EFFICIENCY IMPROVEMENT OF PHOTOVOLTAIC PANEL BY TRACKING METHOD

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***Abstract*—Tracking of maximum point (MPP) of a solar photovoltaic array is essential part of PV systems. The efficiency of solar photovoltaic system varies and low, under the low irradiation and weather conditions. To improve efficiency many MPP tracking (MPPT) methods have been developed and implemented. This paper represents the performance analysis of dual axis mechanical tracking system along with electrical tracking. The ultimate objective of this project is to investigate the static panel is more efficient than electrical tracking with dual axis tracking or opposite. This project is divided into two parts dual axis mechanical tracking and electrical tracking. Four LDR are used to capture the maximum light from sun. Two stepper motors are used to orient the solar PV panel to direction of sun. Second part, in electrical tracking incremental conductance method controls the duty cycle of DC to DC buck boost converter to enable the solar PV array operate at maximum operating point at all conditions. The performance of static PV system is compared with the implemented dual axis mechanical and electrical tracking and results showed that, implemented tracking methods is proven more effective for capturing the maximum sunlight source.**

Keywords—solar PV panel, MPPT, dual axis tracking, incremental conductance method

I. INTRODUCTION

Solar energy is rapidly gaining popularity as compared to other renewable energy sources. The installation cost of PV panel along with the other accessories is more. Successful application of PV panel depends upon the efficiency and energy storage. In such case, the output of PV panel must be more so that it will be economical and beneficial for consumer to use it. In general, PV generation systems have two major problems; the conversion efficiency of electric power generation is low (in general less than 17%, especially under low irradiation conditions), and the amount of electric power generated by solar arrays changes continuously with weather conditions [1]. The output current vs. voltage curve of a photovoltaic cell shows a non-linear characteristic. From this nonlinear relationship, it can be observed that there is a unique point, under given illumination and temperature, at which the cell produces maximum power, the so-called maximum power point (MPP). The output power of PV cell varies with depending mainly on the level of solar radiation and ambient temperature corresponding to a specific weather condition. The MPP will change with external environment of PV cell. The tracking process of maximum power point is called maximum power point tracking (MPPT). Due to a nonlinear current voltage characteristic of PV cells, it is difficult to track the MPP [2]. Solar mechanical tracker is a device used to move solar PV panel as per sun's direction. While, the electrical tracking is used when mechanical tracking fails under the low irradiance and partial shading condition. The efficiency of solar PV panel is less when solar PV panel is fixed at particular angle. By using the variable elevation mechanical solar tracker and electrical tracking, the extra power can be produced per annum as compared to static or stationary solar PV system [3]. In this project, the performance of dual axis mechanical tracking with electrical tracking (MPP tracking) is analyzed. The mechanical tracking has three parts, input, controller and output. The input from LDR, the P89LPC938 as controller and stepper motor as output. In electrical tracking, input is solar PV, controller is MSP430 and output is battery. Both, methods are combining to charge the battery. Efficiency is calculated by taking readings of solar PV voltage, battery current and battery voltage.

II. MECHANICAL AND ELECTRICAL TRACKING

A. *Mechanical tracking*

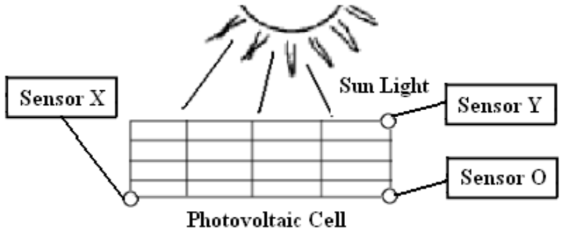

Figure 1. Three LDR installed on solar PV panel

Three LDR are used in the tracking system all are fixed on the upper part of the system near the photovoltaic cell in an X-O-Y manner as shown in figure1. It allows a reference LDR the one at position O which will be compared with the LDR X and Y and depending on the voltage output. The tracker will

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compare X and O positions, the comparison will end after a very near values of outputs of those two LDR are reached, a loop will control the stepper motor motion and steps till a near equality of sunlight distribution will be reached. After reaching an acceptable position and values for the X-O position test, the Y-O photo resistors are tested and compared in the same manner [4].

B. Electrical tracking

In electrical tracking, incremental conductance method is used to track the true MPP. For any electrical tracking method, DC to DC buck boost converter is necessary to vary the duty cycle. The incremental conductance (IncCond) method is based on the fact that the slope of the PV array power curve is zero at the MPP, positive on the left of the MPP, and negative on the right, as given by

$$\frac{dp}{dv} = 0 \qquad \text{at MPP}$$

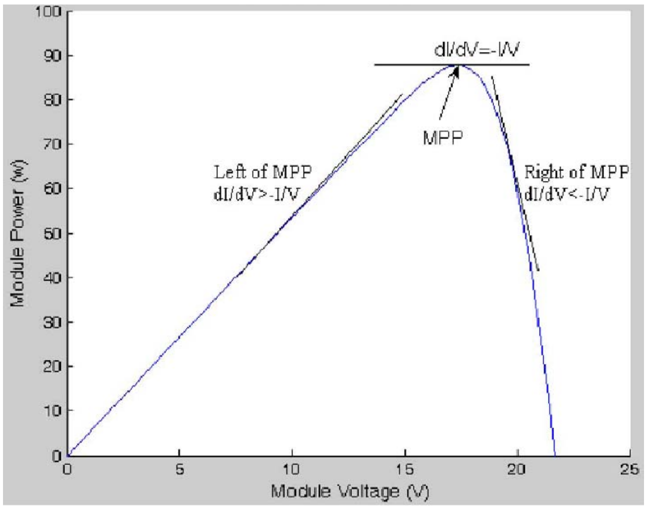

Figure 2. Basic Idea of the Incremental Conductance method on a P-V curve Of a Solar Module

The MPP can thus be tracked by comparing the instantaneous conductance (*I/V*) to the incremental conductance (*ΔI/ΔV*) as shown in the flowchart in Fig.2.1 *Vref* is the reference voltage at which the PV array is forced to operate. At the MPP, *Vref* equals to *VMPP*. Once the MPP is reached, the operation of the PV array is maintained at this point unless a change in *ΔI* is noted, indicating a change in atmospheric conditions and the MPP. The algorithm decrements or increments *Vref* to track the new MPP [5].

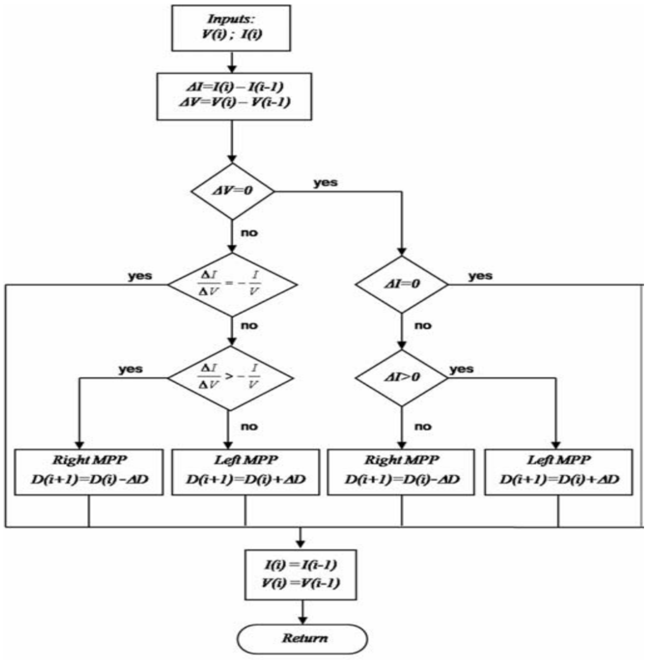

Figure 3. Flowchart of Incremental conductance method [5]

III. DESIGN OF ELECTRICAL AND MECHANICAL TRACKING

A. Solar PV panel specification:-

- Power - 20 watt
- Maximum voltage-17.3volt
- Maximum current- 1.03Amp
- Open circuit voltage-23.1volt
- Short circuit current-1.44 Amp

B. Mechanical tracking:-

1. *Hinge Point Calculation-*

Arc length= r*θ

$= 45*80*(\frac{\pi}{180})$

Arc length=62.8mm

If for θ=80 degree r = 45. Then for θ= 90 degree. The value of R

R θ = Arc length

R ×90 = 62.8

R = 40mm

2. *Gear teeth*

Number of teeth = 40

3. *Face width of gear:-*

Face width of gear = 30 mm

4. *Pitch circle diameter (PCD) of worm:-*

$$Q = \frac{Diameter\ of\ worm(dw)}{module(mt)}$$

To obtain the convenient diameter of worm, we consider the Q is 12.

$$12 = \frac{Diameter\ of\ worm(dw)}{3}$$

Diameter of worm (d_w) = 36

We are nearly taking this value to 40 mm.
So, Diameter of worm (d_w) = 40 mm

5. *Motor torque calculations:-*

Tilting assembly weight is near about 2.5 kg (2 kg panel weight, 400 gm carrier weight and 100 gm hardware weight).

$$Torque = F \times r$$
$$= 2.5 \times 4.5 \text{ cm}$$
$$Torque = 11.25 \text{ kg cm}$$

T (practical) = Factor of safety (FOS) × torque

$$= 1.5 \times 11.25$$
$$T\ (practical) = 16.87 \text{ kg cm}$$

6. *Inertia calculations:-*

$$T_a = (J_L + J_{G1} + J_{G2} + J_M)\ (w_1 - w_0/t)\ \left(\frac{W1 - w0}{t}\right)$$

Where J_L, J_G, J_{G2}, J_M = inertia of the load (kg/m^2)
W_1= Final velocity of motor (rad/sec)
W_2= Initial velocity of motor (rad/sec)
t = Time for velocity change (sec)

In formula,

$$W = 2\pi n$$

Where W= angular velocity (rad/sec)
n= rmp

To move panel from zero position to final position i.e. from initial position to 90 degree position the required angler velocity at both positions must be calculated. At start, angular velocity is zero. i.e. W_1=0. At end, to find angular velocity (W_2) we have to first find n rpm. When panel moves from zero to 90 degree then gear complete 1/4th revolution while time required for it will be near about 5 hours i.e. 300 minutes. If we consider that sun rises at 6:30 and after 1/4th revolution it will reach 90 degree at 12pm.

$$n = \frac{\left(\frac{1}{4}\right)}{t} = \frac{\left(\frac{1}{4}\right)}{300} = 0.0008 \text{ rpm}$$

So final angular velocity is,

$$W_1 = 2 \times \pi \times 0.0008$$
$$W_1 = 0.0050$$

So difference in angular velocity is,

$$\left(\frac{W1 - W0}{t}\right) = \left(\frac{0.0050 - 0}{300}\right) = 0.05.$$

Acceleration is near about zero. So the acceleration torque is not considered in design.

$$T_a = 0$$

7. *Final motor torque:-*

$$Tm = T_L\ (T_{Practical} + Ta)$$

$$Tm = 16.87 \text{ kgcm}$$

8. *Sensitivity of system:* - Stepper motor step angle is mention in specification which is 1.8 degree. When motor moves 1.8 degree then what will be the rotation of gear.

$$\text{Gear ratio} = \frac{number\ of\ teeth\ of\ gear}{number\ of\ start\ of\ worm\ of\ helix} = \frac{40}{1} = 40$$

To complete one revolution of gear, 40 worm gear revolutions are required. So gear ratio is 40:1

$$\text{For gear step angle} = \frac{motor\ stpe\ angel}{gear\ ratio}$$
$$= \frac{1.8}{40}$$

For gear step angle = 0.045 degree. [6]

C. Electrical tracking:-

Incremental conductance method is used to track the MPP under the low irradiance condition or when sun radiations are less. As shown in figure 3, the output of solar PV panel is given to microcontroller and the duty cycle of buck boost converter is varied. In buck case, the ΔD is decreased, while in boost case, ΔD is increased. D is duty cycle of converter. So the calculations of duty cycle and selection of inductor and capacitor for converter is necessary. MOSFET or IGBT is used for switching. So, maximum switching current is also calculated.

- D buck- it gives the value of maximum duty cycle.
  D buck =67.88%
- D boost- it gives minimum duty cycle.
  D buck =61.81%
- Inductor (L) for buck mode-
  L=1.80mH or 1.80×10^{-3} Henry
- Inductor (L) for boost mode-
  L=0.47mH or 0.47×10^{-3} Henry
- Maximum switch current buck mode-
  ΔImax =0.681 A
- Maximum switch current boost mode-
  Isw_{max}=0.722 A
- Minimum output capacitor buck mode-
  $Cout_{min1} = 0.17 \times 10^{-6}$ F [7]

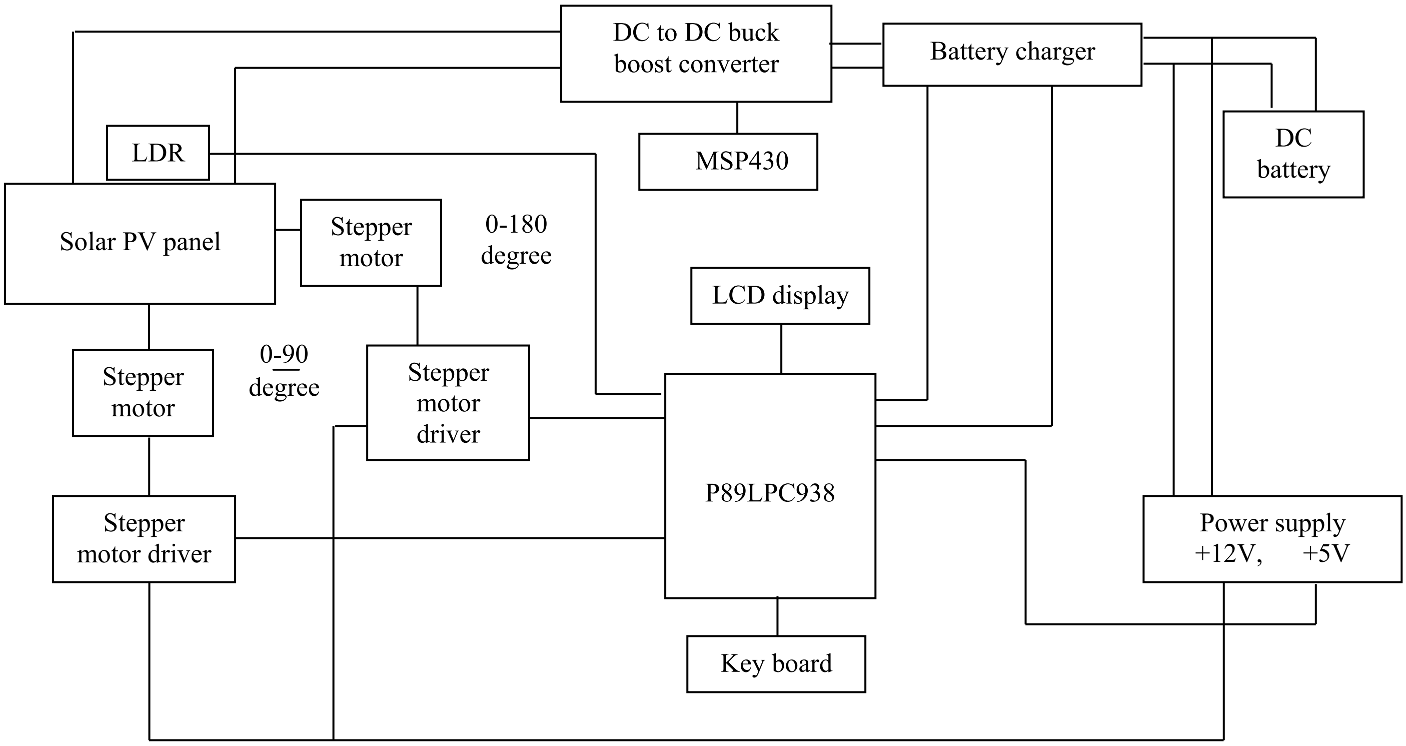

Figure 4. Project block diagram

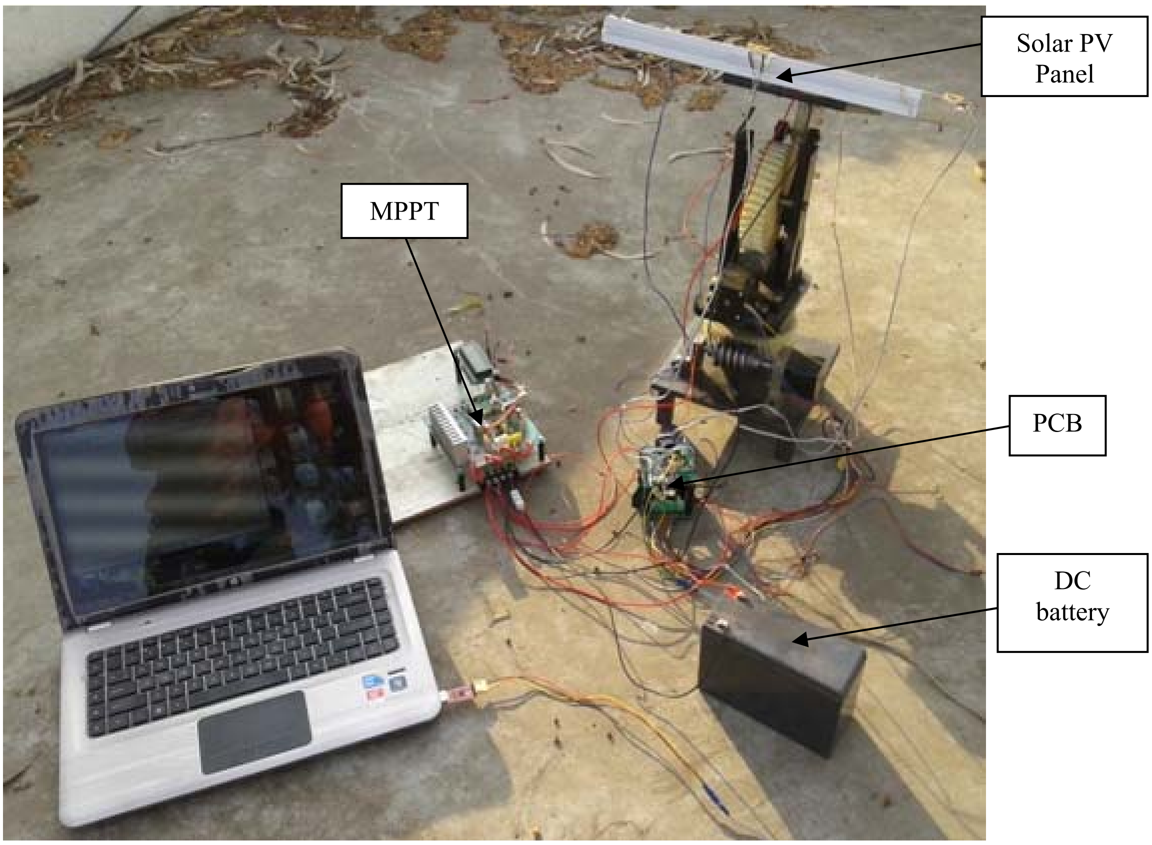

Figure 5. Project Actual setup

The As shown in figure 4 , in mechanical tracking, the dual axis tracking method is used. In dual axis tracking, the solar PV panel can rotate in vertical (90 degree) as well as horizontal (180 degree). As application is low speed and high torque, worm and single helix gears are used. Stepper motor is connected to a single helix gear. The LDR (light dependant resistor) senses the sun light. The P89LPC938 receives analog input from LDRs and it converts the input into digital signal by using analog to digital converter. The controller P89LPC938 sends the signal to the stepper motor to determine movement of solar PV panel.

The solar radiation, solar PV panel voltage is analog type signal and microcontroller only accept the digital signal. So by using the resister divider circuit the voltage is reduced first, because microcontroller works in-between (0-5volt) and voltage given by solar PV panel is more, which acceptable by microcontroller. Then reduced voltage is given to inbuilt ADC of microcontroller. The divider circuit is shown below with example of solar PV panel input in figure 6,

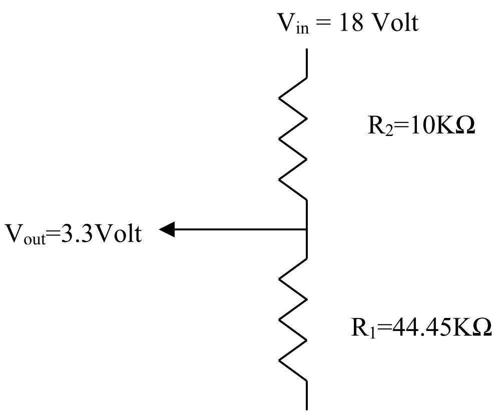

Figure 6. Divider circuit

$$Vout = \frac{R2}{(R2 + R1)} \times Vin$$

Where V_{out}=output voltage feed to microcontroller taken as 3.3volt
R_2=10kΩ
R_1= resistance that user have to calculate
V_{in}= open circuit voltage of SPV panel, i.e.18v

So,

$$3.3 = \frac{10}{(10 + R1)} \times 18$$

R_1= 44.45 kΩ

IV. RESULTS FOR VARIOUS CONDITIONS

The results are taken when solar PV panel was static and when MPPT is used.

time	Static		MPPT	
	Output Power	Input Power	Output Power	Input Power
09:30	6.33	7.5	2.31	2.38
10:00	8.6	11.13	3.2	3.29
10:30	8.72	11.34	3.86	3.97
11:00	8.69	10.3	4.14	4.26
11:30	8.49	11.92	4.71	4.84
12:00	8.11	11.14	5.27	5.43
12:30	7.87	10.99	5.3	5.46
01:00	7.49	10.29	4.92	5.06
01:30	7.24	10.09	4.81	4.95
02:00	6.85	9.34	4.55	4.68
02:30	6.48	8.95	2.95	3.04
03:00	1.11	1.29	1.65	1.69
03:30	0.99	1.15	1.01	1.04
04:00	0.86	1	1.77	1.82
04:30	0.49	0.57	0.5	0.51
05:00	0.49	0.57	0.24	0.25
	88.81	117.57	51.19	52.67

Static SPV converter efficiency-

$$\eta = \frac{output\ power}{input\ power} \times 100$$

$$= \frac{88.81}{117.57} \times 100$$

$$\eta = 75.53\%$$

MPPT converter efficiency-

$$\eta = \frac{output\ power}{input\ power} \times 100$$

$$= \frac{51.19}{52.67} \times 100$$

$$\eta = 97.19\%$$

From above calculations, it can be showed that, when solar PV panel is static and only battery charger is used without MPPT, then constant voltage constant current source charger fails to extract the maximum power from solar PV panel and proved to be inefficient.

When the solar PV panel is static and battery charger with MPPT is used. The DC to DC buck boost converter with variable duty cycle and battery charger actually tracks the MPP and extract the maximum power from solar PV panel and proved to be efficient. The converter efficiency is increased by 21.66%.

V. CONCLUSION

The study of project shows that, the converter efficiency and solar PV panel efficiency can be improved as compared to the static PV panel. The MPP proved to be better under the low sun light or cloudy atmosphere. The method implemented, can be used on large scale.

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