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# Incremental conductance (IncCond) algorithm for Maximum Power Operating Point (MPOP) of Photo-Voltaic (PV) power generation system

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***Abstract: -*** Solar power is considered as a very promising source for electric power generation. The abundance of sunlight over a large area of the earth surface gives rise to several applications of photovoltaic systems. Electricity can be generated from sunlight either by directly employing the photovoltaic effect, or by using energy from the sun to heat up a working fluid that can be used to power up electricity generators. These two technologies are widely used today to provide power to either standalone loads or for connection to the power system grid.

As the maximum power operating point (MPOP) of photovoltaic (PV) power generation systems changes with changing atmospheric conditions (e.g. solar radiation and temperature). An important consideration in the design of efficient PV systems is to track the MPOP correctly.

Many maximum power tracking (MPT) techniques have been considered in the past but techniques using microprocessors with appropriate MPT algorithms are favored because of their flexibility and compatibility with different PV arrays. Although the efficiency of these MPT algorithmic usually high, it drops noticeably in cases of rapidly changing atmospheric conditions. The authors have developed a new MPT algorithm based on the fact that the MPOP of a PV generator can be tracked accurately by comparing the incremental and instantaneous conductance of the PV array. The work was carried out by simulation, with results showing that the developed incremental conductance (IncCond) algorithm has successfully tracked the MPOP, even in cases of rapidly changing atmospheric conditions, and has higher efficiency than ordinary algorithms in terms of total PV energy transferred to the load.

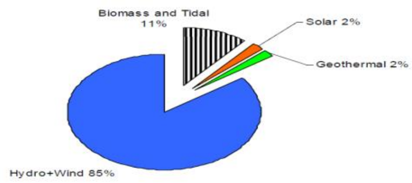
***Keywords: -*** *Photovoltaic systems, MPPT techniques, Perturb and Observe, Incremental conductance.*

## I. INTRODUCTION

The Aim of this chapter is to provide the characteristics of Photovoltaic arrays and the determination of maximum power by using maximum power point tracking techniques such as Perturb and Observe and Incremental conductance and the comparison of above two methods.

Power generation stations rely on multiple fuel sources to cover power demand. Coal is the most Used fuel type because of its abundance and low cost. A drawback of fossil fuels is the large amount of carbon dioxide gas emissions that cause the green house effect. Coal based power generation expectations are susceptible to variations as many countries introduce carbon emission regulations, which may lead to reductions in the number of coal-based power stations. Renewable energy sources, on the contrary, are the fastest growing source of electricity generation with a growth rate of 3% each year mainly driven by expansion in hydro and wind powers [1]. The rest of renewable energy sources including geothermal and solar powers are still not economically competitive with fossil fuel generation.

The renewable energy expected generation in year 2035 is broken down as shown in figure 1-3. It is clear that both hydro and wind powers dominate the share of renewable sources at 85% of the expected renewable energy contribution, while solar and geothermal energies are expected to contribute about 2% each. The cost per KWh of generated energy for solar power is high compared to Fossil fuel based sources, which is why it does not contribute with a significant share.




Photovoltaic (PV's) are arrays (combination of cells) that contain a solar voltaic material that converts solar energy into electrical energy. PV cell is a basic device for Photovoltaic Systems. Such systems include multiple components like mechanical and electrical connections and mountings and various means of regulating and (if required) modifying the electrical output. Materials that are used for photovoltaic are mono-crystalline silicon, polycrystalline silicon, microcrystalline silicon, and cadmium telluride and copper indium selenite. The current and voltage available at the PV device terminals can be directly used to feed small loads like lighting systems or small DC motors. In order to extract maximum amount of power from PV array we have to model converters so that it can track Maximum Power Point (MPP).

### 1.1 CHARACTERISTIC OF PV ARRAY

In recent years, photovoltaic (PV) systems have received unprecedented attention due to the concerns about adverse effects of extensive use of fossil fuels on the environment and energy security [2]. The photovoltaic energy is a clean energy, with a long lifespan and a high reliability. So, it can be considered as one of the most sustainable of the renewable energies. These systems can be located in or near where the necessity takes place, avoiding losses of transmission and contributing reductions to the $CO_2$ emission in urban centres. The photovoltaic module is the result of associating a group of photovoltaic cells in series and parallel figwith their protection devices, and it represents the conversion unit in this generation system. Besides, the obtained energy depends on the solar radiation, the temperature of the cell and the voltage produced in the photovoltaic module.

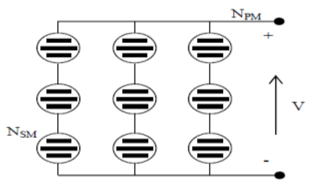
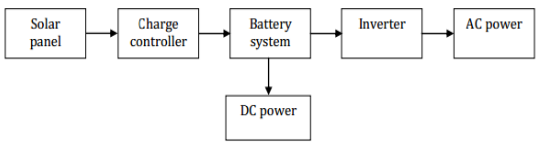



Fig. 1. PV module cell.

#### 1.1.1 Components of a solar PV system

A typical solar PV system consists of solar panel, charge controller, batteries, inverter and the load. Fig shows the block diagram of such a system.




#### 1.1.2Charge controller

When battery is included in a system, the necessity of charge controller comes forward. A charge controller controls the uncertain voltage build up. In a bright sunny day the solar cells produce more voltage that can lead to battery damage. A charge controller helps to maintain the balance in charging the battery.

**1.1.3Batteries**

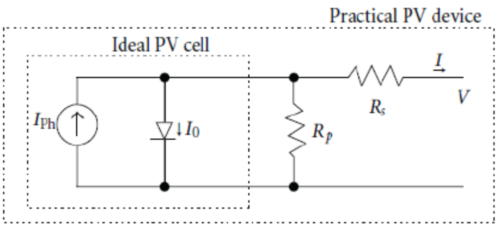
To store charges batteries are used. There are many types of batteries available in the market. But all of them are not suitable for solar PV technologies. Mostly used batteries are nickel/cadmium batteries. There are some other types of high energy density batteries such as- sodium/sulphur, zinc/bromine flow batteries. But for the medium term batteries nickel/metal hydride battery has the best cycling performance. For the long term option iron/chromium redox and zinc/manganese batteries are best. Absorbed Glass Mat (AGM) batteries are also one of the best available potions for solar PV use.

**1.1.4 Inverter**

Solar panel generates dc electricity but most of the household and industrial appliances need ac current. Inverter converts the dc current of panel or battery to the ac current. We can divide the inverter into two categories. They are-

- Stand alone and
- Line-tied or utility-interactive

## II. EQUIVALENT CIRCUIT OF SOLAR PV CELL




The PV array – characteristic is described by the following [4]:

$$i_{pv} = n_p * i_{ph} - n_p * i_{rs}\left[\exp\left(\frac{qv_{pv}}{kT_c A n_s}\right) - 1\right] \quad - (1)$$

In (1),q is the unit charge, k the Boltzmann's constant, A the p-n junction ideality factor, and $T_c$ the cell temperature. Current $i_{rs}$ is the cell reverse saturation current, which varies with temperature according to

$$i_{rs} = i_{rr}\left[\frac{T_c}{T_{ref}}\right]^3 \exp\left(\frac{qE_G}{kA}\left[\frac{1}{T_{ref}} - \frac{1}{T_c}\right]\right) \quad - (2)$$

In (2), $T_{ref}$ is the cell reference temperature, $i_{rr}$ the reverse saturation current at $T_{ref}$ and $E_G$ the band-gap energy of the cell. The PV current $i_{ph}$ depends on the insolation level and the cell temperature according to

$$i_{ph} = 0.01\left[i_{scr} + K_v\left(T_c - T_{ref}\right)\right]S \quad - (3)$$

In (3), $i_{scr}$ is the cell short-circuit current at the reference temperature and radiation, $K_v$ a temperature coefficient, and S the insolation level in kW/m. The power delivered by the PV array is calculated by multiplying both sides of (1) by $V_{pv}$

$$p_{pv} = n_p * i_{ph} * v_{pv} - n_p * i_{rs} * v_{pv}\left[\exp\left(\frac{qv_{pv}}{kT_c A n_s}\right) - 1\right] \quad - (4)$$

Substituting $i_{ph}$ from (3) in (4),$P_{pv}$ becomes

$$P_{pv} = 0.01 * n_p\left[i_{scr} + K_v\left(T_c - T_{ref}\right)\right] * S * V_{pv} - n_p * i_{rs} * V_{pv}\left[\exp\left(\frac{q * V_{pv}}{kT_c A n_s}\right) - 1\right] \quad - (5)$$

Based on (5), it is evident that the power delivered by the PV array is a function of insolation level at any given temperature.

The I-V Characteristics and the P-V characteristics of a PV array for insolation S=100 w/m^2

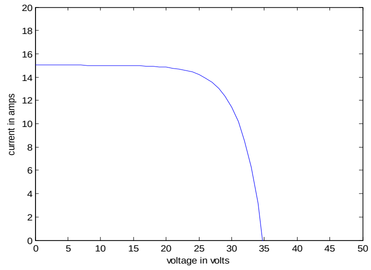



**Fig-1: I-V Characteristics**

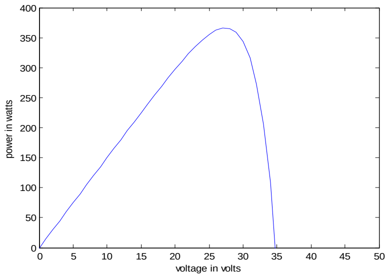



**Fig-2: P-V Characteristics**

At different insolation S values, the I-V characteristics and the P-V characteristics

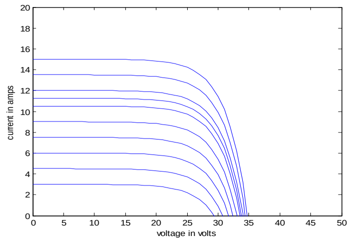



**Fig-3: I-V Characteristics**

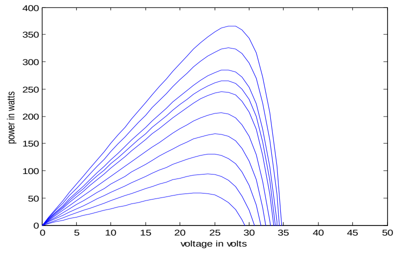
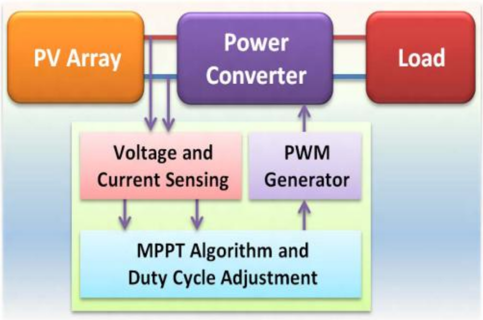



**Fig-4: P-V Characteristics**

## III. MAXIMUM POWER POINT TRAKING TECHNIQUES

Solar energy is the ultimate source of energy, which is naturally replenished in a short time period of time, for this reason it is called “renewable energy” or “sustainable energy”. Due to the severity of the global energy crisis and environmental pollution, the photovoltaic (PV) system has become one kind of important renewable energy source. Solar energy has the advantages of Maximum reserve, inexhaustibleness, and is free from geographical restrictions, thus making PV technology a popular research topic. In this world 80 % of the green houses gases are released due to the usage of fossil fuel based. The world primary energy demand will have increased almost 60% between 2002 and 2030, averaging 1.7% increase annually, increasing still Further the greenhouse gases [5]. Oil reserves would have been exhausted by 2040, natural gas by 2060, and coal by 2300 [6]. This causes issues of high per kW installation cost but low Efficiency in PV generators. [7-8]. currently more research works has been focused on how to extract more power effectively from the PV cells. There are two ways such as solar Tracking system and maximum power point tracking (MPPT) [9, 10]. In the literature survey show that there will be an increasing30-40 % of energy will be extracted compared to the PV system without solar tracking system. The maximum power point tracking (MPPT) is usually used as online control strategy to track the maximum output power operating point of the photovoltaic generation (PVG) for different operating condition of insolation and temperature of the pvg. The author [11, 12] compares and evaluates the percentage of power extraction with MPPT and without MPPT. It clearly shows that when we use MPPT with the PV system, the power extraction efficiency is increase to 97%. The study of developing a PV charging system for li-ion batteries by integrating MPPT and charging control for the battery is reviewed. The author [13] reviews the various Types of non-isolated dc-dc converters for the photo voltaic system. Optimal operating performances by different converter topologies are one of the main points which can be summarized in this research work. It concludes that the best type of converter for PV system is the buck-boost dc/dc converter. The overall block diagram of PV panel with dc-dc converter and MPPT.




The basic characteristics of the PV cell and the simulation model of the circuit with the help of Mat lab/Simulink software. The MPPT controller is necessary for any solar systems need to extract maximum power from PV module. It forces PV module to operate at close to maximum power operation point to draw maximum available power. The MPPT algorithm used in this paper is of Perturb and Observe and variable step size incremental conductance (ic) method. But the optimal performance of the PV system mainly depends on the power converter. The simulation model of the PV based system with MPPT algorithm will be implemented in the mat lab/Simulink.

### 3.1 Perturb and Observe

The Perturb and Observe algorithm is a simple technique for maximum power point tracking. It is based on controlling the duty cycle (d) of a dc-dc converter to adjust the PV array terminal voltage at the maximum power point [14]. The power output of the array is monitored every cycle and is compared to its value before each perturbation is made. If a change (either positive or negative) in the duty cycle of the dc-dc converter causes output power to increase, the duty cycle is changed in the same direction. if it causes the output power to decrease, then it is reversed to the opposite direction. The performance of the algorithm is affected by the choice of the perturbation magnitude ($\Delta d$) of the converter switching duty cycle. Large perturbations cause large output power fluctuations around the MPP while small perturbations slow down the algorithm. Modifications to this technique are published in [15], [16] and [17] to improve performance while maintaining the basic principle of operation. Illustrates the operation sequence of the algorithm.

| Change in duty cycle, Δd | Effect on output power | Next perturbation, Δd (n+1) |
|---|---|---|
| Increase | Increase | Increase |
| Increase | Decrease | Decrease |
| Decrease | Increase | Decrease |
| Decrease | Decrease | Increase |

Perturbation directions for the P&O algorithm based on output power variations

### 3.2 Incremental conductance

This algorithm exploits the fact that the slope of the power-voltage curve of a PV array is equal to zero at the maximum power point. The slope is positive in the area to the left of the maximum power point and negative in the area to the right. Mathematically, this can be summarized as:

$$dP / dV = 0, \text{ At MPP}$$
$$dP / dV > 0, \text{ Left of MPP}$$
$$dP / dV < 0, \text{ Right of MPP} \quad (6)$$

This can be simplified using the following approximation:

$$dP / dV = d(IV) = I + VdI / dV \approx I + V\Delta I / \Delta V \quad (7)$$

From that, (6) can be rewritten as:

$$\Delta I / \Delta V = -I / V, \text{ at MMP}$$
$$\Delta I / \Delta V > -I / V, \text{ left of MMP}$$
$$\Delta I / \Delta V < -I / V, \text{ right of MMP} \quad (8)$$

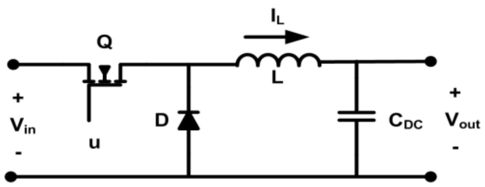
The incremental conductance algorithm is illustrated. Where Vref is used as a reference Control signal for the dc converter Similar to the P&O algorithm, the performance of the incremental conductance MPPT is affected by the increment size of Vref, used here as the control Variable.

## IV. SWITCHED MODE DC-DC CONVERTERS

DC/DC converters are used in a wide variety of applications including power supplies, where the Output voltage should be regulated at a constant value from a fluctuating power source, to reduce the ripples in the output voltage or achieve multiple voltage levels from the same input voltage. Several topologies exist to either increase or decrease the input voltage or perform both functions together using a single circuit. The three basic topologies of dc converters are: buck (step down), boost (step up) and the buck-boost converter topologies.

### 4.1 Buck converter

The schematic diagram of a buck dc converter is shown in fig It is composed of two main parts: a dc chopper and an output lc filter to reduce the ripples in the resulting output. The output voltage of the converter is less than the input as determined by the duration the semiconductor switch *q* is closed. Under continuous conduction mode (CCM), the current IL passing through the inductor does not reach zero. The time integral of the inductor voltage over one period in steady state is equal to zero. From that, the relation between the input and output voltages can be obtained.

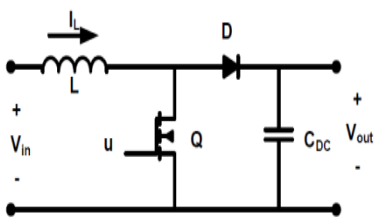



Schematic diagram of a buck DC converter

$$(V_{in} - V_{out})t_{on} - V_{out}t_{off} = 0 \quad \frac{V_{out}}{V_{in}} = \frac{t_{on}}{t_{on} + t_{off}} = d \quad \textit{Where } d = \textit{duty cycle}$$

### 4.2 Boost Converter

The boost dc converter is used to step up the input voltage by storing energy in an inductor for a Certain time period, and then use this energy to boost the input voltage to a higher value. The circuit Diagram for a boost converter is shown in fig. When switch *q* is closed, the input source Charges up the inductor while diode *d* is reverse biased to provide isolation between the input and the Output of the converter. When the switch is opened, energy stored in the inductor and the power Supply is transferred to the load. The relationship between the input and output voltages is given by:

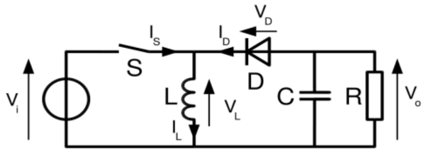



Schematic diagram of a DC boost converter.

$$V_{in}t_{on} + (V_{in} - V_{out})t_{off} = 0 \quad \frac{V_{out}}{V_{in}} = \frac{t_{on} + t_{off}}{t_{off}} = \frac{1}{1-d}$$

**4.3 Buck-Boost Converter**

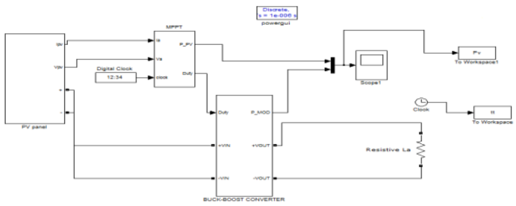
This converter topology can be used to perform both functions of stepping the input voltage up or down, but the polarity of the output voltage is opposite to that of the input. The input and output voltages of this configuration are related through



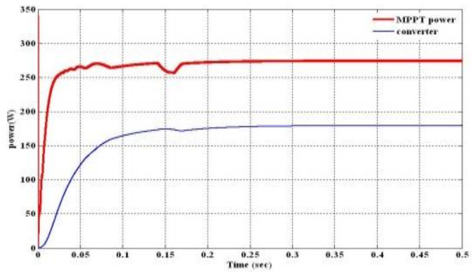

Schematic diagram of a DC Buck - Boost converter.

$$V_{in}t_{on} + V_{out}t_{off} = 0 \quad \frac{V_{out}}{V_{in}} = \frac{-t_{on}}{t_{off}} = \frac{-d}{1-d}$$

## V. SIMULINK MODEL OF PERTURB & OBSERVE

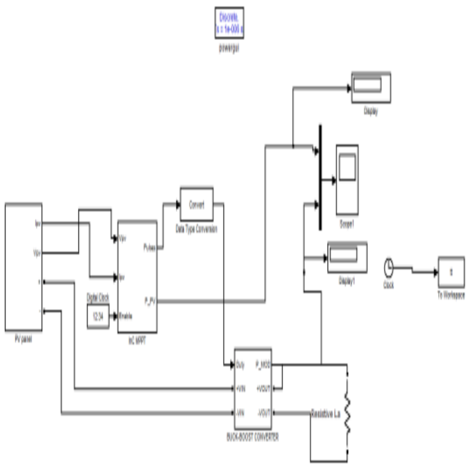


**5.1 Output for Perturb & Observe**

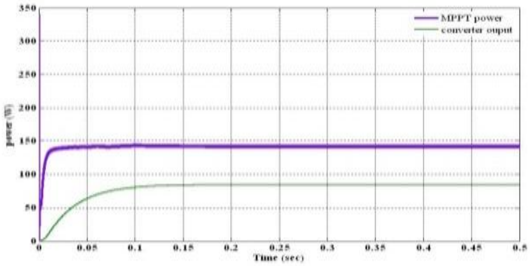



The output current and voltage from a PV array is given as input to MPPT of Perturb and Observe and track the output power and the duty is given as a control signal to converter and the output power is drawn from the converter by connecting the resistive load.The output response shown in above fig is the response drawn for the power from the MPPT and also the power from the converter with respective to time.

**5.2 Simulink for Incremental conductance**



**5.3 Output for Incremental conductance**




The output current and voltage from a PV array is given as input to MPPT of Incremental Conductance and track the output power and the duty is given as a control signal to converter and the output power is drawn from the converter by connecting the resistive load.The output response shown in figure is the response drawn for the power from the MPPT and also the power from the converter with respective to time.

## VI. CONCLUSION

The open loop maximum power point tracking technique aimed at solving the problems present in two of the most common techniques used for that purpose: the perturb and observe (P&O)and incremental conductance algorithms. The main drawbacks of the P&O technique are its poor dynamic response and swinging around the maximum power point during steady state operation. During fast changes in atmospheric conditions, the P&O technique may erroneously move in the Wrong direction on the PV power curve if each perturbation caused power to increase. The other issue is the steady state swing it has when it reaches the maximum power point as it perturbs the duty cycle of a DC converter to check for power variations.

The incremental conductance technique suffers also from a relatively slow dynamic response time. In each control step it is required to carry some computations to calculate the instantaneous and incremental conductance and then compare them to each other. Although it has an improved response time than the P&O technique, it is difficult to implement that technique in grid connected systems in its basic form.

The open loop MPPT technique employed in this thesis aims at providing an improved dynamic response time as compared to the previously mentioned techniques. It does not suffer from high implementation complexity as well. The PV array maximum power point was approximated using test PV cells that kept track of the current weather conditions.

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