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Modeling and Simulation of Solar Photovoltaic dc water pumping system Using MPPT

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Abstract - *Solar Photovoltaic (PV) systems are having growing importance in present time of our power system due to its non-polluting, minimum maintenance, and free fuel characteristics.Photovoltaic systems are comprised of photovoltaic cells, devices that convert light energy directly into electricity. Since the source of light is usually the sun, they are often called solar cells. Photovoltaic modules are widely used in DC applications. One of these applications may be in water pumping system. The boost converter has been used boosting the weak output voltage generated by the cells. Boosting of voltage is being done in reality by the maximum power point technique (MPPT). In this technique the automated tracking to give the highest output power is done by an algorithm. This generated power is fed to a boosting load across which the boosted output voltage is being received. This output voltage is then fed to operate a PMDC motor, driving a pumping system.*

Key Words: Solar PV module, Boost converter, Maximum power point tracking (MPPT), MATLAB (Simulink).

1. INTRODUCTION

Energy is the basic requirement for human lives. So that its supply should be secure and sustainable and at the same time it should be eco-friendly, economic and socially acceptable. The regular hike of fuel prices together with increasing carbon footprints threatens our energy supply. Among all the renewable energy resources such as solar, wind, ocean, geothermal etc. solar is abundant. In recent years, various research work have been done on the application of PV as a alternate energy source. PV energy is one of the promising energy resources as a clean, inexhaustible and can be easily harvested. Several applications employing Solar PV technology

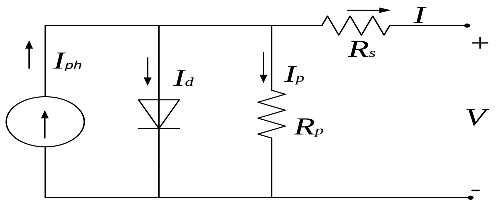

Fig no.1. Practical single diode model with R_s and R_p

have been developed for satellite power systems, solar power generation, solar battery charging station and solar vehicles.

At higher solar irradiance it gives greater value of current. Solar cells are connected in combination of series and parallel according to the voltage, current and power rating is required. The model of solar module is configured by using SIMULINK blocks. Boost converter is used for regulating the voltage of the solar PV system. The gate signal of dc-dc converter is given from the MPPT algorithm. Perturbation and observation technique is used for tracking the maximum power point of the PV module. The algorithm takes voltage and current signal from the solar PV module and after optimizing voltage value a referenced duty cycle is generated which is given to dc-dc boost converter.

1.1 Block Diagram of Model

The objective of this project is to design a DC-DC boost converter with MPPT to run a permanent magnet dc motor in water pump system using (PV cell) photovoltaic as a source. The simulation is able to model a PV array in order to plot the I-V curve and P-V curve to indicate the electrical characteristic of the PV cell. Then the project also includes Mat lab Simulink to verify the output voltage level of the design in DC-DC converter (Boost Chopper), then, the combination of the PV array, DC-DC boost converter with MPPT and permanent magnet dc motor are simulated as well. The simulation is able to draw the curve torque, speed and current of the permanent magnet dc motor and draw the curve Current &Voltage of boost converter are better than without MPPT control mechanism. The block diagram of pumping system using PMDC motor fed by PV cell with MPPT boost converter shown in fig.2. The PV array consists of an array of solar cell modules to provide the desired DC voltage and current. The solar irradiance received on the surface of the PV cells is converted instantaneously into electric power by PV effect .The pumping subsystem is composed of a motor-pump set and a power conditioning equipment. The motor is a machine which transforms the electrical energy into mechanical energy. The motor used in the PV pumping systems is one of two main types, either induction motor or DC motor. In this system, a permanent magnet DC motor is considered.

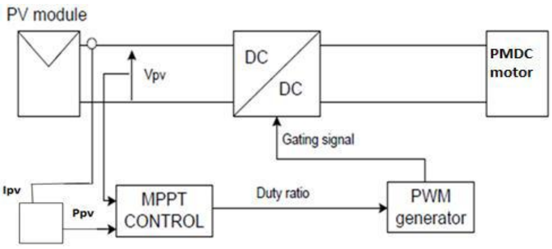

Fig.2. Block diagram of proposed PMDC Pumping system

2. PHOTOVOLTAIC ARRAY MODELING

2.1: model of the photovoltaic cell

PV cell is a semiconductor p-n intersection that transforms sunlight to electrical power.A PV cell is usually embodied by an electrical equivalent of one-diode, resistance series Rs and resistance parallel Rp as shown in Figure 3

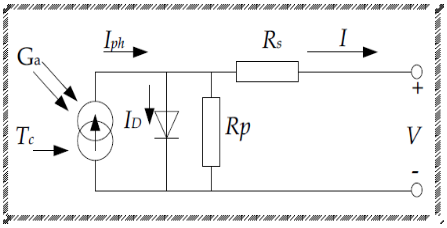

Fig3. Equivalent circuit of solar cell with one diode

From the figure 3 the different parameters characteristics of the PV cells are: Iph: currents generated by the solar cells (A),Rs: resistance series (Ω),Rp: resistance parallel (Ω),Ga: irradiance from the sunlight (W/m2), T: cell temperature (K) Id: diode current (A),I: output current of the PV (A) ,V: output voltage of the PV (V).

Manufacturer of the solar module gives the parameters needed to model the solar cells. The datasheet which gives the electrical characteristics is calculated under standard test condition STC when the temperature T is 25°C and the irradiance G is 1000 W/m2.

The solar cell is model first, then extends the model to a PV module, and finally models the PV array. From figure 3 the output current of the PV cell is

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

Where *Iph*: photon produced by the cell, Id: diode current

By Shockley equation, the diode current Id is given by

$$I_d = I_o\,[e^{\frac{qV_d}{KT}} - 1] \qquad (2)$$

Where I0: reverse saturation current of diode, q: elementary electron charge (1.602x10-19 C), *Vd*: diode voltage,k: Boltzmann constant 1.381x10-23 (J/K)

T: temperature in kelvin (K)

The relation between voltage and current result by replacing the diode current

$$I = I_{ph} - I_o\,[e^{\frac{qV_d}{KT}} - 1] \qquad (3)$$

The reverse saturation I0 is found by using the above equation. By setting the current I equal to zero and calculating at temperature T1

$$I(T_1) = \frac{I_{ph}(T_1)}{[\exp(\frac{qV_{oc}}{KT}) - 1]} \qquad (4)$$

The current generated by the solar cells Iph can be approximated with the short circuit current Isc . The current generated can be calculated for other irradiance. The standard current, temperature and irradiance from the datasheet are used to determine the current at different condition.

$$I_{sc} = I_{ph}$$

$$I_{sc}(T_1) = (\frac{G}{G_{nom}})\, I_{sc}\,(T_{1,nom}) \qquad (5)$$

Where Isc(T1): current at temperature T1 ,T1 nom the temperature of cell from datasheet at STCG nom: irradiance from datasheet at STC After calculation,gives the equation of the PV

$$I = I_{ph} - I_o\,[\,exp\frac{q(V+I\,Rs)}{a\,K\,Ns} - 1\,] - \frac{V+I\,R_s}{R_p} \qquad (6)$$

For a PV module, the cell voltage is multiplied by the total amount of the cells found within the series. The reverse saturation current I0 depends on the temperature T. It is calculated by the following equation.

$$I_0 = I_o\,(T_1)(\frac{T}{T_1})^{\frac{3}{n}} \exp[\frac{q\,V_{d(T1)}}{a\,K}\,(\frac{1}{T_n} - \frac{1}{T})] \qquad (7)$$

2.2: Model of the photovoltaic module

The equation used to calculate the I-V curve is

$$I = I_{ph} - I_o\,[\,exp\frac{q(V+I\,Rs)}{a\,K\,Ns} - 1\,] - \frac{V+I\,R_s}{R_p} \qquad (8)$$

Where Ns: number of cells in series

The current produced Iph is linearly dependent of the solar radiation and the temperature

$$I_{ph} = (I_{phn} + Ki\ \Delta T)\,\frac{G}{Gn} \qquad (9)$$

Where Ki: temperature coefficient current

ΔT: variation temperature

The diode saturation current I0 and the reliance on the temperature can be seen through

$$I_0 = I_o(T_1)\left(\frac{T}{T_n}\right)^3 \exp\left[\frac{q\,V_{d(T1)}}{a\,K}\left(\frac{1}{T_n}-\frac{1}{T}\right)\right] \quad (10)$$

$$I_{on} = \frac{I_{sc,n}}{\left[\exp\left(\frac{V_{oc,n}}{aV_{tn}}\right)-1\right]} \quad (11)$$

The circuit model of the PV module is shown in figure 4. It is a controlled current source with the equivalent resistors and the equation of the model above. The variation of the power being taken by the load varies the PV voltage.

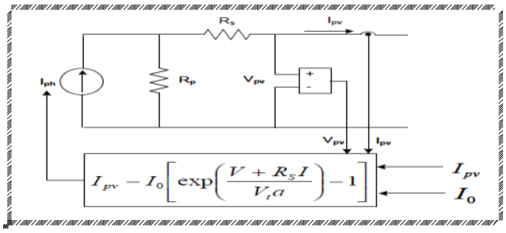

Fig 4: Circuit model of the photovoltaic module

2.3: photovoltaic array

The PV array is composed of several interconnected photovoltaic modules. The modeling process is the same as the PV module from the PV cells. The number of modules connected in series and connected in parallel must be calculated. Photovoltaic array, which consists of multiple modules, linked in parallel and series. Nser is the total quantity of modules within the series and Npar is amount of modules in parallel. The number of modules modifies the value of resistance in parallel and resistance in series. The value of equivalent resistance series and resistance parallel of the PV array are:

$$R_{s,array} = \frac{R_{s,module} \cdot N_{ser}}{N_{par}}$$

$$R_{p,array} = \frac{R_{p,module} \cdot N_{ser}}{N_{par}}$$

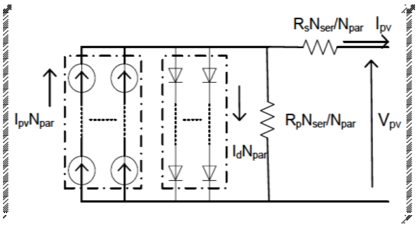

Fig 5 PV Array composed of Nserx Npar modules

After extending the relation current voltage of the PV modules to a PV array, the new relation of current voltage of the PV array

$$I = I_{ph}\,N_{par} - N_{par}.I_o\left[\exp\left\{\frac{q\left(V+I\,Rs\left(\frac{N_{ser}}{N_{par}}\right)\right)}{a\,K\,Ns}\right\}-1\right]-\left[\frac{V+I\,Rs\left(\frac{N_{ser}}{N_{par}}\right)}{Rp\left(\frac{N_{ser}}{N_{par}}\right)}\right] \quad (12)$$

3. Photovoltaic PMDC pumping system with MPPT boost converter

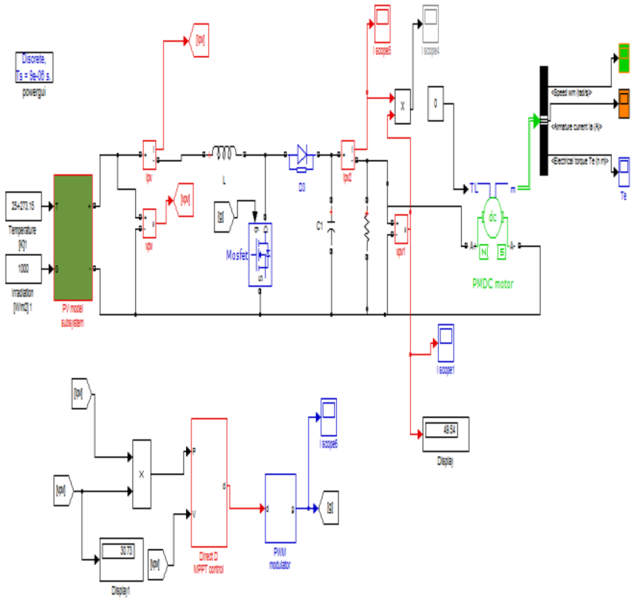

Fig 6 - Photovoltaic PMDC pumping system with MPPT boost converter

Figure 6 shows the implementation of solar PV module with DC-DC boost converter. Voltage and current is sensed from the PV module and boost converter and analyzed in the scope. The output voltage is controlled by using PWM technique by changing the duty cycle.

In this model the duty cycle is constant hence MPP is not achieved all the instant of time. For varying irradiance and temperature signal builder block is used. Various signal of output of PV module and DC-DC converter is analyzed in scope.

4. RESULT ANALYSIS

4.1. Photovoltaic Array Simulation

The simulation of a photovoltaic Array was done using MATLAB / SIMULINK.

The Power (W), Voltage (V), Current (A) vs. Time (s) and I-V, P-V curves from the simulation are as shown fig

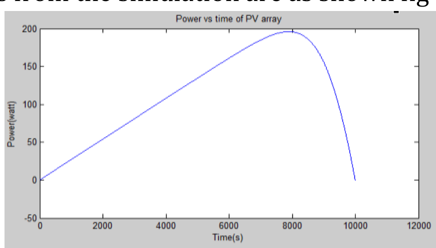

Fig.4.1 (a): Power (w) vs. time(s) of PV array

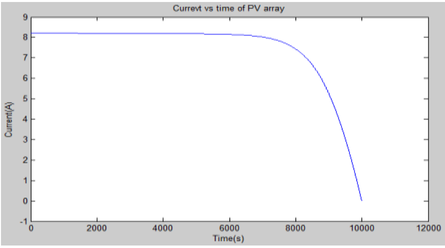

Fig.4.1 (b): Current (A) vs. time (s) of PV array

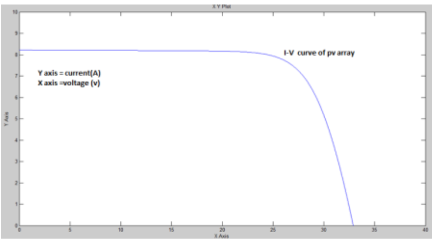

Fig.4.1(c):I-V output characteristics of PV array

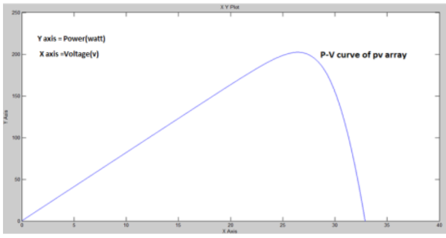

Fig.4.1 (d): P-V output characteristics of PV array

4.2: Effect of variation of solar irradiation

The MATLAB code for PV array P-V, P-I and I-V curves of a solar cell are highly dependent on the solar irradiation values. The solar irradiation as a result of the environmental changes keeps on fluctuating, but control mechanisms are available that can track this change and can alter the working of the solar cell to meet the required load demands. Higher is the solar irradiation, higher would be the solar input to the solar cell and hence power magnitude would increase for the same voltage value. With increase in the solar irradiation the open circuit voltage increases. This is due to the fact that, when more sunlight incidents on to the solar cell, the electrons are supplied with higher excitation energy, thereby increasing the electron mobility and thus more power is generated.

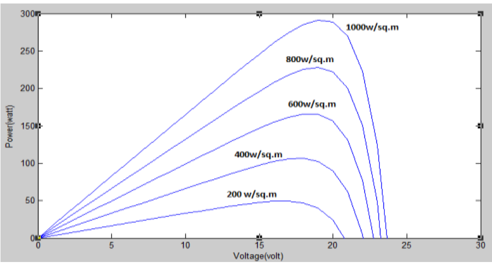

Fig.4.2(a):P-V characteristic for Fixed temperatures and various irradiance at 1000 (W/m2).

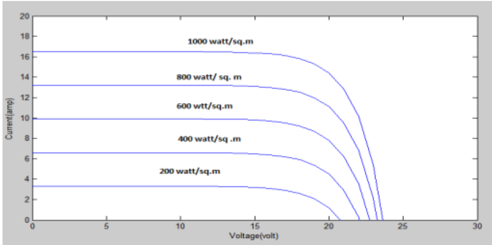

Fig.4.2(b) : I-V characteristic for fixed temperatures at various irradiance at 1000 (W/m2)

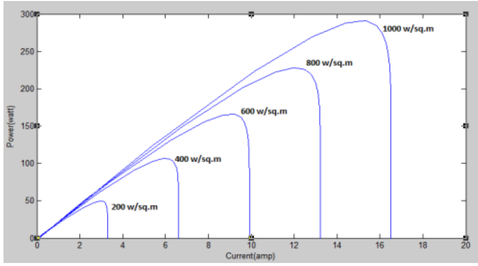

Fig.4.2.(c):P-I characteristic for fixed temperatures at various irradiance at 1000 (W/m2).

4.3: Simulation results of the boost converter model

The simulations were carried out in Matlab/Simulink and the various Voltages (V), Currents (A) and Power (watt) vs. time (s) plots in MPPT and without MPPT were obtained shown in fig

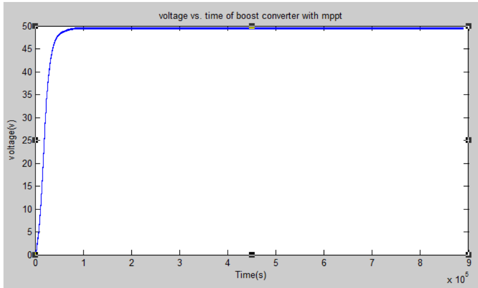

Fig.4.3. (a): Voltage (v) vs. time (s) of boost convertor with MPPT

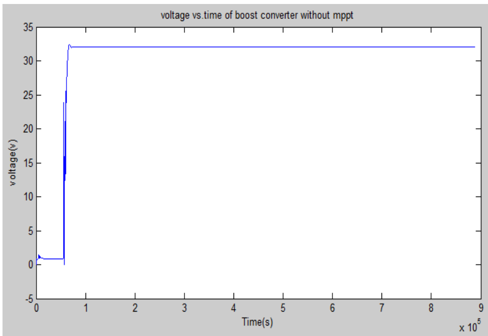

Fig.4.3 (b): Voltage (v) vs. time(s) of boost convertor with MPPT

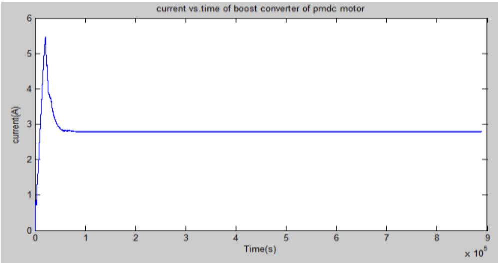

Fig.6.3(c): Current (A) vs. time (s) of boost convertor with MPPT

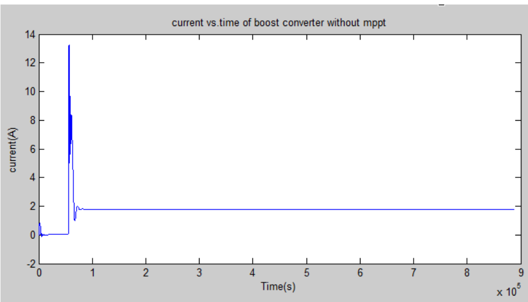

Fig.6.3 (d): Current (A) vs. time (s) of boost convertor without MPPT

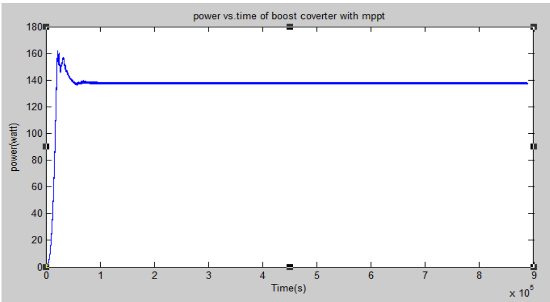

Fig.4.3 (e): Power (w) vs. time(s) of boost convertor with MPPT

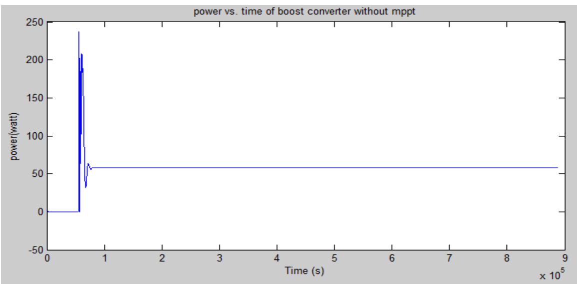

Fig.4.3 (f): Power (w) vs. time (ms) of boost convertor without MPPT

4.4: simulation results of the permanent magnet dc motor at no load

The simulations were carried out in Matlab/Simulink and the various Torque (N-m) ,Armature Currents(A) and Speed(red/sec) vs. time(s)plots in MPPT and without MPPT were obtained shown in fig

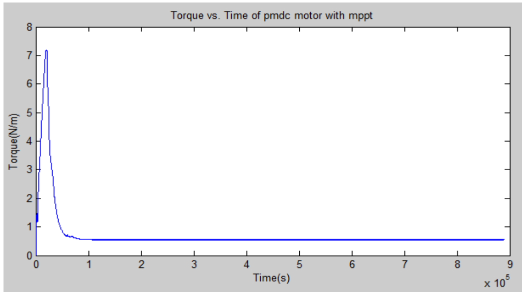

Fig.4.4 (a): Torque (N-m) vs. time (s) of PMDC motor with MPPT

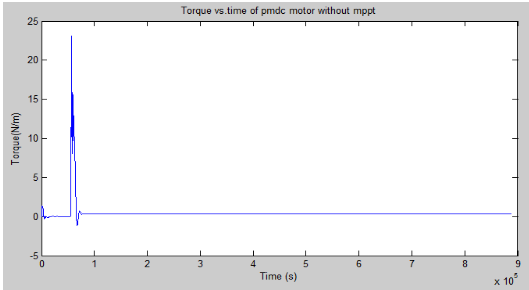

Fig4.4(b): Torque (N-m) vs. time (s) of PMDC motor without MPPT

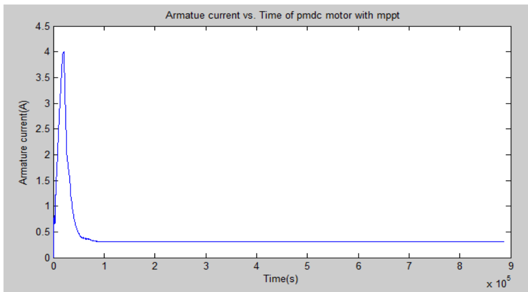

Fig.4.4(c): Armature Current (A) vs. time (s) of PMDC motor with MPPT

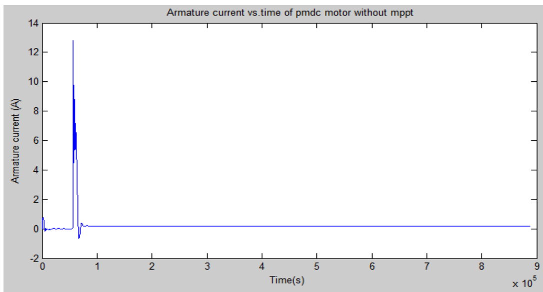

Fig.4.4 (d): Armature Current (A) vs. time (s) of PMDC motor without MPPT

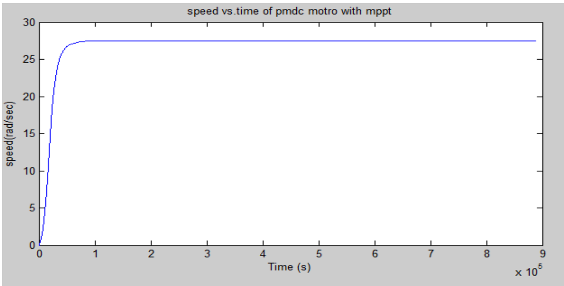

Fig.4.4 (e): Speed (red/sec) vs. time (s) of PMDC motor with MPPT

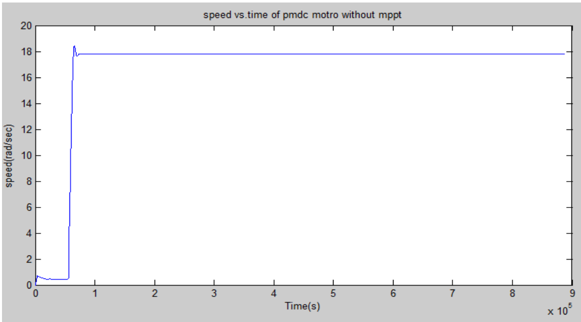

Fig.4.4 (f): Speed (red/sec) vs. time (s) of PMDC motor with MPPT

5. CONCLUSIONSS

First, the simulations of the PVA showed that the simulated models were accurate to determine the characteristics voltage current because the current voltage characteristics are the same as the characteristics given from the data sheet. In addition, when the irradiance or temperature varies, the PVA models output voltage current change. Then, the simulation showed that Perturb and observe algorithm can track the maximum power point of the PVA, it always runs at maximum power no matter what the operation condition is. The results showed that the Perturb and observe (hill climbing method)algorithm delivered an efficiency close to 100% in steady state. Finally the overall cascaded system consisting of PV array, DC – DC boost converter insisting MPPT and PMDC motor without any load is simulated to show the related results such as torque, speed armature current of PMDC motor at no load and current as well as voltage curves of boost converter . After that the results are compared for the system consisting MPPT and without the same. The result shows that PV water pumping system with MPPT is better than without MPPT system.

6: FUTURE WORK

Extensive simulation of the PV system should be done. A voltage control can be implemented to keep the boost converter output voltage constant .

Finally, a laboratory setup should be made to verify the simulation results with the experimental tests.

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BIOGRAPHIES

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