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Implementation of Incremental Conductance Algorithm in Dual Axis Solar Tracker for Maximum Solar Panel Output

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Abstract: *The demand of energy has increased which has resulted in the depletion of conventional energy resources. The focus of the entire world is now on renewable energy resources. Solar and wind are the most popular among them. In this paper the focus is on improving the output of a solar panel by combing Dual Axis Solar Tracking (DAST) and Maximum Power Point Tracking (MPPT). For better accuracy Incremental Conductance (IC) algorithm is the MPPT technique used.*

Keyword: *Dual axis solar tracker, MPPT, Incremental conductance.*

1. INTRODUCTION

The efficiency of a solar panel is found to be around 15%. Which means it converts only 15% of energy it receives from the sunlight. Moreover maximum energy conversion is possible only if the temperature is optimum, irradiation is maximum and tilt angle is exactly 90^o. Among the three factors temperature cannot be controlled cost effectively, so the focus is on irradiation and tilt angle. Variation in tilt angle can be controlled by use of Dual axis solar tracker whereas IC algorithm, is used to adjust the variability in irradiation. The block diagram of the proposed idea is shown as Fig. 1.

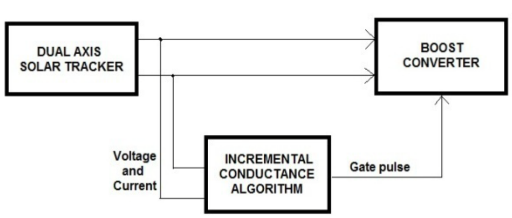

Fig. 1: Block Diagram

2. SOLAR PANEL

Solar panel works on the reverse principle of diode. When solar irradiation falls on a solar cell, it gets excited. When the excited electrons move from conduction band to valence band, energy is released. Thus solar cell converts solar energy to energy that's can be utilized [6]. The power produced by a solar cell will be too low. A series parallel combination of solar cells to form a solar panel which can deliver the desired voltage and current. A group of solar panels form a solar farm. The output from a solar farm can energize a small village.

2.1 Efficiency of a solar panel

When solar cell was initially introduced (in 1954) the maximum efficiency attained was 4%. The efficiency of currently installed solar panels is (15%-20%). Recent advancement in technology have made it possible to achieve a maximum efficiency of 44.7% (in 2013).

3. TILT ANGLE

Solar tilt angle is also known as Solar Zenith Angle is the angle measured from directly overhead to the geometric centre of the sun. The solar elevation angle is the angle of the sun, the angle between the horizon and the centre of the sun. If solar zenith angle is 'θ_s' the solar elevation angle is $\alpha_s = 90° - \theta_s$.

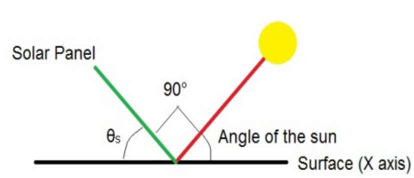

Fig. 2: Tilt Angle θ_s

4. SOLAR TRACKING

A Solar Tracker can be defined as a mechanism which can orient the solar panel towards the sun. In flat solar panels trackers are used to minimize the tilt angle between the incoming sunlight and the panel. Decrease in tilt angle can considerably increase the amount of energy produced from a panel. Solar tracking is also done in concentrated photovoltaic and concentrated solar thermal applications because they do not produce energy unless it is perpendicular to the sun.

4.1 Need for Solar Tracking

Sunlight has two components, the “direct beam” which carries about 90% of the solar energy and the remaining part is “diffuse sunlight” which is responsible for the blue sky on a clear day and increases considerably on cloudy days. From this it is clear that majority of sunlight is direct beam and maximizing collection of it requires the panel to be perpendicular to the sun as long as possible. The Fig. 3 shows the % of power lost due to misalignment.

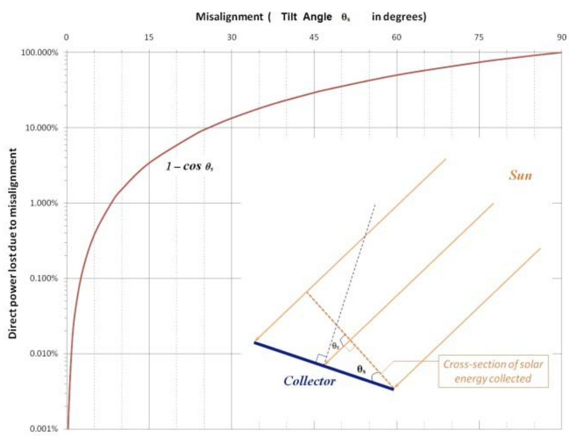

Fig. 3: % Power lost due to misalignment

The energy contributed by the direct beam drops off with the cosine of the tilt angle. Table 1 and table 2 shows the % of power loss due to misalignment of tilt angle.

Table 1: % Power loss w.r.t θ_s

θ_s	Power Loss= 1 - cos(θ_s)
0°	0%
1°	0.015%
3°	0.14%
8°	1%
23.4°	8.3%

Trackers that have an accuracy of ± 5° can deliver greater than 99.6% of energy delivered by the direct beam added to 100% of energy delivered by the diffuse beam. Thus the need for solar tracking is emphasized.

Table 2: % Power loss w.r.t time

θ_s	Hours	Power Loss
15°	1	3.4%
30°	2	13.4%
45°	3	30%
60°	4	>50%
75°	5	>75%

4.2 Single Axis Solar Tracker

The sun travels through 360° east to west per day. But from the perspective of a fixed point, it travels through 180° during one half of the day. Local horizon effect will decrease it to 150°. Let us consider a fixed solar panel, it will face 75° between dawn to dusk.

From Table 2 we can see that it will lose 75% of energy for a misalignment of 75°, in the morning and evening. Rotating panels to the east and west can help reduce these losses. A tracker rotating east-west direction is called a Single Axis Solar Tracker. It is done based on Solar Azimuth angle.

4.3 Dual Axis Solar Tracker

When single axis tracking is performed the output of the panel is far better than stationary panel. But the sun moves through 46° north and south during a year. Which accounts for 30% of power loss. A tracker which accounts for both daily and seasonal motion is known as Dual Axis Solar Tracker. Dual axis trackers have two degrees of freedom that act as axes of rotation. These axes are typically normal to one another. The axis that is fixed with respect to the ground can be considered a primary axis. The axis that is referenced to the primary axis can be considered a secondary axis.

The orientation of the module with respect to the tracker axis is important when modelling performance. Dual axis trackers typically have modules oriented parallel to the secondary axis of rotation. Dual axis trackers allow for optimum solar energy levels due to their ability to follow the sun vertically and horizontally. No matter where the sun is in the sky, dual axis trackers are able to angle themselves to be in direct contact with the sun [4].

5. MPPT

In solar panels Maximum power point tracking (MPPT) is used to get maximum power. Solar cells have a complex relationship between solar irradiation, temperature and total resistance that produces a nonlinear output which can be verified based on the I-V curve. Since environmental conditions cannot be controlled by us, MPPT technique is used to apply proper resistance to obtain maximum power for any environmental conditions. Maximum power point is the product of the MPP voltage (V_{mpp}) and MPP current (I_{mpp}) [2].

5.1 Theory of MPPT

For a given operational conditions, a solar panel has a single operating point where the values of the current (I) and voltage (V) of the panel results in a maximum power output. These values correspond to a particular load resistance which is equal to *V/I*. Hence the power delivered from the panel can be optimized when the derivative *dI/dV* of the I-V curve is equal and opposite the *I/V* ratio. This is known as Maximum Power Point (MPP) and corresponds to "knee" of the curve [7].

5.2 Working of MPPT

A load with a resistance equaling R= V/I draws the maximum power from the device, which is called the characteristic resistance of the cell. The characteristic resistance of the panel changes with variations in environmental conditions. If the value of this resistance is greater than or less than the optimum value, the power drawn will be less than the maximum available. Hence the efficiency of the cell will be low. Maximum power point tracking uses different types of control circuit or logic to search for this point and thus aid the converter circuit to extract the maximum power available from the panel.

5.3 Incremental Conductance

The incremental conductance [3] method computes the maximum power point by comparison of the incremental conduction (*dI/dV*) to the array conductance (*I/V*). When these two values become same (*I/V* = *dI/dV*), the output voltage is called MPP voltage (V_{mpp}). The controller measures changes in panel current and voltage to predict the effect of a voltage change. This method require complex computation technique. The Incremental conductance (*dI/dV*) of the panel to compute the sign of the change in power with respect to voltage (*dP/dV*).

Condition for MPPT

$$\frac{dp}{dv} = \frac{d(vi)}{dv} = 0 \quad (1)$$

Left hand side of MPPT:

$$i + v\frac{di}{dv} > 0 \quad (2)$$

Right hand side of MPPT:

$$i + v\frac{di}{dv} < 0 \quad (3)$$

These equations can be expressed as a graph, shown in Fig. 4.

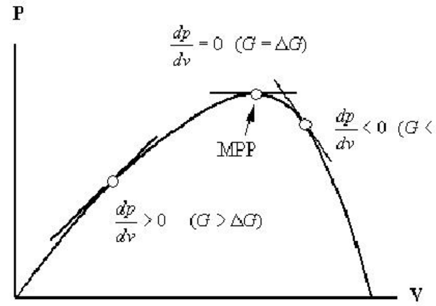

Fig. 4: PV curve for Incremental Conductance

6. BOOST CONVERTER

The output of a MPPT controller is gate pulses. These gate pulses can be used to trigger any DC-DC converter. DC-DC converter used is Boost converter, shown in Fig. 5.

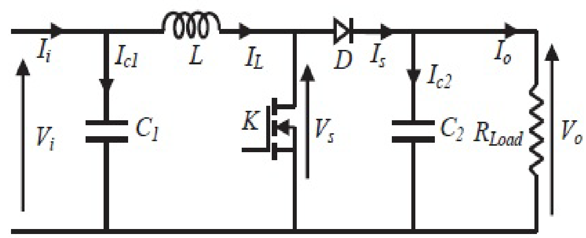

Fig. 5: Boost Converter

The parameters of the boost converter [1] are shown in Table 3.

Table 3: Parameters of Boost Converter

Components	Value
L	0.15 mH
C1	0.1 µF
C2	15 µF
R	80 Ω

7. SIMULATION RESULTS

The equivalent circuit for solar cell is shown in the Fig. 6.

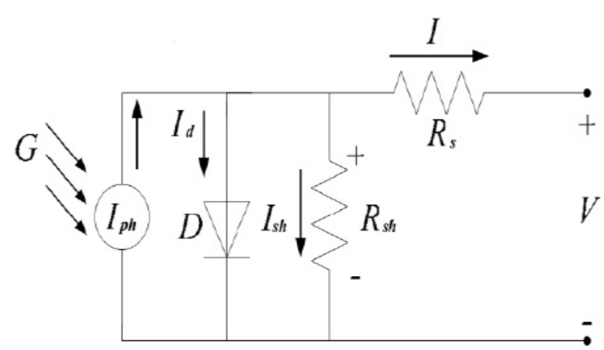

Fig. 6: Equivalent circuit of a solar cell

Initially solar panel was designed based on a set of equations and its I-V and P-V curve plotted.

$$V_t = \frac{kT_{op}}{q} \quad (4)$$

$$V_{oc} = V_t \ln \frac{I_{ph}}{I_s} \quad (5)$$

$$I_d = [e^{\frac{(V+IR_s)}{nV_tCN_s}} - 1]I_s N_p \quad (6)$$

$$I_s = I_{rs}(\frac{T_{op}}{T_{ref}})^3 e^{[\frac{qE_g}{nk}(\frac{1}{T_{op}}-\frac{1}{T_{ref}})]} \quad (7)$$

$$I_{rs} = \frac{I_{sc}}{[e^{(\frac{V_{oc}q}{kCT_{op}n})}-1]} \quad (8)$$

$$I_{sh} = \frac{V+IR_s}{R_p} \quad (9)$$

$$I_{ph} = G_k[I_{sc} + k_I(T_{op} - T_{ref})] \quad (10)$$

$$I = I_{ph}N_p - I_d - I_{sh} \quad (11)$$

Using these equations [5] solar panel was modeled in Matlab as shown in Fig. 7.

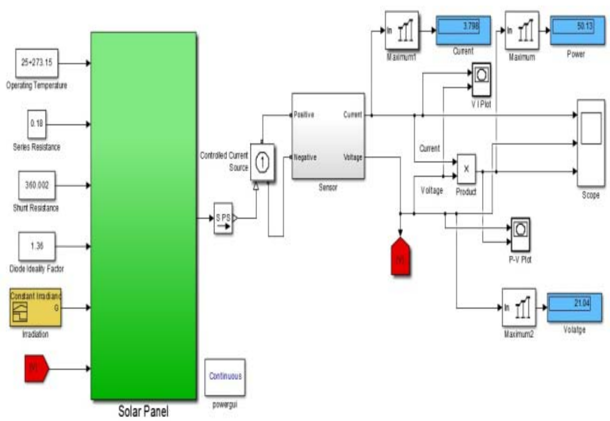

Fig. 7: Matlab Model of Solar Panel

The output plot, I-V and P-V curves are shown below in Fig. 8 and Fig. 9.

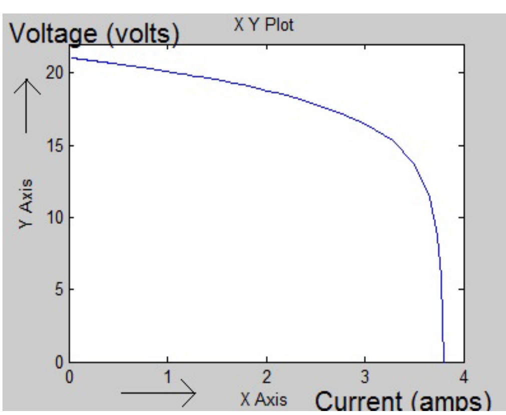

Fig. 8: I-V Characteristics of Solar Panel

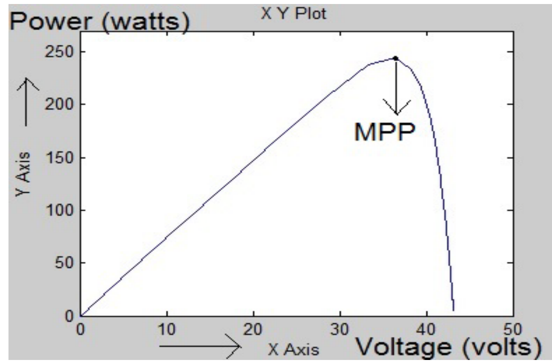

Fig. 9: P-V Characteristics of Solar Panel

The panel output before applying MPPT is shown below in Fig. 10.

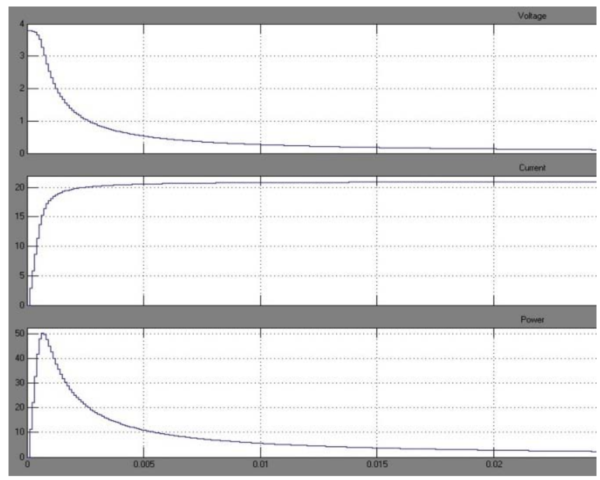

Fig. 10: Output of Solar Panel (without MPPT)

Boost converter is added to the above model and a pulse generator of frequency 31250 Hz and Duty Cycle 76%. The modified Matlab model is shown in Fig. 11.

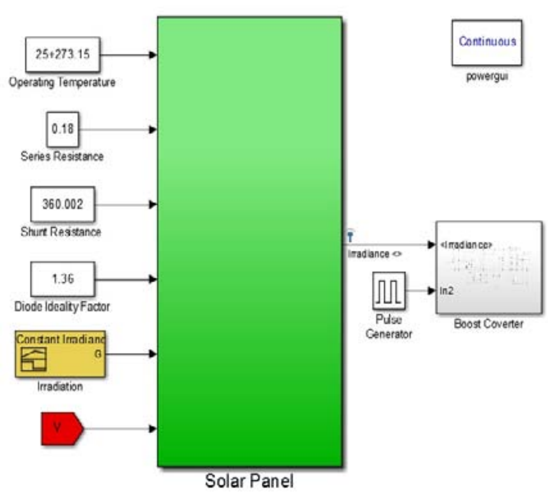

Fig. 11: Solar panel with boost converter

The gate pulse given by the pulse generator is shown in Fig. 12.

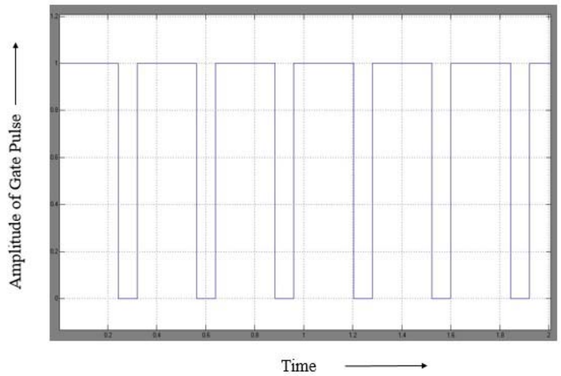

Fig. 12: Gate pulse generated by pulse generator

The input values of voltage, current and power given to the boost converter triggered by pulse generator is shown in Fig. 13.

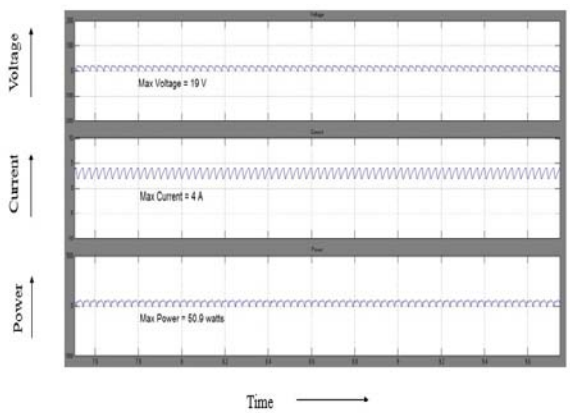

Fig. 13: Voltage, current and power input

The voltage, current and power signals which are given out by the boost converter is shown in Fig. 14.

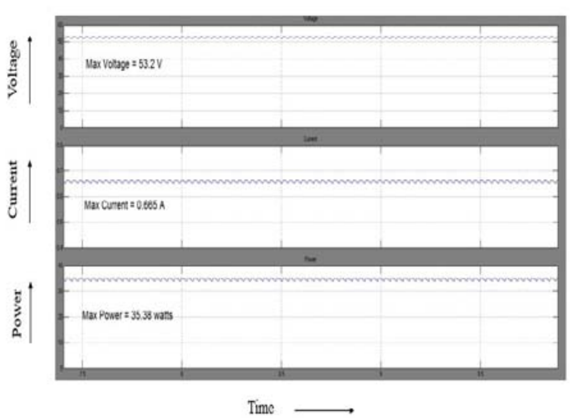

Fig. 14: Voltage, current and power output

Now the pulse generator is replaced by MPPT controller using Incremental Conductance algorithm. The modified Matlab model is shown in Fig. 15.

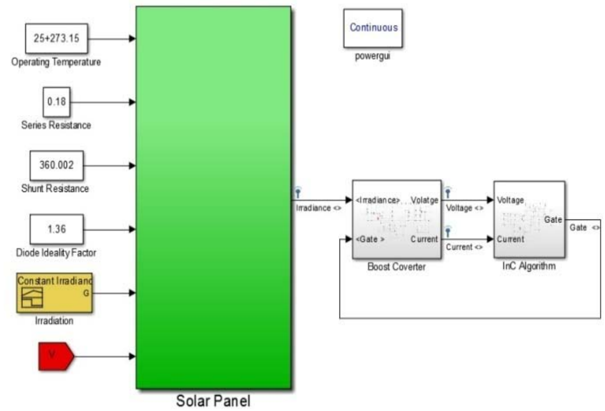

Fig. 15: Panel with converter fed by IC

The gate pulse generated by IC controller is shown in Fig. 16.

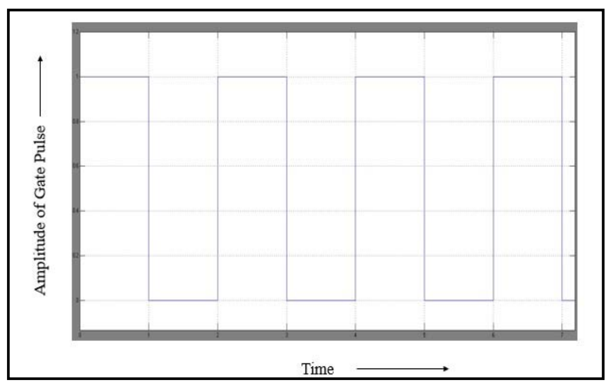

Fig. 16: Gate pulse generated Incremental Conductance Algorithm

The input values of voltage, current and power given to the boost converter which is triggered by the gate pulse generated by Incremental Conductance is shown in Fig. 17.

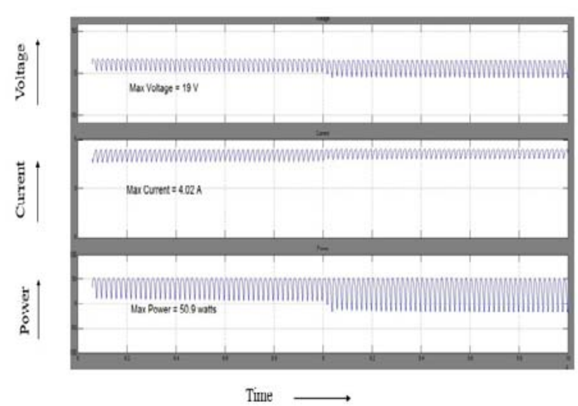

Fig. 17: Voltage, current and power input

The voltage, current and power signals which are given out by the boost converter which is triggered by the gate pulse generated by Incremental Conductance is shown in Fig. 18.

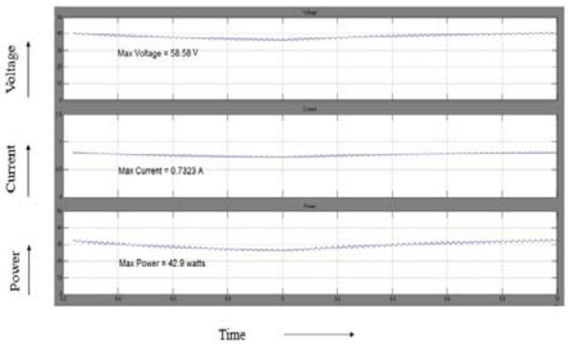

Fig. 18: Voltage, current and power output

8. TABULATION

Simulation	Efficiency
PV panel with boost converter fed with pulse generator	69.51 %
PV panel with boost converter fed with Incremental Conductance	84.28 %

9. CONCLUSION

The output voltage from the solar panel was improved by maximum power point tracking. To obtain the maximum power, the combination of mechanical tracking and electronic tracking is used. Incremental Conductance algorithm is used for MPPT and DAST can be used for mechanical tracking.

Due to simulation constraints, the panel output power obtained by giving constant irradiation given as input, is considered as the output power from DAST. The boost converter is used to stabilize the output power from the PV panel. Incremental conductance algorithm performed the switching operation in boost converter.

Initially solar panel was modelled and boost converter was switched using pulse generator (without Incremental conductance). Considering the maximum values of output power and input power the efficiency obtained was 69.51%. Solar panel output is given to boost converter which is switched using Incremental Conductance algorithm, for which the efficiency obtained in 84.28%. Thus the proposed idea improves the output from the solar panel.

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