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# Performance Analysis of Maximum Power Point Tracking based Photovoltaic Module with Cuk Converter for Electrical Applications

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**Abstract:** In recent days, Photovoltaic power generation systems are becoming increasingly prevalent in distribution and generation systems. Many industrialized nations are installing significant solar power capacity in their grids as a supplement or alternative to other power sources. This project presents an MPPT based PV module with CUK converter for electrical applications. In conventional system, high ratio DC-DC converter is having high switching loss due to extreme duty ratios and numerous turns' ratios in the coupled inductor. Also the converter used is single stage, having low power. Also the DC-DC converter used is the boost converter, whose voltage gain is comparatively lower. It also possess severe diode reverse recovery problem. If high duty cycle is used for getting high output voltage, will lead to poor dynamic responses. To overcome these difficulties and to use in application level CUK converter with a PWM inverter is used. In the proposed method, instead of using the boost converter, the CUK converter with a PWM inverter is used. The PWM inverter uses a filter to reduce the harmonics .The PV model also uses MPPT to track maximum power from the panel.

**Keywords:** Photovoltaic (PV) cell; MPPT; Cuk Converter; Boost converter; PWM inverter; single phase asynchronous AC motor.

## I. INTRODUCTION

Conventional energy sources based on coal, oil and natural gas have proven to be highly effective drivers of economic progress, but at the same time damaging to the human health and to environment. Furthermore, they tend to be cyclical in nature, due to the effects of oligopoly in production and distribution. Therefore, these traditional fossil fuel-based energy sources are facing increasing pressure on a host of environmental fronts,
with perhaps the most serious challenge to face the future use of coal being the Kyoto Protocol greenhouse gas (GHG) reduction targets.

Solar PV modules (Solar cells) are solid-state semiconductor devices with no moving parts that convert sunlight into direct-current electricity. The basic principle underlying the operation of PV modules dates back more than 150 years, but significant development really began following Bell Labs' invention of the silicon solar cell in 1954.

Today, Photovoltaic (PV) generation is becoming increasingly important as a renewable source since it offers many advantages such as no fuel costs, no pollution, requires less maintenance, and does not produce any noise, among others. It is clear that PV modules have relatively low conversion efficiency; therefore, in a PV system the controlling Maximum Power Point Tracking (MPPT) for the solar array is essential. Solar panels generate power by using the photovoltaic effect: electrons are transferred between different energy bands in the atom by means of irradiation. The solar panel has a characteristic p-v characteristic where a global maximum is present. This means that for a different operating point of the solar panel, a different output power is obtained. Therefore, only for one specific operating point, the maximum power output is obtained from the solar panel. This point in the P-V characteristic is called the Maximum Power Point (MPP). This MPP changes when the irradiation and temperature changes or when the solar panel is partially shaded. At the maximum power point, the PV operates at its highest efficiency. Therefore, several methods have been developed for determining the MPPT.

The output from the Photovoltaic module is very low which is insufficient for drive the load. So a Cuk converter is used to boost the output voltage from PV module. CuK converter is actually the cascade combination of a boost and a buck. This is used because it has continuous input and output current. It's output voltage is either greater or less than input voltage.

In this paper, an MPPT based PV module with Cuk converter is used for electrical applications. Here the water pumping application is considered. A single phase induction motor is used for pumping the water. The MPPT algorithm here used is the Perturb and Observe (P & O) algorithm. The P and O algorithm is very simple and easy to implement.

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## II. SYSTEM CONFIGURATION AND MODELING

Fig 1. shows the block diagram of the MPPT based PV module with Cuk converter for water pumping application. There are five key components in the system: 1) PV cell 2) Cuk converter 3) PWM inverter 4) Battery 5) Single phase asynchronous motor.

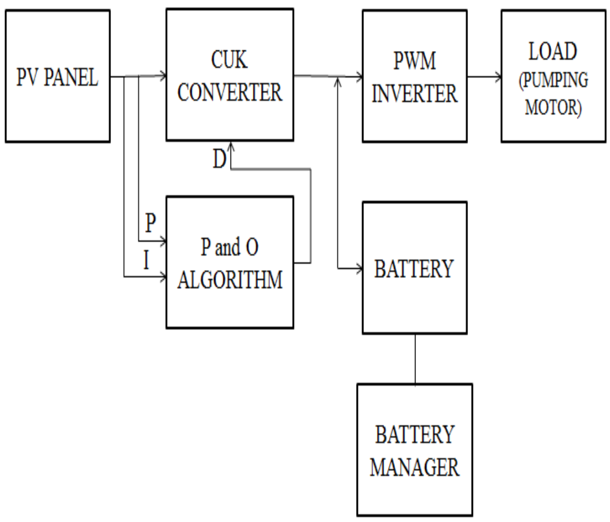


Fig.1. Block diagram of MPPT based PV module with Cuk converter for water pumping application.

In this proposed system, the PV module produces a low DC output voltage. For boosting this PV voltage a Cuk converter is used. It is clear that the output from the PV panel is varying. So an MPPT algorithm is used to track the maximum power from the PV panel. Here the Perturb and Observe (P & O) algorithm is used because of its simplicity and ease to implement. Here power and current is taken as the input to the P & O algorithm. By analyzing the variations in power and current, a corresponding duty cycle is produced. This duty cycle signal is given as the gate signal for Cuk converter. The boosted output DC voltage from the cuk converter is converted to single phase AC signal using a PWM inverter. Here a battery is used as a backup source due to insufficiency of solar light in some situation. The output voltage from the inverter (230V) is given to the motor for pumping the water.

### A. PHOTOVOLTAIC CELL MODELLING

The photovoltaic system (PV) for converting solar energy into electricity is a vital way for the generation of electricity only if, for all weather conditions it can produce the maximum possible output. The PV array has a highly non-linear V-I characteristic varying with the irradiance and temperature that substantially affects the array power output.

The Maximum Power Point Tracking (MPPT) control of the PV system is therefore critical for the success of a PV system. MPPT algorithms are ranging from simple hill-climbing algorithms to fuzzy logic and neural network algorithms. The hill climbing algorithms are widely used for the practical PV systems because of its simplicity and it does not require prior study or modeling of the source characteristics and can account for characteristics drift resulting from shadowing, ageing, or other operating irregularities. The P & O algorithm is the most commonly used hill climbing algorithm.

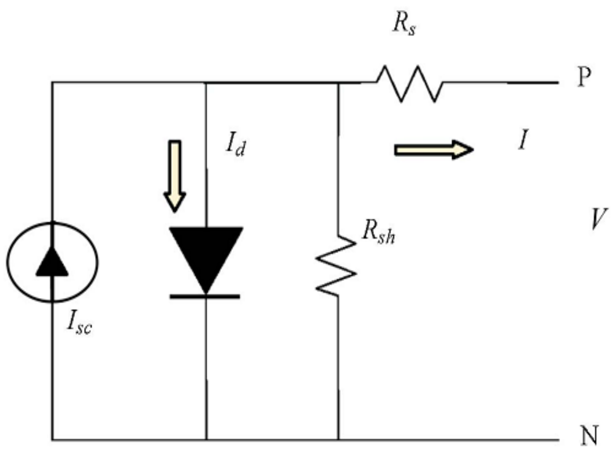


Fig.2. Equivalent circuit of a PV cell

The building block of PV arrays is the PV cell, which is basically a p-n semiconductor junction, shown in figure.2. The V-I characteristic of a solar cell is given by the Eq.(1).

$$I = I_{sc} - I_o\{\exp[(q(V+R_sI))/nkT_k]-1\}-((V+R_sI)/R_{sh}) \quad (1)$$

Where the output voltage and current of the PV cell is represented by V and I respectively; *Rs* and *Rsh* are the series and shunt resistance of the cell; *q* is the electronic charge; *Isc* is the light-generated current; *Io* is the reverse saturation current; *n* is a dimensionless factor; *k* is the Boltzmann constant, and $T_k$ is the temperature in kelvin.

Voltage output of a PV cell:

$$V_{pv} = [NsAKT/q]\ln[(Np\times Iph-Ipv+Np\times Io)/Io]-IpvRs \quad (2)$$

Current output of a PV cell:

$$Ipv = Np\times Iph-Np\times Io[\exp[(q(Vpv+RsIpv))/NsAkTk]-1] \quad (3)$$

The output power P of PV array can be calculated by using the following equation:

$$Ppv = Ipv\times Vpv \quad (4)$$

$$Ppv=Vpv\times Np\times Iph-Vpv\times Np\times Io[\exp[(q(Vpv+RsIpv))/NsAkTk]-1] \quad (5)$$

Where,

$N_s$ is the total number of series connected cells.
$N_p$ is the total number of cells connected in parallel.

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$V_{pv}$ is the output voltage of a PV cell (V).
$I_{pv}$ is the PV cell output current (A).

Saturation Current,

$$Is=Io*((T/T_r)^\wedge 3)*\exp(((q*Ego)/(K*A))*((1/T_r) - (1/T))) \quad (6)$$

Where,

Ego – Band gap for silicon (1.1 eV).
$T_r$ – Reference temperature.
T – Cell temperature.
K – Boltzmann Constant (1.3806e-23Nm/K).
q – Charge of electron (1.602e-19Coulomb).
A – Ideality factor (1.4952)

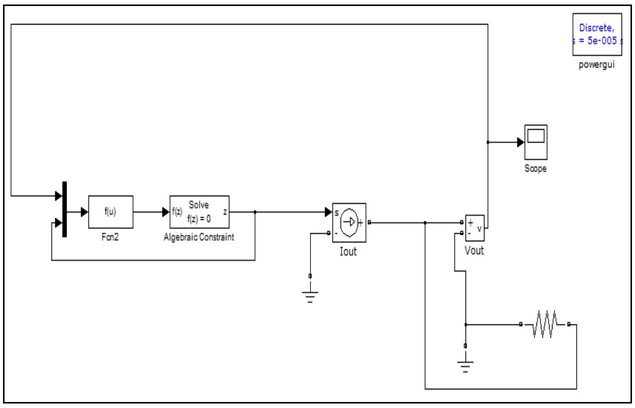


Fig 3. Simulink model of a PV cell

Here the MATLAB coding is used to design the PV module. 72 cells are used here to develop the required voltage.

## B. MAXIMUM POWER POINT ALGORITHM

The maximum power operating point in a PV module depends on the operating temperature, solar radiation level, and load current. That's why control algorithms are developed in order to ensure that operating point achieves its optimal value. Maximum Power Point algorithms are necessary in PV applications because the MPP of a solar panel varies with the irradiation and temperature, therefore the use of MPPT algorithms is required in order to obtain the maximum power from a solar array.

### B1. PERTURB AND OBSERVE TECHNIQUE

The perturb and observe (P and O) algorithm, also known as the hill climbing method, is very popular and the most commonly used alogorithm because of its simplicity in algorithm and the ease of implementation. The basic form of the P&O algorithm operates as follows. Figure 4 shows a PV module's output power curve as a function of voltage (P-V curve), at the constant irradiance and the constant module temperature, assuming the PV module is operating at a point which is away from the Maximum Power Point. In this algorithm the operating voltage of the PV module is perturbed by a small increment and the resulting change of power ΔP is analyzed. If the ΔP is positive, then it is supposed that it has moved the operating point closer to the MPP. Thus the further voltage perturbations in the same direction should move the operating point toward the MPP. If the ΔP is negative the operating point has moved away from the maximum power point and the direction of perturbation should be reversed to move back toward the MPP. Figure 5 shows the flowchart of this algorithm.

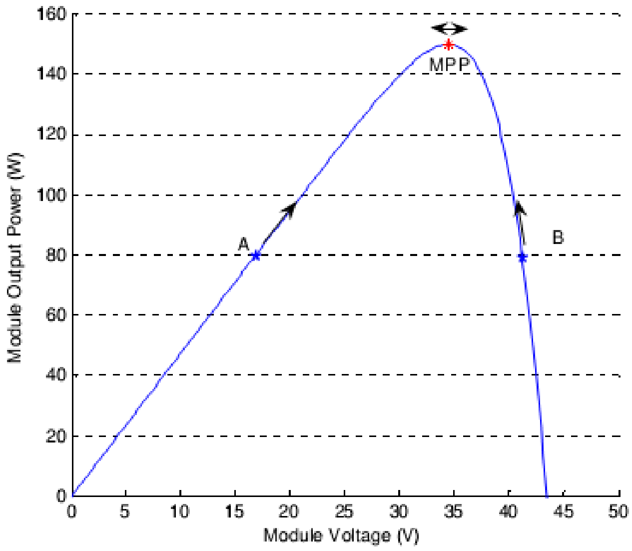


Fig 4. P-V characteristics of a PV cell

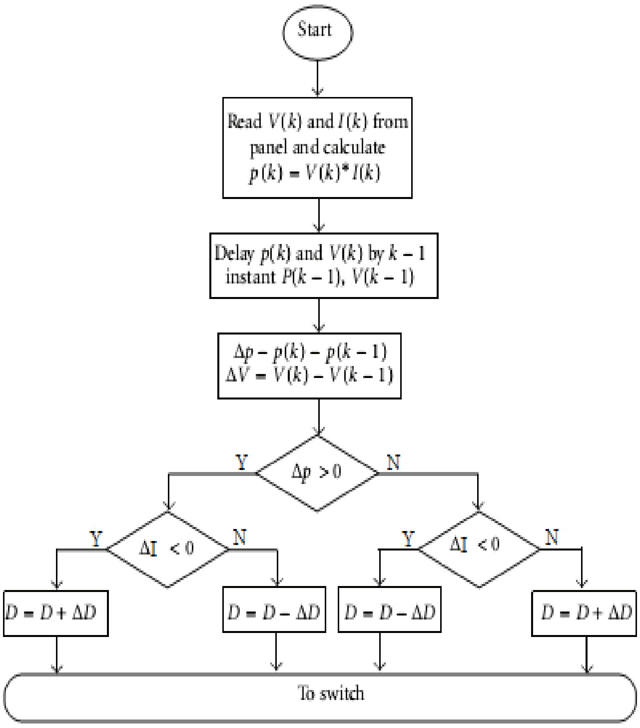


Fig 5. Flowchart of P & O MPPT algorithm

## C. CUK CONVERTER

Cuk converter is the cascade combination of a boost and a buck converter. Cuk converter has the following advantages.

- Continuous input current.
- Continuous output current.
- Obtained output voltage can be either greater or less than input voltage.

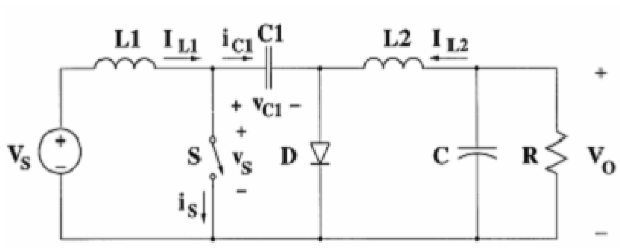


Fig 6. Cuk Converter

The circuit of the Cuk converter is shown in Fig.5. It consists of an input dc voltage source $V_S$, input inductor $L_1$, energy transfer capacitor C1, controllable switch S, diode D, filter capacitor C, filter inductor L2, and load resistance R.
The main advantage of this topology is a continuous current at both the input and the output of the converter.

### D. MATLAB/SIMULINK MODEL OF AN MPPT BASED PV MODULE WITH CUK CONVERTER

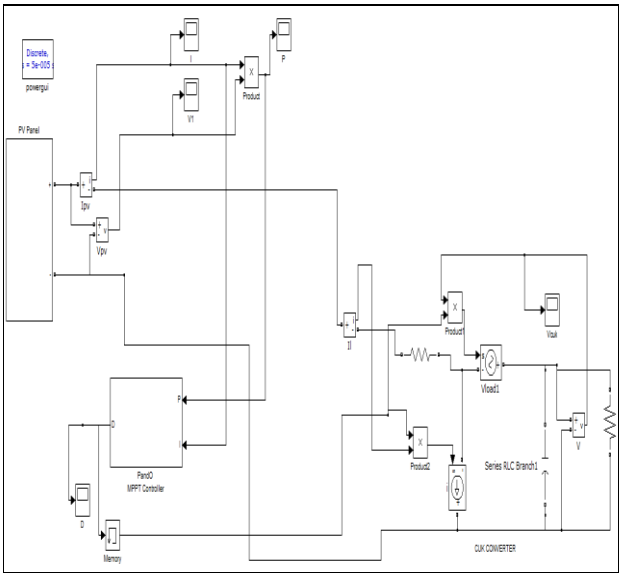

Fig 7. Simulink model of an MPPT based PV module with Cuk converter

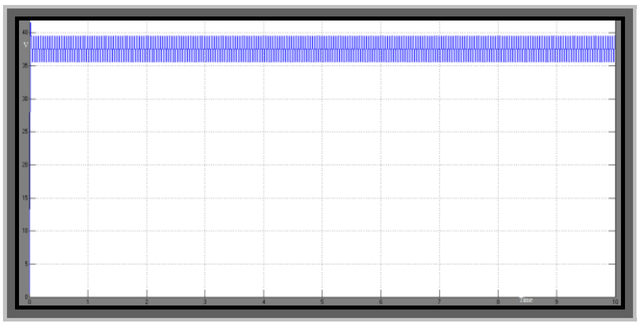

Fig 8. Output Voltage waveform of the PV module

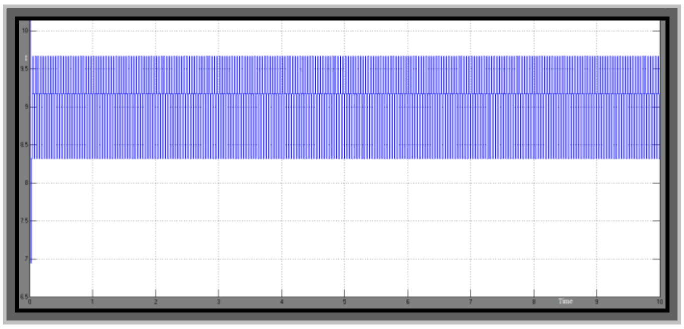

Fig 9. Output current waveform of the PV module

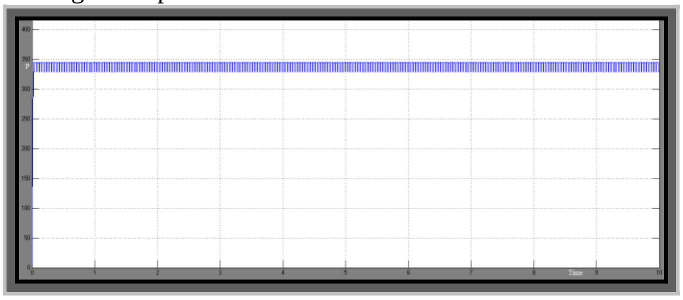

Fig 10. Output power of the PV module

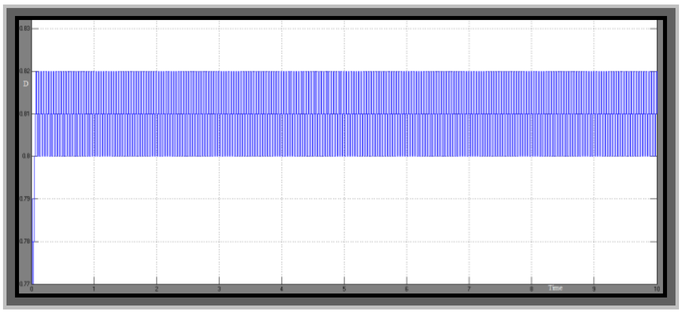

Fig 11. Duty Cycle from the MPPT algorithm

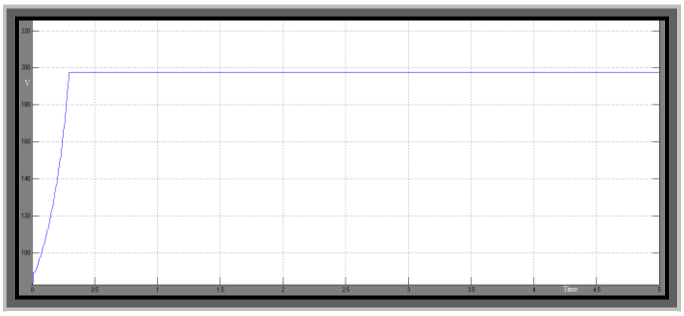

Fig 12. Cuk converter output voltage

### E. BATTERY

Many battery systems have been used for electric applications, that is, by using Ni-Cd, Pb acid, or Ni-MH type. Practical experience shows that Ni-MH type, in spite of its higher cost, is the most suitable system in terms of endurance and reliability. As a result, the hybrid system developed in this paper,it includes a Ni-MH battery. The battery specifications are 300 Ah and 215 V. It has been modeled by the Ni-MH battery model included in SimPowerSystem.

$$U_{bat} = E - R_i \cdot i \qquad (7)$$

$$E = E_o - K \cdot (Q/(Q-\int i \cdot dt)) + A \cdot \exp(B \cdot \int i \cdot dt) \qquad (8)$$

Where $U_{bat}$ is the battery voltage, E is the no-load voltage, $R_i$ is the internal resistance, I is the battery current, $E_o$ is the constant voltage, K is the polarization voltage, Q is the battery capacity, A is the exponential voltage, and B is the exponential capacity.

In the transportation application using Ni-MH batteries, the state of charge (SOC) is preferably kept as close to 50% as possible or within 30% to 70%. Since at these SOC's, the Coulombic charge efficiency is very high. Thus, the implemented model calculates the battery SOC as

$$SOC = 100 \cdot (1-(\int i \cdot dt)/Q) \quad (9)$$

### F. SIMULINK MODEL OF AN MPPT BASED PV MODULE WITH CUK CONVERTER FOR WATER PUMPING APPLICATION

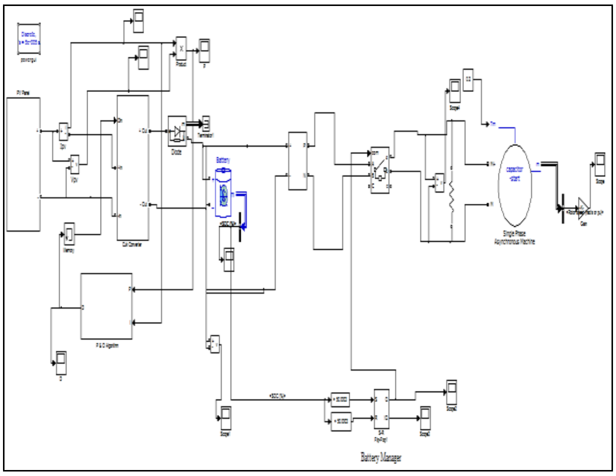

Fig.13. Simulink model of an MPPT based PV module with Cuk converter for water pumping application.

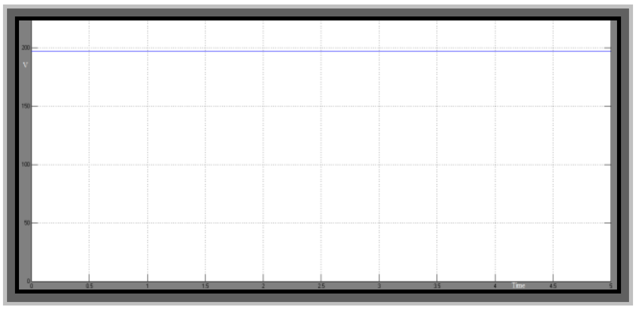

Fig.14. Output Voltage of battery

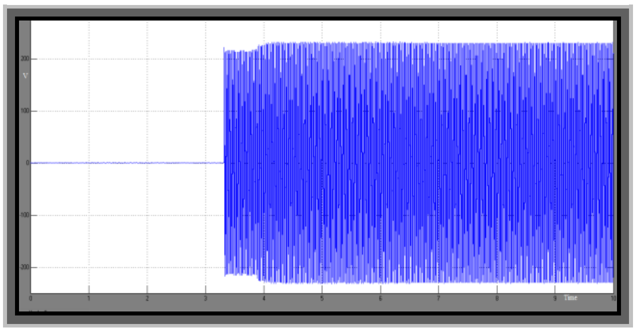

Fig.15. PWM inverter Output Voltage

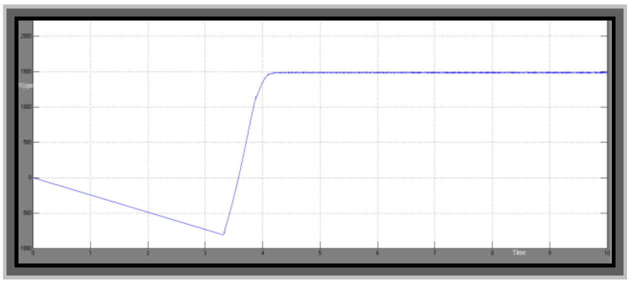

Fig.16. Speed of the motor

## CONCLUSION

In this paper, a high-performance stand-alone PV generation system for water pumping application is successfully developed. Perturb and observe algorithm has been used for maximum power point tracking. The results validate that MPPT can significantly increase the efficiency of energy production from PV and the performance of the PV water pumping system. According to the results, the conversion efficiency of the proposed converter is higher than the conventional converters. Also, the ac output voltage of the PWM inverter can almost maintain a sinusoidal waveform, and the corresponding THD value is between 2 to 3%, which satisfies the demand of the harmonic standards in industrial applications . The effectiveness of the system is verified through the MATLAB simulation.

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