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# An Incremental Conductance Algorithm based Solar Maximum Power Point Tracking System

**Gomathi B**
*Assistant Professor*
*Electrical and Electronics Engineering,*
*PSNA College of Engineering and Technology, Dindigul,Tamil Nadu*

**Sivakami P**
*Assistant Professor*
*Electrical and Electronics Engineering,*
*PSNA College of Engineering and Technology, Dindigul,Tamil Nadu*

**ABSTRACT**
One of the greatest sources of renewable energy generation is the generation of power from Solar Energy using Photovoltaic (PV) cell. The importance of PV cell used in solar energy generation is high because they directly convert the sun's radiation into Electric energy without affecting the atmosphere. The main drawback of the Solar Energy Systems is that the solar radiation keeps on changing with time on hourly basis. The efficiency of the panels can be improved by using suitable DC- DC converters and a highly efficient Maximum Power Point Tracking (MPPT) algorithm to extract maximum power from the panel. Among many MPPT algorithms available, Incremental Conductance Algorithm is highly efficient as it has Steady State accuracy and it gets easily adjustable for the changing environmental conditions thus increasing the efficiency of PV system. Additionally if the Solar radiation is also modelled using slope of the panel, latitude the temperature of the place where the solar panel is installed the panel can be installed in such a way it can produce maximum power throughout the day. In this paper, the solar radiation and the PV module is modelled using basic equations of solar cell and implemented in Simulink. Incremental Conductance Algorithm is implemented using m- files of MATLAB. DC- DC converters are modelled using Electric network elements available in Sim Power System of the MATLAB.

**Keywords—** Solar radiation, Photovoltaic Module, Maximum Power Point Tracking, Incremental Conductance Algorithm, Direct Control method, DC-DC converters

## I. INTRODUCTION

The power demand is increasing day by day due to the depletion of Conventional energy sources, hence now a days a very high importance is given to the Renewable energy Sources like Solar and wind where the energy is available seasonally. Among Renewable Energy sources available, solar energy is easy to install and at the same time it is abundantly available in most of the South Asian countries. It can be harvested in two different fashions. One is the Stand alone type where the energy obtained can be stored in the batteries and used for supplying the loads nearby. Second is the Grid type where the harvested energy is directly fed to the Grid. The two different types are chosen based on the Geographical locations.

The two important factors that hinder the Solar Energy generation is the Cost of installation and the Conversion efficiency. Hence in this paper methods are discussed to increase the conversion efficiency i.e constant voltage should be delivered to the load irrespective of the variation in the solar radiation.

## II. SYSTEM LAY OUT

The overall system consisting of Solar panel, MPPT Controller and resistive load is shown in the fig. 1

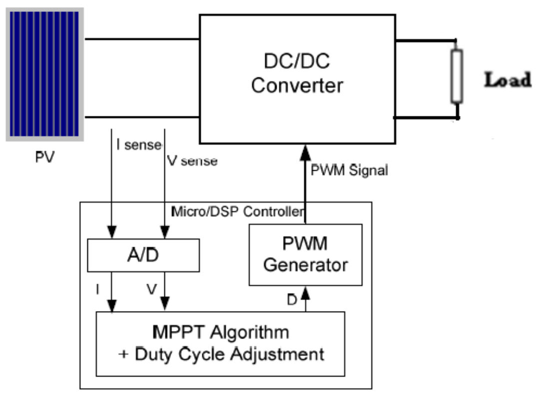


**Fig. 1** Overall System layout

Solar panel converts solar radiation in to electrical energy directly. MPPT is a package of MPPT Algorithm and DC- DC converter. It is inserted in between Solar panel and the load. The DC –DC converter which is the core of the entire supply converts dc electrical power at one potential to the electrical power at another potential. The main purpose of the DC- DC converter is to provide constant voltage or current.

## III. PHOTOVOLTAIC MODULE

### *A. Modelling of Solar cell*

Solar cell consists of P-N junction fabricated in a thin wafer or layer of Semiconductor like Silicon or germanium. The equivalent circuit of the Photovoltaic cell is shown in the fig. 2

The equation can be obtained by applying Kirchoff's Current law.

$$\mathrm{Is} = \mathrm{Id} + \mathrm{Ir} \quad (1)$$

The normal diode equation is given by

$$\mathrm{Id} = \mathrm{Io} * \exp \mathrm{e} * \frac{\mathrm{Vs}+\mathrm{Rs}*\mathrm{Is}}{\mathrm{m}*\mathrm{k}*\mathrm{Tj}} - 1 \quad (2)$$

Substituting the eqn. (2) in eqn. (1)

$$\mathrm{Is} = (\mathrm{Io} * \exp \mathrm{e} * \frac{\mathrm{Vs}+\mathrm{Rs}*\mathrm{Is}}{\mathrm{m}*\mathrm{k}*\mathrm{Tj}} - 1) + \mathrm{Ir} \quad (3)$$

Where Io is the saturation current (A)
Vt is the Thermal Voltage which is given by

$$\mathrm{Vt} = \frac{\mathrm{m} * \mathrm{k} * \mathrm{Tj}}{\mathrm{e}}$$

In which m is the ideal factor of the PV cell which can be either 1 or 2.
K is the Boltzmann's constant
e is the Electron charge in Coulomb.

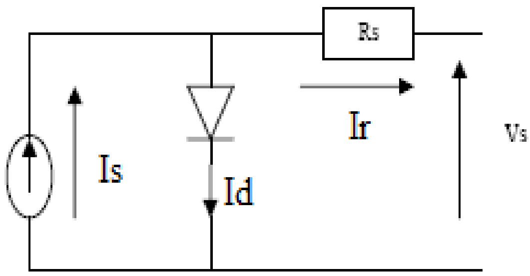


**Fig.2** Equivalent circuit of PV cell

While modeling the solar cell the following assumptions are made:

(i) The source current is the short circuit current of the panel.
(ii) The exponential term in the equation is always greater than 1 and hence -1 in the equation is neglected.

Now the equation becomes

$$\mathrm{I} = \mathrm{Isc} * [1 - \exp\left(\frac{\mathrm{Vs}-\mathrm{Voc}+\mathrm{Is}*\mathrm{Rs}}{\mathrm{Vt}}\right)] \quad (4)$$

Where Voc is the open circuit voltage [V]
From the above equation V-I curve of the PV cell can be obtained.

### *B. Modelling of PV module*

PV cells are connected in parallel and series to form the Photovoltaic Module. If Np and Ns are the number of PV cells in parallel and series the equation for modeling PV module can be obtained by multiplying the voltages by Nsm and the current by Npm.

## IV. MAXIMUM POWER POINT TRACKING (MPPT)

### *A. Selection of MPPT Algorithm*

MPPT is the only way of increasing the efficiency of the solar cell by extracting the maximum power from the solar panel and delivering constant voltage irrespective of variation in solar radiation. In direct coupled method i.e without MPPT solar power is delivered directly to the load the voltage will quickly collapse to zero. This can be understood from the I-V curve obtained from the solar panel. Hence a system with MPPT presents the collapse of the voltage by keeping the operating point near the Maximum Power point. A wide range of MPPT Algorithms are available. Of all the available algorithms Incremental Conductance Algorithm lends itself well to the DSP and Microcontroller [1]. A comparison between the Perturb & Observe (P & O) and the Incremental Conductance Algorithm (INC) reveals that the efficiency of P & O method is 95 % and INC Algorithm is 98.2 % [2] The drawback of using PI controller in the Maximum Power Point Tracker due to Nonlinear nature of the PV cell [3] is overcome by using Direct control method in this paper. MPPT using Fuzzy control and Neural Network [4] [5] is highly accurate but require sound technical knowledge in creating the rule based table. Hence among all the techniques discussed above Incremental Conductance Algorithm is found to be best technique and easily adaptable to the changing environmental conditions.

### *B. Incremental Conductance Algorithm*

The equation for implementing the INC algorithm can be easily obtained from the basic power equation.

The equation for power is given as

$$P = V * I \qquad (5)$$

Differentiating the above equation with respect to voltage yields,

$$\frac{dP}{dV} = \frac{d(V * I)}{dV}$$

$$\frac{dP}{dV} = I + V * (\frac{dI}{dV})$$

The condition for the maximum power point tracking is that the slope dP/dV should be equal to zero.

Substituting in the above equation,

$$\frac{dI}{dV} = -\left(\frac{I}{V}\right) \qquad \ldots\ldots \qquad (6)$$

The above equation is implemented in Matlab m-files to track the maximum Power point of the PV panel. The flow chart describing the INC Algorithm is shown in the fig. 3

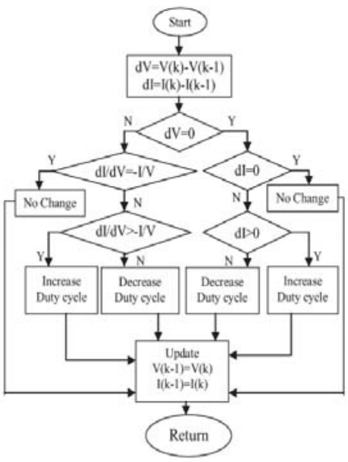


**Fig.3** Flow Chart of INC Algorithm

### *C. MPPT Control strategies*

In the conventional MPPT Systems there are two independent control loops to make the operating point of the Panel to be at the maximum power point. The first loop is the MPPT algorithm and the second one is the PI controller. INC Algorithm is entirely based on the Instantaneous and Incremental conductance to generate an error signal which is the made zero at the MPP point. But due to the nonlinearity nature of the PI controller in this paper Direct control strategy is applied. The main objective of selecting this method is to eliminate the second control loop and to provide a simple control circuit only with the tracking algorithm. Hence In this method the controller is eliminated and the duty cycles of the converters are adjusted directly. The feasibility of the proposed system is verified using various DC- DC converter topologies.

## V. DC-DC CONVERTER

DC- DC converter is the core of the Maximum Power Point tracker. The main objective of using DC-DC converter in MPPT is (i) Regulating the input voltage at the PV MPP and (ii) for providing load matching for the maximum power transfer. DC-DC converters are of many types. Basically there are two types (i) Isolated and Non Isolated topologies. Isolated topologies provide DC isolation between input and output. They find application in switch mode DC power supplies. In PV applications this type of topology is used in grid tied system for safety reasons. Isolation transformers are not present in Non-isolated type. The main topologies are (i) Buck (ii) Boost (iii) Buck – Boost (iv) Cuk converters. Buck topology is used in charging batteries and in LCB for water pumping systems. In MPPT buck converter is not suitable when the maximum power point goes below the charging voltage of the battery and also at low irradiance time. Boost converter can provide a medium tracking of the MPP because when the maximum power point is at a very low operating point Boost converter will not be suitable. But Boost converter has the capability to increase the overall efficiency by boosting the voltage. There are also other topologies (i) Cuk (ii) Buck – Boost which can either step up or step down voltage and hence can provide accurate maximum Power Point tracking. Both the converters almost give same output but the energy is stored in inductor in the case Buck – Boost whereas its Capacitance in case of Cuk converter. The advantage of Cuk over Buck- Boost is that the output current has less ripples and Cuk can be connected in parallel to measure PV modules with greater power.

## VI. MODELLING OF SOLAR RADIATION

In most of the simulation of Photovoltaic modules the solar radiation is kept as constant. But by modeling the Solar radiation using day, hour, latitude, slope of the panel, temperature the efficiency of the panel can be increased. It will be easy to analyze the performance of the panel for various areas, environmental conditions, and also for various slopes. Hence a solar panel installation can be made effectively. There are three types of solar radiation impinging the solar panel. They are (i) Direct radiation (ii) Diffuse radiation (iii) Ground reflected radiation

$$R_t = R_d + R_{df} + R_r \quad (7)$$

$$R_d = R \cos \quad (8)$$

$R_d$ is the direct beam radiation on the surface of the Earth and θ is the angle of incidence between the normal to the panel and incoming direct beam.

$\cos\theta = \cos\beta\cos(\Phi s - \Phi p)\sin\Psi + \sin\beta\cos\Psi$(9)

Ψ is the slope of the panel

Φp is the azimuth angle of the panel.

Φs is the azimuth angle of the Sun

$$\Phi s = \sin^{-1}(\cos\delta\sin H)\,/\cos\beta \quad (10)$$

δ is the declination angle between plane of the equator and a line drawn to the centre of the Earth,

H is the hour angle

β can be found from the following equation

$$\sin\beta = \cos L\cos\delta\cos H + \sin L\sin\delta \quad (11)$$

L is the latitude of the Place.

The diffuse radiation can be obtained from the following equation

$$R_{df} = S * R\,(1 + \cos\frac{\Psi}{2}) \quad (12)$$

S is the Sky diffuse factor

The Ground reflected radiation is given by

$$R_r = \rho\,R\sin(\beta + S)\,(1 - \cos\Psi/2) \quad (13)$$

P is the ground reactance.

Substituting $R_d$, $R_{df}$ and $R_r$ in the eqn. (7) the total radiation impinging on the panel can be found

**VIII. SIMULATION RESULTS**

The overall simulation diagram is given in the fig (4). It contains four important blocks. (1) Solar radiation block which is a subsystem containing the equations modelling the solar radiation which is described in the section VII. (2) PV module Block which is subsystem based on the equations described in the section III. (3) INC algorithm block which is an embedded matlab function containing m-file coding based on the flowchart shown in fig. 3. (4) DC-DC converter section which is constructed using electrical elements to from the respective DC-DC converters i.e Buck. Boost. Buck- Boost. Cuk converters

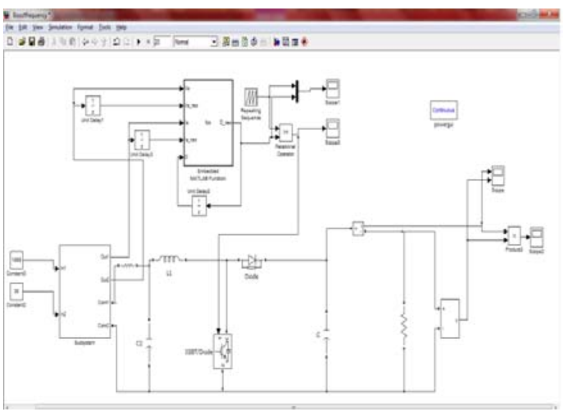

**Fig. 4** Overall Simulation diagram

The simulation results are obtained for the U5 solar module with the following specifications.

**TABLE NO.**1 U5 SOLAR MODULE ELECTRICAL SPECIFICATIONS

| **Parameters** | **Ratings** |
|---|---|
| Maximum Power | 5 W |
| Open circuit voltage (Voc) | 21.7 V |
| Short circuit current (Isc) | 0.527 A |
| Voltage at maximum power Vmpp | 17.39 V |
| Number of cells | 36 |

The Voltage Vs current waveform of the PV module is obtained for the above specifications given in the Table No.1 which is the basis for tracking the maximum power point. The output of the Solar panel U5 obtained is 21.7 V

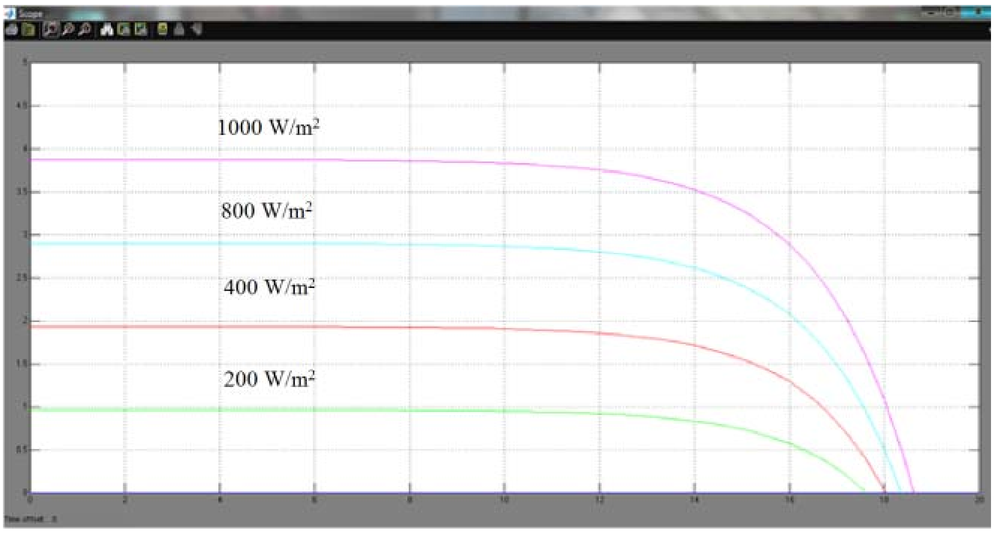


**Fig. 5** V-I Curves obtained for various radiation levels

The V-I curve shown in the fig. 5 is the input to the Incremental Conductance algorithm. INC algorithm using the flowchart shown in fig, (3) computes the duty cycle required to product the maximum power at the output. The PWM pulse which is obtained from the INC Algorithm is shown in the fig. (5)

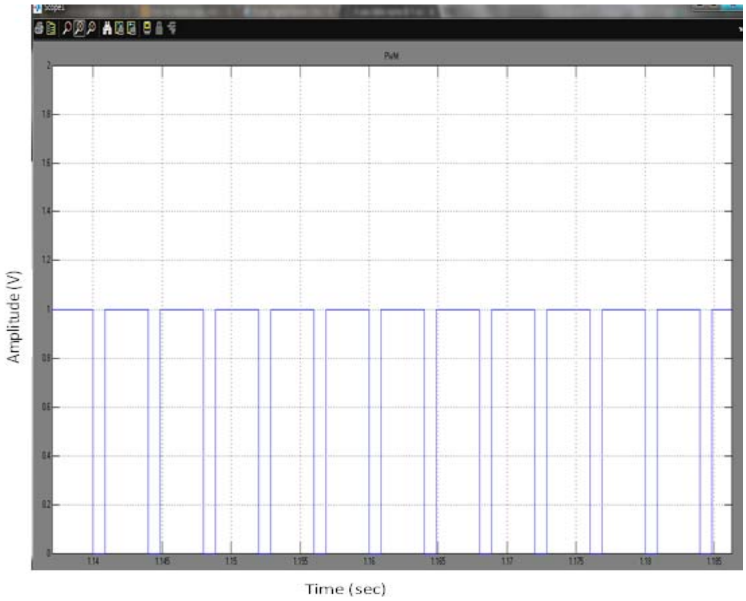


**Fig. 6** PWM signal obtained from INC algorithm

The PWM pulse is then given as Gate signal to the IGBT used in the DC- DC converters. In the DC-DC Converter sections, different dc-dc converters like Buck, Boost, Buck Boost and Cuk converters are analysed and the corresponding output of each converter is given in the following figures. Fig. (1) shows the Voltage and Current output of Buck Converter Vo = 12.4 V Fig. (2) shows the Voltage and Current output of Boost Converter Vo =56.8 V Fig. (3) shows the Voltage and Current output of Buck- Boost Converter Vo = 35.1VFig. (4)shows the Voltage and Current output of Cuk Converter Vo = 35.1 V

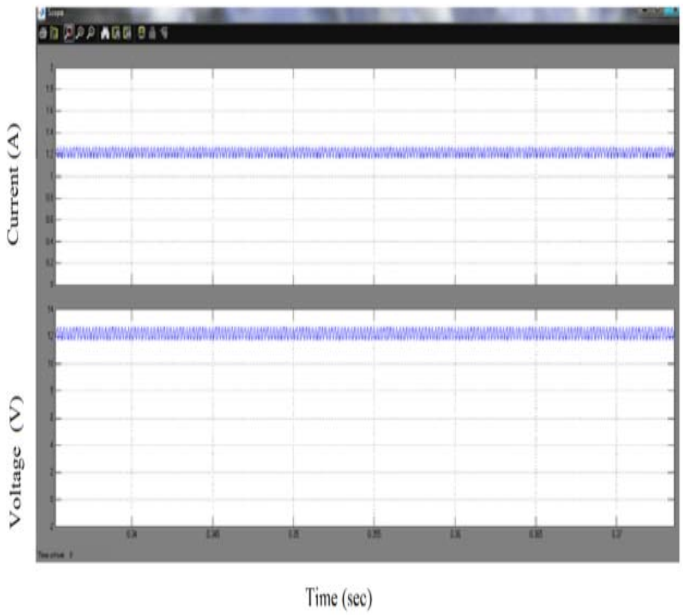


**Fig. 7** Current and Voltage output of Buck Converter

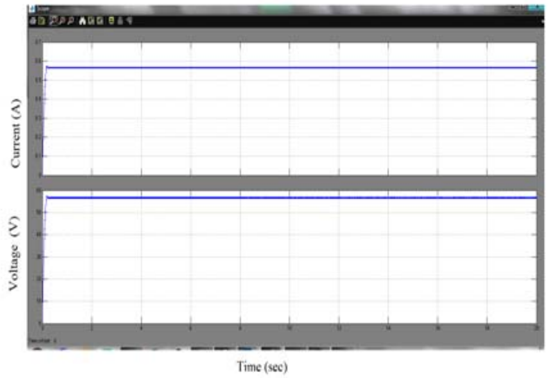


**Fig. 8** Current and Voltage output of Boost Converter

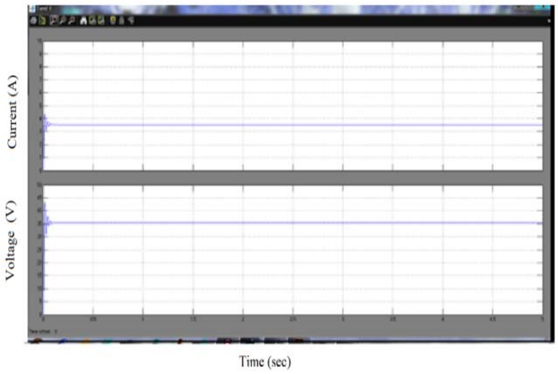


**Fig.9** Current and Voltage output of Buck - Boost Converter

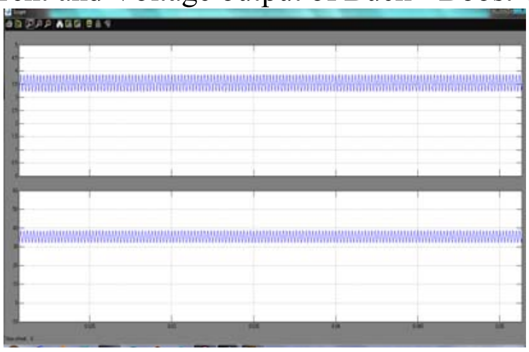

**Fig. 10** Current and Voltage output of Cuk Converter

## IX. CONCLUSION

This paper has presented a comparison of Buck, Boost, Buck-Boost and Cuk Converters used in a solar Maximum power point tracking. The P-V and I-V curves were obtained from the simulation of the PV array designed in MATLAB environment explains in detail its dependence on the irradiation levels and temperatures. Among the converters used Boost and Cuk converter provide best results for the MPPT controller. Cuk converter is still more advantageous than Boost converter as they have fewer ripples in the load current.

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