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STUDY OF PV PANELS AND ANALYSIS OF VARIOUS MPPT TECHNIQUES

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ABSTRACT

The paper provides an in-depth study concerning the photovoltaic (PV) types, factors affecting the solar array efficiency and effective methodology for selecting a right Maximum Power Point Tracking (MPPT) algorithm for desired application. The paper provides numerous factors to be considered during choice of MPPT to the PV panels and also compares the normally used MPPT technique. This paper should serve a reference guide for selecting type of panels and choice of MPPT technique for future analysis and applications.

Keywords: *Photovoltaic Cell, MPPT, Direct Current, Fuzzy Logic, Neural Network*

1. INTRODUCTION

As the power demand increases in the country its essential to find alternative sources for feeding this power-hungry society. Another important factor to the current system is the fast increase of the carbon foot print by the thermal stations and vehicles which increases pursuit for an alternate energy supply to become crucial. Alternative resources like the Wind, solar, Hyde, tidal, etc. have stated their role in satisfying the load demand. Major drawbacks of these systems are their reliability and cost. Solar panels are considered to be major alternative resources since they can be modeled and installed in home as a standalone device. The government is also providing a lot of subsidies to bring down cost of panels and increase awareness among the public to increase the use of solar panels. By increasing the employment of alternative energy the dependency of diesel generators will facilitate in reducing the discharge of greenhouse gases. Solar energy provides the effective answers for handling the energy demand in distributed system and provides an energy security. The basic element in solar-energy generation is PV cells that convert solar energy into DC current. The PV cells are connected in parallel or series array to supply additional electricity. The foremost downside of the alternative energy production is it depends on the factors like climatic conditions, i.e. irradiation and temperature. Thus, it becomes necessary to extract most energy when optimum weather condition is available in the area. This paper provides a detailed review about the solar panels and factors influencing the choice of MPPT techniques according to the applications.

The section 2 of the paper gives the overview about the PV array, types of PV arrays and also gives basic idea about the need of MPPT to the current systems. The section 3 of the paper explains the various MPPT techniques in detail. Section 4 gives the application of the various MPPT techniques and in Section 5 the paper is concluded.

2. SYSTEM OVERVIEW

The overall system consists of PV cells, i.e. silicon cells, which are arranged in series or in parallel to increase the output and to form a PV module. The PV modules are linked in forming a PV array for huge applications. The systems are classified according to the applications such as standalone and Grid connected. The mountings of the panels are usually roof mounted for the domestic purpose, and Pole mounted or ground mounted for large power production. MPPT technique is connected to the solar panel to maximize the output power where the charge controllers are used to avoid damage to the battery from charging and discharging.

2.1 PVArray:

The photovoltaic effect was discovered by Becquerel in 1839 but not developed as a power source until 1954 by Chapin, Fuller and Pearson using doped semiconductors. Photovoltaic power is one of the fast-developing renewable-energy resources. A PV cell is a p-n semiconductor junction. When it is exposed to the sunshine, a DC current is generated where the generated current varies linearly with the sun’s irradiance [1].

The equivalent circuit of a perfect electric cell can be treated as a current supply parallel with a diode shown in figure 1.

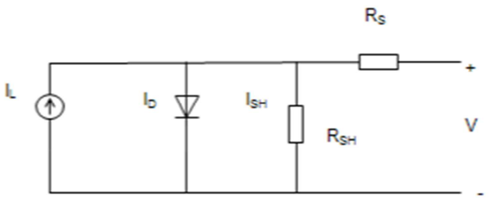

Figure1: Equivalent circuit of a PV Panel.

Solar cells have complex relationship between solar radiations, temperature and total resistance that produces a nonlinear output efficiency known as I-V curve. The I-V characteristics of the equivalent electric cell circuit may be determined by following equations [1].

$$I = I_L - I_0 \left[exp\ q \left(\frac{(V+IR_S)}{KT}\right) - 1\right] - \frac{(V+R_S)}{R_{Sh}} \qquad (1)$$

$$I = I_L - I_0 - I_{Sh} \qquad (2)$$

When Diodes are connected in series the equation changes as,

$$I = N_P I_L - N_P I_0 \left[exp\ q \left(\left(\frac{V_{PV}}{N_S} + \frac{IR_S}{N_P}\right) AKT\right) - 1\right] - N_P \left(\frac{\frac{V_{PV}}{N_S} + I_{PV} R_S}{R_{Sh}}\right) \qquad \mathbf{(3)}$$

Where,
I=cell current (Amps)
I_L = Light generated Current (Amps)
I_0 = Diode saturating Current
q= Charge of electron
A=Diode ideality constant
K=Boltzman constant (j/k)
T=Temperature in cell
R_s = solar cell in series (ohms)
R_{sh}=Solar cell in Shunt resistance (Ohms)
N_p = Number of cells in Parallel
Ns= Number of cells in series

2.2 Types of PV Panels:

2.2.1 Mono crystalline Panels:

Solar cells in mono crystalline panels are slices cut from pure drawn crystalline silicon bars. The entire cells are aligned in one direction, so that when the sun is shining brightly on them at an ideal angle, they are extremely efficient. The pure cells are octagonal in shape, so there are huge unused spaces in the corners when the lot of cells is aligned to make into a module. These panels are most efficient and costly.

2.2.2 Polycrystalline Panels (Multicrystalline):

Polycrystalline panels are made from the silicon off cuts, molded to form blocks and create a cell made up of several bits of pure crystals. Because the individual crystals are not necessarily perfectly aligned together and there are losses at the joints between them, they are not quite efficient. This misalignment helps in working of cells at all angles of light and in low light. These panels are cost effective during manufacturing and most commonly used in residential due to low cost.

2.2.3 Hybrid Panels (Amorphous Modules):

The hybrid module has a thin layer of amorphous solar film behind the mono crystalline cells. The extra amorphous layer extracts more energy from the available light, particularly during the low light conditions. They are effective in handling the partial shading and more effective in hotter climatic conditions.

2.3 Types of Operations:

Based on the functional and operational requirements they are classified as

2.3.1 Standalone or off-grid:

This system operates independently of the electric grid and widely used in rural areas where the electric grid does not reach or where the electricity cost for access to the grid are higher than the cost of an alternative energy system. The DC power generated in this system is stored in batteries and converted to AC power using the inverter for household or commercial use. A stand-alone Solar Power system are suited for remote village and countrified electrification projects, and provides a reliable source of electricity, particularly in remote rural areas utilizing only diesel generators.

2.3.2 Grid connected:

In a grid-connected system, the solar panels are connected to the electricity grid. When the sun shines, the panels produce electricity and store the charge in the battery. However, when the excess charge is produced than the required energy, the remaining energy can be supplied to the grid by using a smart meter so that the energy supplied to the mains can be calculated. In modern grid-connected solar system does not require battery for storage thus it reduces the cost of installation of the system.

2.4 Maximum Power Point Technique (MPPT):

The basic work by MPPT is to work out the PV output voltage or output current that the PV array can produces at most output power in a given temperature and irradiance and conjointly will increase the in operation time period of the PV system[2]. In a basic Module of a PV system (Figure 2)consist of PV panels and Load where a DC/DC converter is used between them in advanced modules MPPT used to extract the Maximum power from the PV module and transfer to the load [3, 4]. A dc/dc convertor (step up/ step down) serves as a transferring medium between the PV modules to the load. The load impedance is varied by changing the duty cycle to match to supply the maximum power [4].

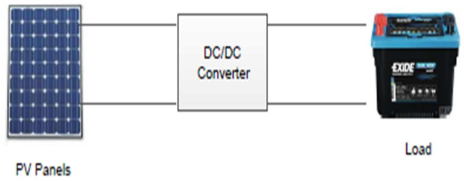

Figure 2: Basic Module of the PV panels connected to the DC-DC converter

A shadow on the even part of one solar panel in your solar array can potentially disturb the output of the whole system. In some cases, shading in spite of one cell could flatten the output of the panel and in turn the entire string. Many modern panels are equipped with bypass diodes to minimize the effects of partial shading by enabling the electricity to flow around the shaded cell or cells. Fluctuations in system output are basically unavoidable when clouds passing through the sky during the day. Solar panels are installed differently based on their geographic locations throughout the world. The sun is in a different place in the sky, so panels need to be tracked according to this positioning. The optimal situation is when the sun is hitting the panels at a perfectly perpendicular angle (90°). This maximizes the amount of energy striking the panels and being produced. The angle is controlled by the orientation (North/South/East/West) and the angle of the panels from the surface of the Earth.

The selection of MPPT Technique depends on following factors:

- Implementation complexity
- Hardware required
- Ability to detect multiple local maximum points
- Cost
- Application
- Response time

Further the MPPT are classified as

- Indirect Methods (quasi seeks)
- Direct methods.

Where in indirect methods, Maximum Power Point (MPP) is estimated from Voltage, Current, irradiance by using empirical data and mathematical expressions of numerical approx. The estimation is carried out for a specific PV panel installed in the system. Direct Methods (true seeking) use voltage and/or current information where prior knowledge of PV panel is not required. It is independent of isolation, temperature and degradation levels.

3 MPPT TECHNIQUES:

3.1 Perturb and observe (P&O) technique/Hill – climbing Method:

P&O can be implemented by applying perturbations to the reference voltage or reference current signal of the solar panel [5, 6, and 7]. Hill-climbing [8] changes the perturbation on the duty cycle of the power converter and P&O changes a perturbation in the operating voltage of the DC link between the PV array and the power converter.

The different steps of the Perturb and Observe methods are:

1. Take current and voltage measurements and also the power calculation.
2. If the power is constant, return to take new measurements.
3. The voltage variation is tested, if the power is decreased or increased.
4. The current is modified according to the direction of the voltage variation.

First, the PV voltage and current are measured, and hence corresponding power P1 is calculated. Considering a small perturbation of voltage (ΔV) or perturbation of the duty cycle (Δd) of the DC/DC converter in one direction corresponding P2 is calculated. P2 is then compared with P1. If P2>P1, then perturbation is in correct direction, otherwise it should be reversed. In this way, the peak power point is recognized, and corresponding MPP is calculated. The following table 1 explains the Perturbation Change in power next perturbation.

Table 1: Perturbation Change in power next perturbation

Perturbation	Change in power	Next perturbation
Positive	Positive	Positive
Positive	Negative	Negative
Negative	Positive	Negative
Negative	Negative	Positive

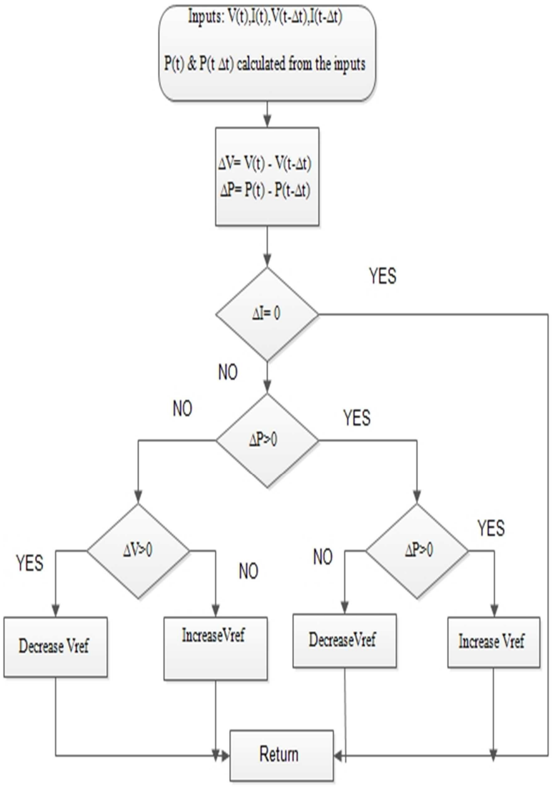

Figure 3: Block diagram of Perturb and observe (P&O) technique/Hill –climbing Method

Perturbation is done in this manner. Perturbing the duty ratio of the power converter perturb the PV array current and consequently, perturb the PV array voltage.

Disadvantages:

- The major drawback of the P&O/Hill climbing are occasional deviations from the Max operating point in the case of rapidly changing atmospheric conditions such as broken clouds.
- Predicting correct perturbation size is important in providing good performance in both dynamic and steady-state response.
- When the system operating point changes quickly, the algorithm will be prone to tracking errors.

Solution:

- To overcome this problem, a modified adaptive hill climbing technique with a variable perturbation step size can be used.
- An automatic turning controller varies the perturbation step size to a large value when the power changes in a large range primarily due to environmental variations, to satisfy the fast response requirement during transient stage.

3.2 Incremental Conductance (Inc-Cond Technique)

The incremental conductance method employs the slope of PV array-power characteristics to track MPP [9, 10]. The method is based on the slope of the PV array-power curve is zero at MPP [11, 12], positive for values of output power smaller than MPP and negative for values of output power greater than MPP.

$\frac{dP}{dV} = 0$, at MPP

$\frac{dP}{dV} > 0$, left of MPP

$\frac{dP}{dV} < 0$, right of MPP

By using the power formula, P=V.I, its derivative becomes:

$$dP = V.dI + I.dV \tag{4}$$

$$\text{When, } \frac{dp}{dv} = 0 \text{ and } \frac{d(VI)}{dV} = 0; \tag{5}$$

$$I + \frac{VdI}{dV} = 0; \tag{6}$$

On comparing the equation (5) and (6),

$$I + \frac{V\Delta I}{\Delta V} = 0; \ \frac{\Delta I}{\Delta V} = -\frac{I}{V} \tag{7}$$

So that,

$$\frac{\Delta I}{\Delta V} = -\frac{I}{V}, \text{ at MPP;}$$
$$\frac{\Delta I}{\Delta V} > -\frac{I}{V}, \text{ left of MPP;}$$
$$\frac{\Delta I}{\Delta V} < -\frac{I}{V}, \text{ right at MPP;}$$

Thus the MPP is tracked by comparing the instantaneous conductance (I/V) to incremental conductance (ΔI/ΔV).

V_{ref} - Reference voltage at which PV array is forced to operate.

At MPP, V_{ref}=MPP

Once the MPP is reached, the operation of PV array is maintained at this point unless a change, in "I" occurs. The algorithm then tracks the MPP by applying decrement or increment to Vref. The size of increment or decrement determines how fast MPP is tracked.

ADV:

- Increment method could provide a better tracking of MPP.
- It offers an effecting solution under rapidly changing environment.

Disadvantage:

- This method requires complex control circuitry.

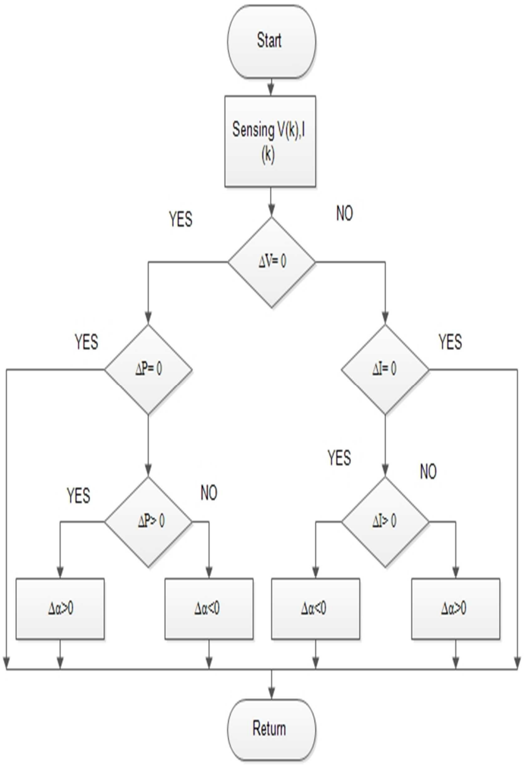

Figure 4: Block diagram of Incremental Conductance (Inc-Cond Technique)

3.3 Fraction Open Circuit Voltage Technique (FOCV):

This is one of the common and easy methods [13, 14] where, V_{MPP} can be calculated from empirical relationship as follows,

$$V_{MPP} \approx K_1 V_{OC} \qquad (8)$$

The value of K_1 varies between 0.78 and 0.92. K_1 can be calculated by analyzing the PV system at a wide range of solar radiations and temperature. The PV system is open circuited at the load end for a second to measure V_{OC} . The power converter has to be shut down momentarily due to which loss of power occurs in each measurement. Figure 5 shows the basic flow diagram of the FOCV technique. Major drawback of current method is that it is incapable of tracking the MPP under irradiation slopes, because the determination of V_{MPP} is not continuous. Where the MPP reached is not the real one because the relationship is only an approximation. V_{OC} is measured and then V_{MPP} is measured using the above formula. Repeating this process V_{OC} is sampled repeatedly in every few seconds and value of V_{MPP} is updated.

Disadvantage:

- There is a temporary loss of power while measuring V_{OC} in open circuit condition.
- Value of K1 is no more valid in the presence of partial shading of PV array this leads to implantation complexity and incurs more power loss.

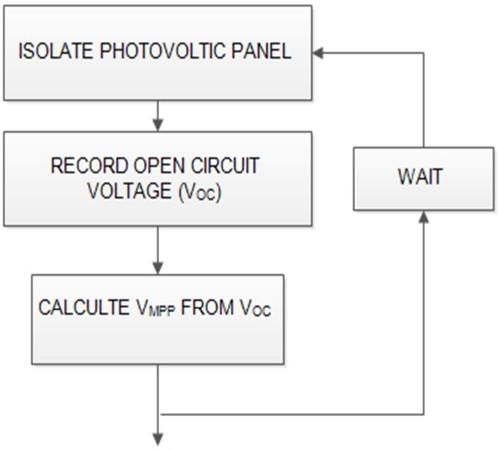

Figure 5: Block diagram of the open circuit voltage method

3.4 Fractional Short Circuit current (FSCI):

In the FSCI technique [15,16] the non-linear VI characteristics of PV system are modelled using mathematical equations by taking account of various environmental conditions and degradation

level of PV panels. Figure 6 shows the basic flow diagram of the FSCI technique.
Based on the VI characteristics mathematical relationship between IMPP and ISC is constructed, as IMPP is linearly dependent on Isc by a relation.

$$I_{MPP} \approx K_{SC} \times I_{SC} \tag{9}$$

Value of the K_{SC} fixed between 0.64 and 0.85

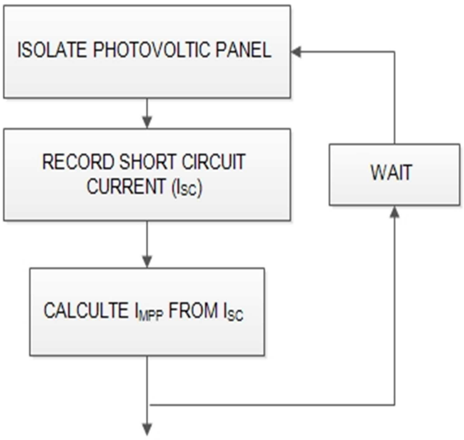

Figure 6: Block Diagram of the short circuit current method.

Difficulties in implementing:

- Measuring the Isc during the operation is Problematic.
- Cost of the system further increases due to the addition Switch has to be added to the power converter circuit to periodically short the PV array So that Isc can be measured using the current sensor.
- Power output is reduced when finding Isc and also causes the MPP never perfectly matched.

3.5 Current sweep Technique:

The current sweep technique uses a sweep waveform for PV array current such that I-V characteristics of PV array is obtained ad updated at a constant time interval[17].
The VMPP is then computed from the characteristic curve at same interval.
The function chosen for current sweep waveform is directly proportional to its derivative as,

$$i(t) = K_1 \left[\frac{di(t)}{dt}\right] \tag{10}$$

At MPP,

$$\frac{dp(t)}{dt} = \frac{d[V(t)i(t)]}{d(t)} = 0$$

$$i(t)\left[\frac{di(t)}{dt}\right] + V(t)\left[\frac{di(t)}{dt}\right] = 0;$$
$$\left[K_1 \frac{dV(t)}{dt} + V(t)\right]\frac{di(t)}{dt} = 0; \tag{11}$$

Solution of equation (10)

$$i(t) = Ce^{\frac{t}{K_1}}$$
$$i(t) = I_{max}e^{\frac{-t}{\tau}}, \tau = -K_1; C = I_{max}.S$$
$$\left[\frac{dp(t)}{di(t)}\right] = V(t) + K_1\left[\frac{dv(t)}{dt}\right] = 0 \tag{12}$$

Once V_{MPP} is computed after current sweep, the above equation can be used to double check whether MPP has been reached. The current sweep takes about 50ms implying some loss of available power.

In fixed time interval the reference point is frequently updated and hence the yield accurately results if proportionality coefficient K_1 and C are properly chosen.

3.6 Ripple correlation control (RCC):

The switching action of power converter imposes voltage and current ripple on the PV array when connected to the Power converter, this results PV array power to ripple. RCC makes use of ripple to perform MPPT [18].
RCC correlates the time derivative of time varying PV array power P with the time derivative of the time varying PV array current I or voltage V to derive the power gradient to zero, thus reaching MPP.

$$i = \frac{di}{dt}, \dot{V} = \frac{dv}{dt}, \dot{P} = \frac{dp}{dt} \tag{13}$$

$\frac{dv}{dt} > 0\ (or) \frac{di}{dt} > 0$ and $\frac{dp}{dt} > 0$, then V<MPP (or)

$\frac{dv}{dt} > 0\ (or) \frac{di}{dt} > 0$ and $\frac{dp}{dt} < 0$, then V > MPP, I > MPP

Operating point is above MPP. Combining the observations PV or PI are positive to left of MPP, Negative to right of MPP and Zero at MPP. When power converter is a boost converter results in increasing the duty ratio increases the inductor current which is same as PV array current but decreasing PV array voltage,
Therefore the duty ratio control input is calculated by equation (13)

$$d(t) = -K_3 \int \dot{P}\dot{V} dt \qquad (14)$$
$$d(t) = K_3 \int \dot{P}\dot{I} dt \qquad (15)$$

Controlling duty ratio in this method assures that MPP will be continuously tracked making RCC a true MPP tracker.

Advantages:

- The real time implementation can be done with Simple and inexpensive analog circuits
- It does not require any prior information's about PV array characteristics.
- The MPP is tracked accurately and quickly even under varying irradiance levels.

3.7 Fuzzy logic based MPPT technique:

Fuzzy logic control is one of the intelligent MPPT techniques [19, 20]. Where Figure 7 shows the block diagram of a basic Fuzzy logic control.

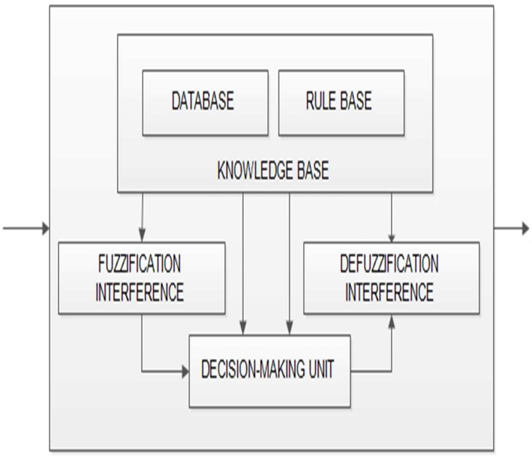

Figure 7: Block diagram of fuzzy logic and Membership functions diagram.

They achieve very good performances, fast response with no overshoot and less fluctuations in steady state for rapid temperature and irradiance variations. Fuzzy Logic based MPPT do not require the knowledge of exact PV model.

Fuzzy Logic has two inputs and one output. The two input variables are error (e) and change in error (Ce) at the Kth sampled time are defined as follows.

$$e(k) = \frac{dp}{dv}(k) - \frac{dp}{dv}(k-1) \qquad (16)$$
$$Ce(k) = e(k) - e(k-1) \qquad (17)$$

e(k) – error of position of operating point of load at Kth instant.

Ce(k) – Moving direction of this point.

The three stages of the Fuzzy Logic control are,

Fuzzification- Where numerical Input variables are converted into linguistic variables based on a membership function.

Rules - Decisions are made as per the Look up table.

Defuzzification- The fuzzy logic controller output is converted from a linguistic variable to numerical variable.

The number of membership functions depends on the accuracy of the controller to be designed, but it mostly varies between 5 and 7 levels.

For eg: In the figure five levels are used.

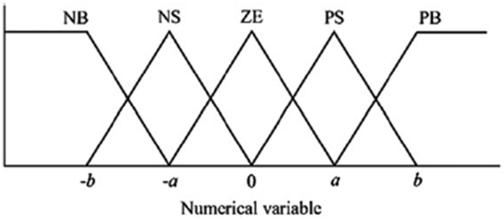

Figure 8: Membership function for inputs and output of fuzzy logic controller

The values *a* and *b* are based on the range values of the numerical variable. Where the inputs are *e(K)* and Ce(K), as defined in (16) and (17), and the output is a change in the DC-link voltage, Ce(K). For example, if the operating point is far to the right of the MPP, *e(K)* is NB, and Ce(K) is zero, then to reach the MPP the reference voltage should decrease, so dV should be NB (Negative) to move the operating point towards the MPP. This provides an analog signal that is used to control the Power converter to the MPP.

Where table 2 shows the rules set for the seven level fuzzy logic controller and the member functions are written as ,NB -Negative Big, NM - Negative Medium ,NS –Negative Small,. ZE – Zero, PS - Positive Small, PM - Positive Medium, PB -Positive Big,

Table 2: Rules set for seven level fuzzy logic controller

E(k) \ Ce(k)	**NB**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

3.8 Neural Network:

Neural network control operates like a black box model, requiring no detail information about PV system. Neural network normally has three layers: input (i/p), hidden and o/p layers [21, 22]. The numbers of nodes in each layer vary and they are user dependent. The input variables will be PV array parameters such as Voc, Isc, irradiance and temperature.

The output is usually single or several reference signals like duty cycle used to drive the power converter to operate at or close to MPP.
The link between the nodes is weighted. To accurately identify the MPP, weights (W_{ij}'s) have to be carefully determined through a training process, the database for training is obtained by testing the PV panels over a month and pattern between input and output of neural network are recorded.

The characteristics of PV array also changes with time, implying that neural network has to be periodically trained to guarantee accurate MPPT.

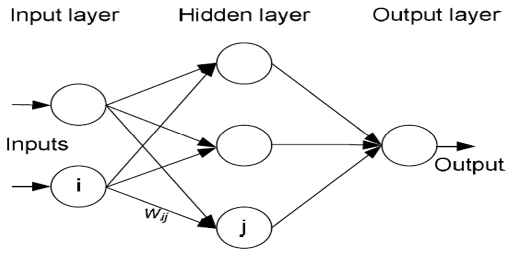

Figure 9: Block diagram of Neural Network

3.9 DC Link capacitor droop control technique:

DC link capacitor droop control technique is designed to work with a PV system that is connected in parallel with an AC system Line[23,24]. The duty ratio (d) of an ideal boost converter is represented as,

$$d = 1 - \left[\frac{V}{V_{link}}\right] \qquad (18)$$

Where V- voltage across PV array
V_{link} –Voltage across DC link.
If V_{link} is kept constant, the power coming out of converter can be increased by increasing the current going into inverter.

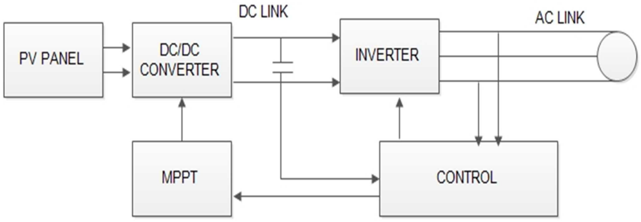

Figure 10: Block diagram of DC Link capacitor droop control technique.

When the current is increasing, the voltage V_{link} is kept constant across as long as power required by an inverter does not exceed the Maximum power available from array, else the V_{link} starts drooping. The current control command of inverter is at its maximum before the drooping point and PV array operates at the MPP.
The AC system line current is fed back to the DC link to prevent V_{link} from drooping and d is optimized to achieve MPPT.

3.10 Sliding Mode Based MPPT techniques:

Sliding Mode: The trajectory Motion of the system along a chosen line/plane/surface of the state space.
Sliding mode control is robust control approach where a higher-order system is transformed into first-order system. Sliding mode controller design provides a systematic approach to the problem of maintaining stability and consistent performance in the face of modelling imprecision for the class which it is applied. On the other hand, by allowing the tradeoffs between modelling and performance to be quantified in a simple manner, it can illuminate the whole design process [25].
Essentially, sliding mode control utilizes discontinuous feedback control laws to force the system state to reach, and finally to remain on a fixed surface within the state space (the so called sliding or switching surface). The system is dynamic when fixed to the sliding surface as

described in ideal sliding motion and represents the controlled system behavior.

The design of the sliding mode control law is divided in two steps:

1) Step 1- Construction of a suitable sliding surface so that the dynamic system is fixed to the sliding manifold produces a desired behavior.

2) Step 2 - The design of a discontinuous control law which forces the system trajectory to the sliding surface and tries to maintain it there.

4 APPLICATIONS:

Some of the applications of MPPT are,

- **Agriculture Water Pumping, Water Treatment and Hybrid Vehicles:** Where fast convergence to MPP is required. MPPT such as Fuzzy logic control, neural network, RCC, load current or load voltage maximization may be considered.
- **Industry, Residential and Street Lighting:** Charges the battery during the day time where Easy and cheap implementation is more important. MPPT techniques such as Fractional VOC and/or Fractional ISC can be considered.
- **Communication Satellite and Radio Tower applications:** Where the Cost and complexity is not an issue algorithm such as Hill climbing/P&O, Inc Cond, and RCC are appropriate.
- **Health:** Especially applications like refrigeration where Partial shading issues affect the efficiency of the system and increases the payback time. Algorithms such as two stage incremental conductance, current sweep methods, OCC MPPT may be considered.

5 CONCLUSION:

In this paper various MPPT techniques are analyzed and explained in detail. The advantages and disadvantages of the techniques were discussed and finally the results are formulated in a table 3 for easy understanding. The various factors affecting the performance of MPPT and types of panels are also discussed which can serve as a quick guide in selecting the panels and MPPT technique for specific applications.

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Table 3: Comparison of MPPT techniques

MPPT	Control Strategy	PV array dependent	Analog /Digital	Parameters Sensed	Periodic Timing	Convergence speed	Complexity	Training	Cost	Converter used	Application
P&O	Sampling Method	NO	Both	V,I	NO	Varies	Low	NO	High	DC/DC	Standalone
INC-COND	Sampling Method	NO	Digital	V,I	NO	Varies	Medium	NO	High	DC/DC	Standalone
FOCV	Indirect Method	Yes	Both	V or I	Yes	Medium	Simple	Yes	Low	DC/DC	Standalone
FSIC	Indirect Method	Yes	Both	V or I	Yes	Medium	Simple	Yes	Low	DC/DC	Standalone
Current Sweep	Modulation Method	Yes	Digital	I	Yes	Slow	Complex	No	High	DC/AC	Grid
RCC	Modulation Method	NO	Analog	V or I	NO	Fast	Low	NO	High	DC/DC	Standalone
Fuzzy Logic	Intelligent	Yes	Digital	V or I	Yes	Fast	high	Yes	High	Both	Both
Neural Network	Intelligent	Yes	Digital	V or I	Yes	Fast	high	Yes	High	Both	Both
DC-DC link capacitor Droop	Modulation Method	NO	Both	V	NO	Medium	low	NO	High	Two stage DC/DC+ DC/AC	Grid
Sliding Mode	Sampling Method	NO	Digital	V or i	NO	Fast	high	Yes	High	Both	Both