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Design of Solar PV Tracking System Using Heliostat for Pump Drive System

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Abstract: This paper deals with the tracking heliostat isolated with Photo voltaic (PV) for standalone and rural areas is proposed. Here, a heliostat is used to provide light radiation to solar PV system to convert renewable energy solar PV power into electrical power. An actuation system based on BLDC motor drive and a controller is proposed to change direction of heliostat device such that the radiation falls on PV panels to generate electrical power. Thus proposed system holds advantage of reducing heat that falls on PV panels and increase life time of PV panels. Here an effective tracking control algorithm of heliostat is proposed with BLDC motor drive and conventional PID techniques. The proposed system is carried as pilot project and tested in different solar PV radiations conditions.

Keywords: Heliostat, Solar Energy, Actuation System, Tracking, BLDC Motor, Controller.

I. INTRODUCTION

Growing of energy demands increases day by day due to reduction in conventional energy generation it's a necessary to reduce dependency on fossils fuels based power. The widespread energy shortage of India nation is 24,077 million units disturbs both the normal life of a common man and the economy our nation. More than eighty percent of the global energy demand is supplied by burning the fossil fuels. But due to the burning of fossil fuels, global warming and air pollution are increasing dangerously. Also the reserves of fossil fuels are diminishing at a fast rate. Hence in this scenario it is very important to switch over to harmless power generation schemes for finding the solutions for all the above problems. Hence the utilization of renewable energies like solar energy, wind energy,etc in a sophisticated way can find solution for the power shortage and environmental problems. Solar power generation system with boost dc-dc conversion and dc-ac conversion was presented by Carlos Meza & Domingo Biel (2005). The output power of the panel is affected by many variables that continually changes throughout the day. This produces fluctuation in voltage and current that makes the panel less efficient. The oscillating conditions are determined by environmental factors, chemical composition of the panel, and the angular position of the sun

The most abundant fuel source in the area of renewable energy is the sun. Solar panels produce electricity through individual photovoltaic cells. This form of energy collection is viable in regions of the world where the sunlight is plentiful, and can be used in isolated regions or on houses to supplement the rising cost of electricity from a power grid. To convert the sun's energy, the cells capture photons to create free electrons that flow across the cells to produce usable current (Penick & Louk 2007). The efficiency of the panel is determined by the semiconductor material that the cells are made from as well as the process used to construct the cells. Solar panels come in three types: amorphous, mono-crystalline, and polycrystalline (Messenger & Ventre 2000).To maximize the efficiency, there are many features that can be used to control the output of the photovoltaic panels. The solar PV power generation is to increase the efficiency of the renewable energy generation systems simultaneously provide stability to power grid. Further a tracking device help power efficiency improvement in solar PV panel and improves existing energy production. The literature survey recites the solar power generation in different categories namely the application and advantages of proposed controller over conventional controllers in solar energy generation for tracking devices.

Heliostat is with process of receiver, storage and power cycle of solar radiation. Further, heliostats reflect solar radiation to one solar PV panel to absorb more energy. This generates high temperature steam or air which operates steam or gas turbine power generator. As the solar radiation from heliostat to receiver is depended on the angle and location of the heliostat, the algorithm of controlling the heliostat in real time is the most important factor to influence system efficiency and performance. [1-4] Therefore, this study was conducted to design and control of heliostat using a solar tracking device and a configuration factor commonly used in radiation heat transfer applications.Generally Dc to DC based solar power generation scheme consists of solar photovoltaic array, boost dc to dc converter and a full bridge inverter. The output voltage of solar photovoltaic panel is boosted by the boost dc to dc converter and the resultant voltage is converted to ac by using dc to ac inverter. But the said system results in larger size, higher cost and more switching losses due to two conversion stages.. Since solar energy is only produced during the day, requiring an energy storage application by either a battery or connecting to the power grid to provide power during the night.

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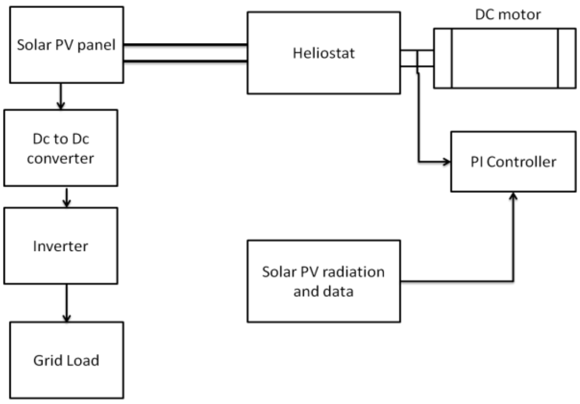

Fig. 1. Overview of Proposed Drive System

II. Photo Voltaic Modeling

The equivalent model of a photovoltaic cell can be represented by figure 2 as shown below. To obtain maximum power from solar are connected in series or in parallel, which forms a module. Again, these types of modules are connected in parallel or in series to get required voltage and current. The characteristics of PV cell can be derived using the equation given below.

$$I = Ipv - Io[e^{\frac{V+RsI}{Vt\,a}} - 1] - (\frac{V+RsI}{Rp}) \quad (1)$$

For making analysis easy, a mathematical model of moderate complexity was modeled. This equivalent model as in the Figure 2.5 consists of a current source and a diode connected in parallel with the current source, which determines the V-I characteristics of the cell. The output of the current source is directly proportional to the light falling on the cell.

A. Solar Cell:

A series resistance (R_{se}) was included which give a more accurate shape between the maximum power point and the open circuit voltage. Also the shunt resistance (R_{sh}) was connected in parallel with the diode to achieve characteristics match. The output current of the solar cell is given by

$$Io = I_L - (I_d + I_{sh}) \quad (1)$$

$$I_d = I_0\left(\exp\left[\frac{q(V_O + R_{Se}I_O)}{kT_k}\right] - 1\right) \quad (2)$$

$$I_0 = I_L - I_0\left(\exp\left[\frac{q(V_O + R_{Se}I_O)}{kT_k}\right] - 1\right) - \left(\frac{V_O + I_O R_{Se}}{R_{Sh}}\right) \quad (3)$$

Where I_{pv} = photo voltaic current, I_0 = Nil or saturation current, $V_t = N_s kT/q$, array thermal voltage, N_s= pv cell connected in series, T = PV panel diode temperature, k = constant of Boltzmann, q = electron charge, R_s= equivalent resistance of the series connected array, R_p= equivalent l resistance of parallel connected array, a = ideality constant of diode. The resistance connected in series ($R_{s)}$ can be regulated from the value of shunt resistance R_p either high or low when compared to the value of series resistance R_s. The saturation current generated by the light is linearly depends upon the solar irradiation from sun and temperature which, influence the generation of photovoltaic current in the solar cell which is derived by the following equation.

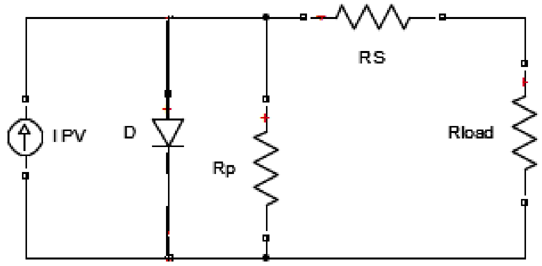

Fig. 2. Photo Voltaic Cell Equivalent Circuit

$$Ipv = [Ipv,n + K_I \Delta T]\frac{G}{Gn} \quad (4)$$

B. Design of Solar Tracking Device:

Fig. 3 shows a overview of the solar tracking device, which consists of a controller, DC motors, with four CdS sensors. The controller determines using MATLAB Simulink to calculate the solar PV position and operates the DC motors. DC motors are commonly used in servo positioning control applications due to its dynamic speed torque charters tics lead to selection of this drive system. The DC motor used in the prototype with specification of 24 V, 0.072o per step, and 0.567 torque N.m.

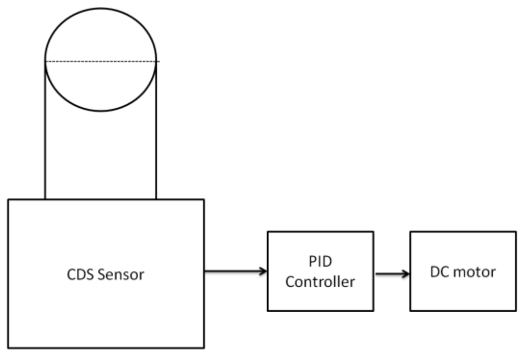

Fig. 3. Schematic Diagram For Solar PV Tracking

The voltage of the CdS sensor changes with the brightness of the light. Depending on the position of the sun, the cylindrical pillar has differing shadows. On the outside of the cylinder, north-, south-, east-, and west-facing CdS sensors detect the brightness of the ambient light. The voltage values, which vary with the brightness of the light, are inputted to an analog-to-digital converter. Mean voltage values (east–west and north–south) are set at a threshold value. When a CdS sensor provides a value lower than the threshold voltage, the system automatically adjusts the direction of azimuthal and elevation angle. Of the four CdS sensors (A, B, C, D), A and B are used to detect the azimuthal angle, while C and D to detect the elevation angle. As the sun moves to the west, shadows are formed on the east side. The reduced light causes the voltage value of the east-side ambient CdS sensor to decrease relative to that of the ambient CdS sensor located on the west side. Thus, tracking the sun is performed by activating the motor to move the heliostat toward the west until the output voltage of two CdS sensors A and B (azimuthal) is equal. The cylindrical housing height is calculated as follows: h is the height of the cylindrical housing, d is the diameter of the CdS sensor, and the trigonometric formula is tan / θ = h d . If the angle of the shadow formed by the cylindrical pillar is within 1°, h can be obtained by tan1o h d = · . If a CdS sensor (R1) and a resistor (R2) are connected to a circuit voltage, the output voltage can be calculated by the following expression: 2 / (2 1) V VR R R out in =· + When using this equation, output voltage increases in bright places because of the reduced resistance of R1 and decreases in dark places due to the increased resistance of R1. The output voltage is inputted to an analog-to-digital converter.

C. Solar Tracking Algorithms:

When CdS sensors located on the east side and west side detect voltage values, the average voltage of the two CdS sensors is calculated. This average value is set to a threshold value.

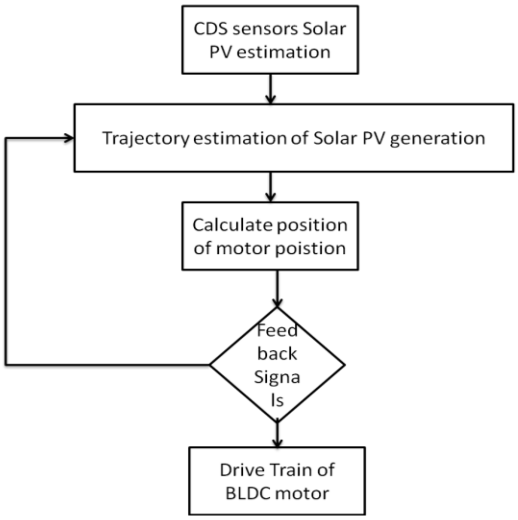

Fig. 4. Algorithm of Solar PV Tracking Device

If the voltage on the east side is lower than the threshold of the average azimuthal voltage and higher than a cloudy threshold, the condition causes the true value. If this condition is not satisfied, it generates a false value. The sensor value of the west side is calculated in the same way by a conditional statement. Also, solar tracking is stopped when the average threshold calculations per second (east–west, north–south) is lower than the cloudy threshold criterion.

If the control signal for forward and reverse rotation is entered into the motor at the same time, the motor causes the step out. Thus, one of the signals should be sent to the motor. The control algorithm for clockwise and counterclockwise movement is the same as above for the elevation angle. The procedure for calculating the azimuthal or elevation angle is as follows. Firstly, the number of pulses is calculated when the motor operates clockwise. Secondly, the clockwise angle is computed by multiplying the per pulse angle of the moving motor. Thirdly, the clockwise rotation angle is calculated by subtracting the counterclockwise angle. Finally, the azimuthal angle can be obtained by adding the initial azimuthal angle. The calculation algorithm for the elevation angle is the same as above.

III. DC TO DC CONVERTER

DC-DC converter is widely used in many applications especially in solar PV power generation to boost and regulated energy power.

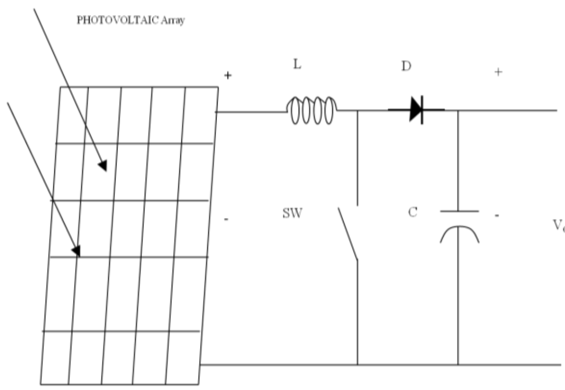

Fig. 5. Equivalent Circuit of Buck Converter

Here a basic DC-DC converters are used a pair of switched, usually one controlled switch as MOSFET and one uncontrolled switch as diode, to achieve unidirectional power flow from input and output power supply. A capacitor and inductor is filter and continuous energy deliver to load to store the energy purposes from the input; it can also filter the excess noise like voltage and current

The boost converter operates on two modes as continuous conduction mode and discontinuous conduction mode.

A. Continuous Conduction Mode (CCM):

When the switch is on for a time duration DT, the switch conducts the inductor current and the diode becomes reverse biased. These results positive voltages appear across the inductor. This voltage may lead to increase the load current.

B. Discontinuous Conduction Mode (DCM):

When the switch is off, the stored energy can flow through the diode for a time duration (1-D)T until the switch is turned o again. equivalent circuit of buck converter where the R is the load winding resistance and external resistance. The circuit has been normalized to the switching frequency through the assumption of L and C.

C. Difference Equation Method:

During the period of steady state the governing equation is to examine the current passing through a capacitor that is operating in periodic steady state.

$$v(t) = v(t_o) + \frac{1}{C}\int_{t_o}^{t_{o+t}} i(t)dt \qquad (5)$$

Since the capacitor is in periodic steady state, then the voltage at time t_0 is the same as the voltage one period T later, average current through a capacitor operating in periodic steady state is zero.

$$v(t_o + T) - v(t_o) = 0 = \frac{1}{C}\int_{t_o}^{t_{o+T}} i(t)dt \qquad (6)$$

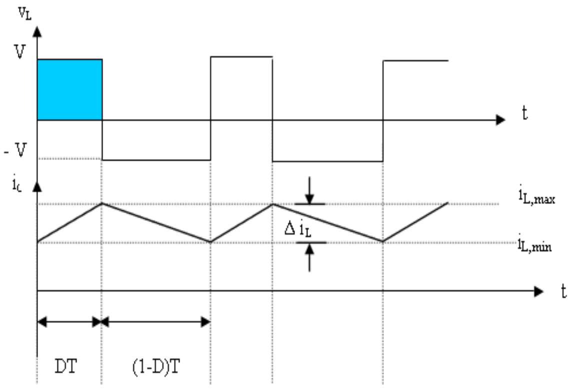

Fig. 6. Effects o Coupled Inductor

Assuming the duty cycle has an increase of DT during the transient, the inductor current has increases after one switching cycle. For the transient response, a small inductance is preferred so that a high transient inductor slew rate can be achieved. For the steady state operation, a large inductance is preferred so that the inductor current ripples can be reduced. As equation from (5)

This leads to

$$v(t) = L\frac{di(t)}{dt} \qquad (7)$$

$$i(t) = i(t_o) + \frac{1}{L}\int_{t_o}^{t_{o+t}} v(t)dt$$

Since the inductor is in periodic steady state, then the voltage at time t_0 is the same as the voltage one period T later, so

$$\int_{t_o}^{t_{o+T}} v(t)dt = 0 \qquad (8)$$

Which means that the average current through a inductor operating in periodic steady state is zero.

Duty cycle (δ) of a boost Converter can be given as

$$\delta = 1 - \frac{V_{in}}{V_o} \qquad (9)$$

Where V_{in} = input voltage of the Boost Converter which is equal to output of the photovoltaic array

V_o = output voltage of the Boost Converter

The value of the inductor (L) can be given as

$$L = \frac{V_{PV}\delta}{2\Delta i_1 Fsw} \qquad (10)$$

Where $V_{photovoltaic}$ = output voltage of the photovoltaic array.

IV. SIMULATION RESULTS & DISCUSSION

To validate the proposed block implemented in MATLAB Simulink environment. The radiation of solar PV is kept as constant value of block with value of irradiance 1000w/m^2. Converter and inverter circuits are such that to maintain output corresponds to input solar radiation data connected with cloud.

A PWM is generated according to output of solar feds and extract maximum power though heliostat to drive the motor constantly. Fig. 7 shows the representation solar pv tracking output in day light system and a sensor data of solar PV through cloud. Output voltage of solar PV is shown in Fig.8 to represent corresponding output to solar PV in real-time with corresponding heliostat output is simulated in fig. 8(b). The output voltage of inverter and converter fed to grid which needs to maintain constant output in sinusoidal with reduced harmonics as shown in fig. 9.

Fig. 7. Solar PV without Tracking

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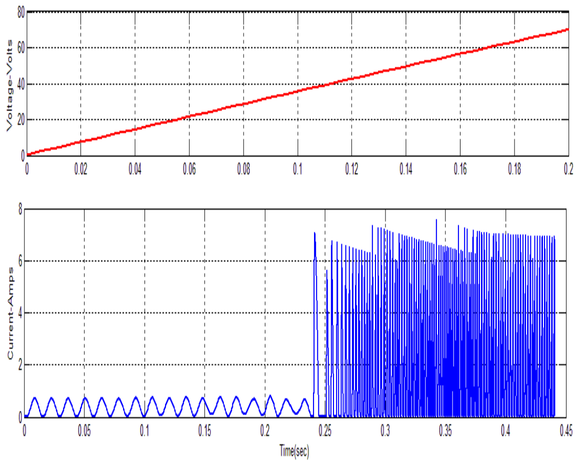

Fig. 8 Solar PV Power Generation with Heliostat Tracking

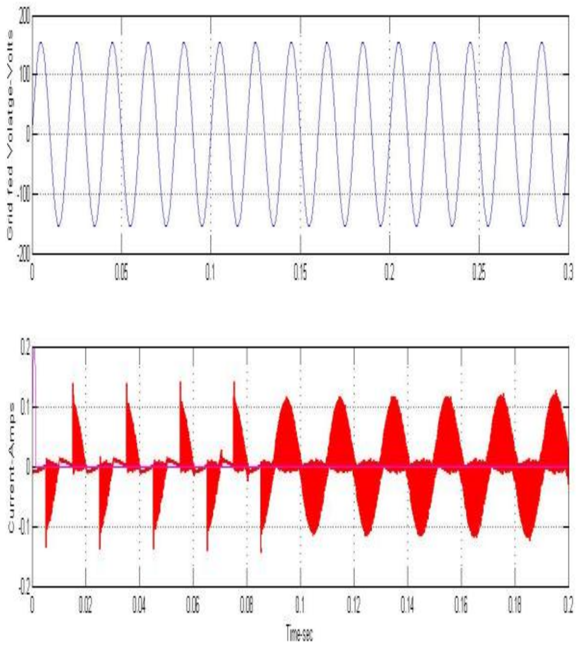

Fig. 9. Grid Fed PV Voltage with Heliostat Tracking

V. HARDWARE VALIDATION

Experimental verification was carried out from 10 a.m. to 5p.m. Solar tracking device heliostat was operated by a proposed algorithm to drive PV radiation fall on panel. The proposed system is developed in real-time prototype as shown in fig.10 here a 20 watts solar PV panel as arranged to solar radiation on panel with intensity 100w/m^2.

Converter and inverter arrangement is made to run with corresponding dSPIC controller and generation PWM signals to drive MOSFET switches to boost the input heliostat solar PV voltage and invert as ac voltage source for grid. Fig. 11 show the corresponding PWM signals generation for converter to drive and boost the voltage of solar PV.

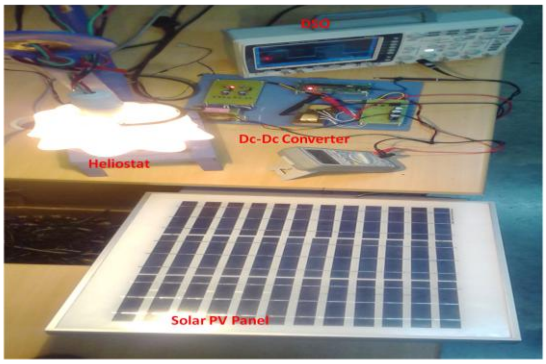

Fig. 10. Hardware Setup of Proposed System

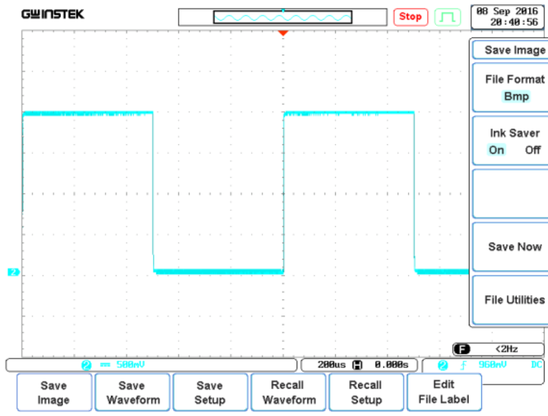

Fig. 11. PWM Generation to Drive DC-DC Converter

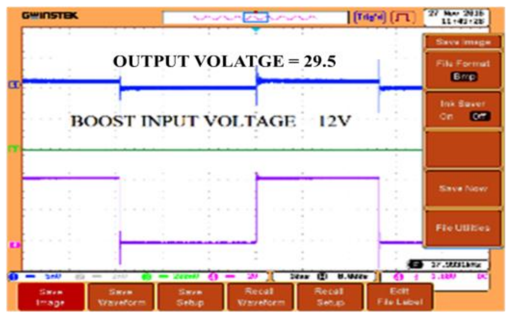

Fig. 12. Input Voltage Level of Heliostat Based Solar PV and Output Voltage of Boost Converter @ 30 Volts Output

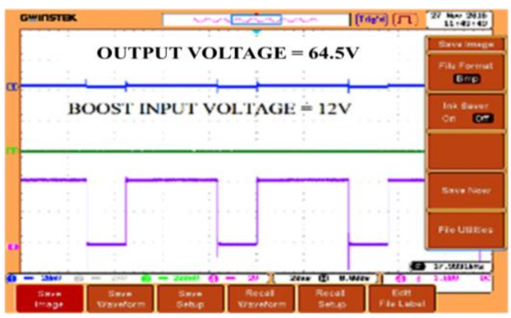

Fig. 13. Input Voltage Level of Heliostat Based Solar PV and Output Voltage of Boost Converter @ 64.5 Volts Output

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The output of heliostat based solar pv is fed into corresponding voltage of 30 volts and 64 volts as shown in fig. 12&13. A high level gain is attained to boost solar PV system output and fed to inverter and corresponding controller generates with respect to solar PV data from cloud.

Inverter output voltage and corresponding fed the same into grid as shown in fig. 14 with minimum harmonics it's further eliminated through a LC filter. Test comparison is made the grid fed voltage corresponding heliostat based tracking and without heliostat tracking in which the heliostat based holds better efficiency and improves voltage handling capacity to drive solar pump driven system. The performance of pump system is as shown in fig. 15 and comparison of conventional solar PV and heliostat system is shown in fig. 16. Cloud data further transmit delivers efficient data to consumer to overcome grid absent mode.

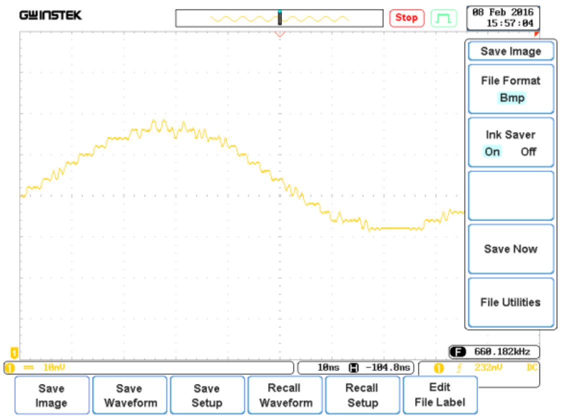

Fig. 14. Grid Power Fed PV Voltage

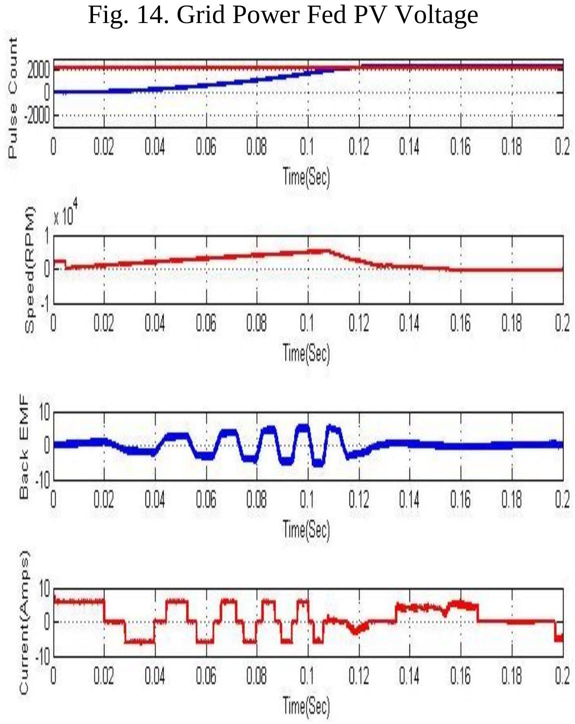

Fig. 15. Solar Heliostat Pump Driven Performance

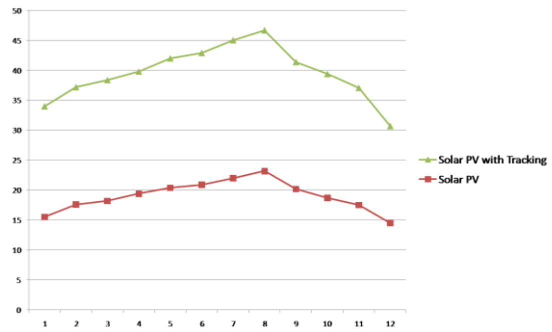

Fig. 16. Comparison of Solar PV with Tracking System

VI. CONCLUSION

Heliostat based tracking system is implemented to extract maximum power from solar PV in rural & urban areas. To promote efficiency of heliostat through dc-dc converter as per solar radiation data source is implemented and to drive BLDC motor for water pumping and irrigation purposes. Proposed system will be more effective in rural areas where less source of grid and more PV source corresponding to availability. A prototype of heliostat is designed with high gain dc-dc converter and solar pv which drives BLDC motor acts as pumping drive for irrigation and as renewable power.

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