of commutator in a conventional dc motor is replaced by Electronic commutation with static switches as shown in the fig 10[9-12]. Hence BLDC Motor can also call Electronic Commutation Motor (EC Motor). The simulink model of BLDC motor is shown in the fig11. In this work a 1 HP BLDC motor is considered with Photovoltaic system with MPPT. The simulink model of total system is shown in the fig 12

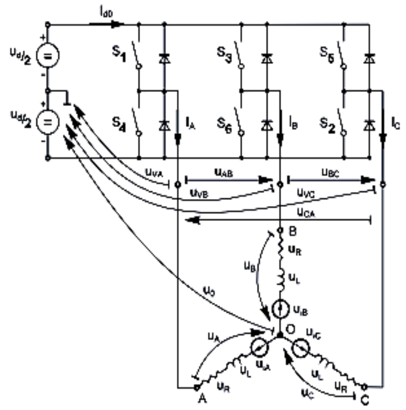

Fig10: Electronic commutation of BLDC motor

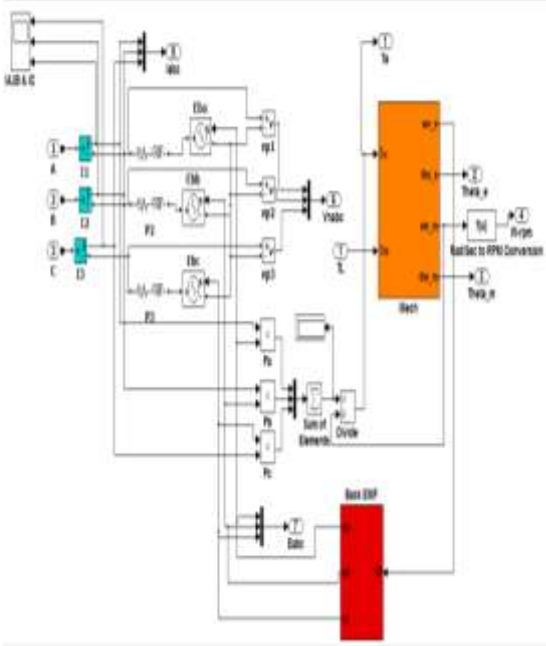

Fig11: Simulink model of BLDC motor

4.1 Modeling of BLDC Motor

The Mechanical part equation is

$$T_e - T_l = \left(J \times \frac{d\omega}{dt}\right) + (B \times \omega) \qquad \text{---------} \quad (7)$$

T_l - Load Torque, Nm
J - Inertia of rotor and coupled shaft [kgm^2]
B - Friction constant [$Nms.rad^{-1}$]
ω - Speed (rpm)

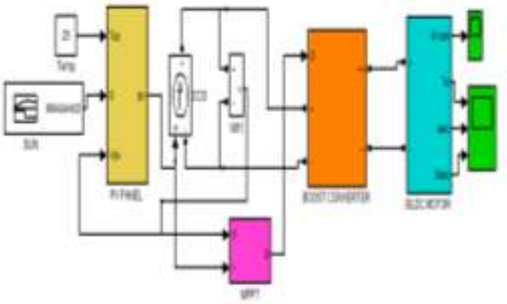

Fig12: Simulink model of Total system

V. Results and Discussions

The I-V and P-V curves of a PV panel may vary with changes in irradiance and temperature as shown in the fig3 and fig13. The changes output voltage, current, power and V_{mpp} with corresponding changes in irradiance and temperature is tabulated below (Table II)

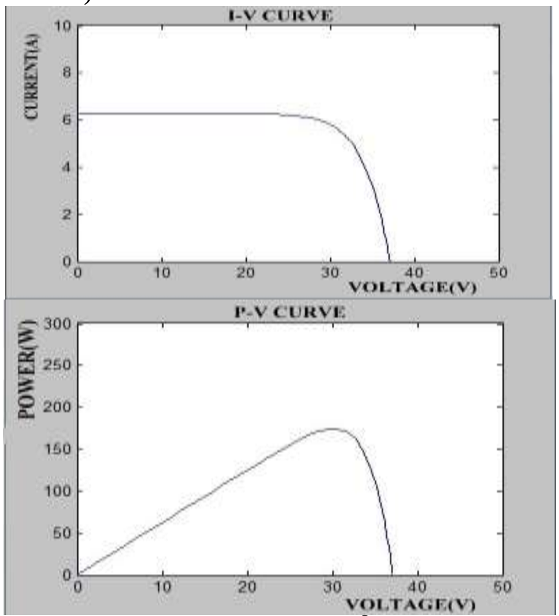

Fig13: Irradiance (G)=700w/m^2 & temp=25^o/C

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

G	Temp	(V_{oc})	(I_{sc})	(P)	(V_{mpp})
1000	25	38	8.95	252	31
800	25	37.45	7.25	200	30
600	25	36.73	5.5	150	29
1000	40	36.2	9	248	28
1000	50	35.02	9	230	28
1000	55	34.41	9.1	225	26

From the Table II, it is observed that with respect to changing irradiance and temperature the voltage, current, power & voltage at maximum power point (V_{mpp}) varies. With decrease in irradiance there is a decrease in open circuit voltage, short circuit current whereas with increase in temperature there is an increase in short circuit current, decrease in open circuit voltage.

5.1 Considering Irradiance (W/M^2) data

(August, Visakhapatnam, Andhra Pradesh, India)

The PV cells are sensitive to atmospheric conditions. A practical irradiance data of changing irradiances and constant temperature is shown in the fig 14(a). The irradiance data is considered as input to simulink model of PV panel connected directly to ‘R’ load as shown in the fig8. The response of the system is shown in the fig14 (b)

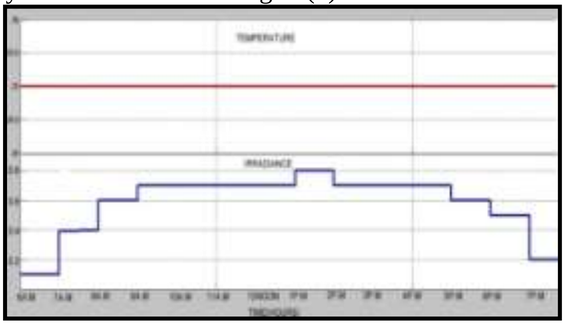

Fig14 (a): Practical irradiance data of a day and temp=25°/C

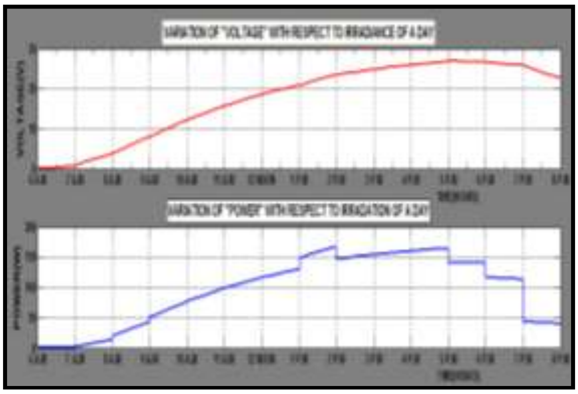

Fig14 (b): Pv Panel Directly Connected to ‘R’ load

It is observed with change in irradiance the V_{mpp} corresponding to particular irradiance is not maintained constant. During mid day and noon, the maximum power is extracted from PV panel whereas during remaining time, as the irradiance is low, the power that can be extracted from the panel is low as shown in the fig 14(b).

Fig 9 depicts the simulink model of PV panel connected to ‘R’ load with MPPT controller. The input data to this system is shown in the fig 14(a). It is observed that with changing irradiance the voltage and power corresponding to maximum power is extracted and maintained as shown in the fig 14(c). The controller required to maintain continuous power from the output of the PV panel to load is modeled and functions satisfactorily.

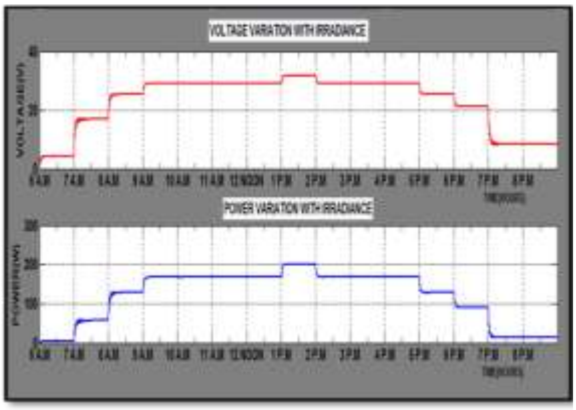

Fig14 (C): PV Panel Connected to ‘R’ Load With MPPT (Hill Climbing) Controller

5.2.PV Panel Connected to BLDC Motor with MPPT

The performance of BLDC motor with changing irradiance and constant temperature is depicted in the figures 15(b)-15(f)

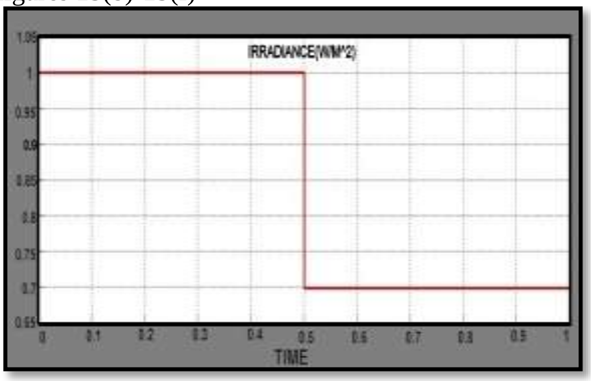

Fig 15(a): Irradiance change as I/p to to Motor

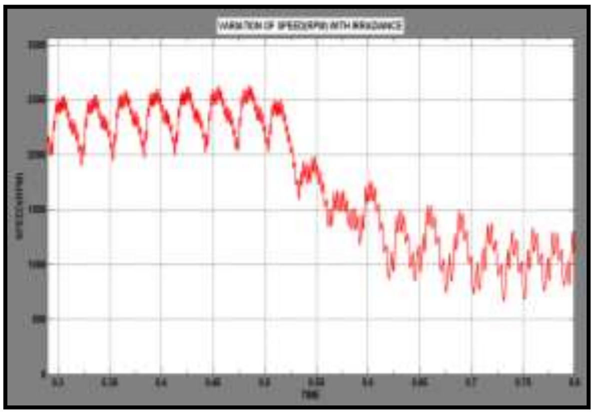

Fig 15(b): Change in SPEED (rpm) with respect to irradiance

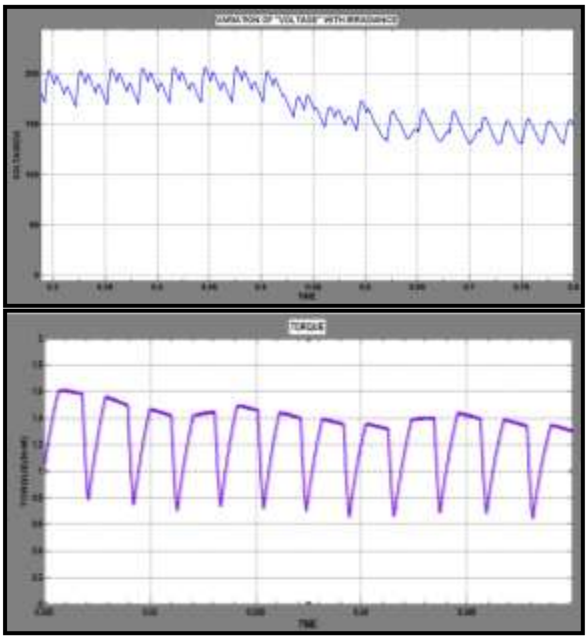

Fig 15(c,d): Depicts Output Voltage & Output Torque of BLDC motor

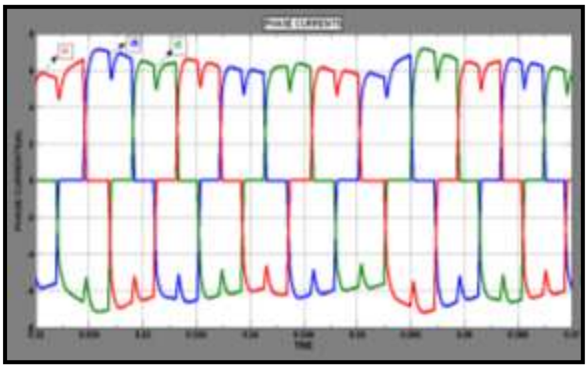

Fig 15(e): Trapezoidal shaped phase currents

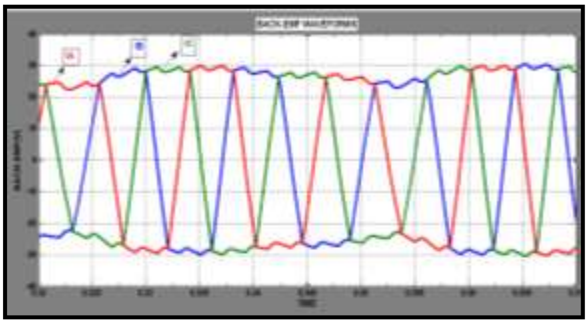

Fig 15(f): Trapeziodal shaped Back-emfwaveforms

The irradiance data considered is shown in fig 15(a). It is observed that with respect to change in irradiance there is a corresponding change in speed as shown in fig 15(b), change in input voltage to the BLDC motor as shown in fig 15(c).The torque as shown in fig 15(d) is pulsating because of phenomenon called cogging, ripple. The trapezoidal shape phase currents and back-emf waveforms are shown in fig 15(e) and fig15(f).

Torque is not constant but pulsating due to ripples occurred during switching sequence. In order to maintain constant Torque a Hysteresis Current controller can be used.

VI. Conclusion

In this paper, a comprehensive study of a stand-alone PV system for agricultural application is analyzed. The study includes modeling and simulation of PV fed BLDC motor which can be used for pumping application. Comparative performance analysis of directly connected PV pumping systems with systems using MPPT controller. Accurate modeling of PV cell has been analyzed with simple diode equivalent circuit model. Hill climbing algorithm is adopted for MPPT controller. Hill climbing is easy to implement, realize and suitable in situations where dynamic response requirement is not necessary.

The BLDC motor model responds well with changes in irradiance and temperature. It is observed that with changes in irradiance/temperature there is a corresponding change in speed, back-emf and phase currents of the motor. The performance of the PV system with MPPT controller is simulated and verified for a resistive load and for a BLDC motor. MPPT based scheme offers better energy utilization compared to directly connected system.

From the simulation results it is observed that, the performance of modeled PV based pumping systems using BLDC motor working satisfactorily by delivering the torque required to drive the pump.

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Email: venkat.basam@gmail.com

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