

TECHNICAL REVIEW ON MPPT TECHNIQUES ON PHOTOVOLTAIC SYSTEMS

Omorogiuwa Eseosa, Itelima Kingsley

Electrical/Electronic Engineering, Faculty of Engineering,
University of Port Harcourt, Rivers State, Nigeria.

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*Corresponding Author

Omorogiuwa Eseosa
Electrical/Electronic
Engineering, Faculty of
Engineering, University of
Port Harcourt, Rivers State,
Nigeria.

ABSTRACT

Technical researches on solar Photovoltaic (PV) systems including its technological development and advancement have displayed tremendous growth in the last few years, making them commercially achievable but not really affordable currently. It is because of this challenge of non-affordability that has led to the development of maximum power point tracking of solar energy for its maximum

efficiency and effective utilization. This work is on review of maximum power point tracking (MPPT) techniques for PV systems including its design, characteristics, principles of operations, construction, planning of PV arrays and the necessity of such systems. Various techniques reviewed in this study include offline, hybrid, three points, temperature based, Artificial intelligence (AI) control as well as the fuzzy logic control techniques. The offline techniques include open circuit voltage, short circuit current and look-up table. Perturbed and Observed method (P&O) as well as the incremental conductance controlled method is among the hybrid technique reviewed. Also considered is this significance of Irradiance and fill factor to MPPT technology.

1.0 INTRODUCTION

The first photovoltaic effect was discovered by French Scientist Edmond Becquerel in 1839. It is a process where electrical voltage is created when light is sucked up by a material. To achieve this effect, some modern solar cells utilize silicon crystals (www.solarpowerauthority.com). The Photoconductivity of Selenium was discovered by a

young English electrical engineer Smith Willoughby in 1873. This is a process of becoming electrically conductive when it assimilates light. However, without heating or the position of the parts that can fail, Richard Evans and William Grylls discovered that selenium can generate electric power from light three years later (www.solarpowerauthority.com). That energy from the sun was way easy to achieve and maintain, needing small parts than other power sources-such as plants that produces power through the use of coal was proven from this discovery. The first solar cell which was designed by covering selenium with a fine thickness of gold was made by a certain Charles Fritts, an inventor from New York in 1883. Fortunately, the energy conversion rate of this cell was between 1–2%. The efficiency of modern solar cells is between 15–20% .The process where solid surface liberates free electrons with the use of light; metal mainly to produce power known as photoelectric effect was first observed by the German physicist Heinrich Hertz in 1887. This series of event generated greater energy when it was made visible to ultraviolet light instead of a more exceeding strong visible light (www.solarpowerauthority.com). This effect was further elaborated by Scientist Albert Einstein that earned him a Nobel Prize. Conversion of sunlight into power (Photoelectric effect) is what solar cells at present rely on. The discovery that silicon is far more efficient than selenium led to the creation of the first practical solar cell which is now 6% efficient by some Physicists at Bell Laboratories in 1953. However, solar cells being able and efficient to power electrical equipment were discovered. Nonetheless, commercial licenses were being sold in 1956 by Western Electric for its silicon PV technologies, however silicon solar cells cost kept them from expansion in the market. The government supported the use of energy from the sun to power exploration equipment in space following years of tests to raise the effectiveness and exploitation of solar energy. In half of a century in orbit, the first satellite powered by solar energy, Vanguard 1 traveled round the earth 197,000 times in 1958. However, to reduce cost and increase production, more research was carried out on this application. The need for solar energy increased as the price of oil increased in the 1970s (Abbasi et al, 2011). Costs from \$100/watt to \$20-\$40/watt was achieved when the firm, Exxon Corporation supported the research to design solar cells made from lower grade silicon and cheaper material. However, The National Renewable Energy Laboratory (NREL) was formed in 1977 when the Federal Government signed several solar-friendly bills and initiatives. The Atlantic Richfield Solar Company constructed the first solar park in Hesperia, California, 1982. At maximum capacity, Arco Solar Park produced 1MW, or 1,000kw/h which can light a 100kw bulb for approximately 10hrs. Similarly, Arco Solar constructed the second park in Carrizo Plains, California in 1983. It

contained 100,000 PV modules that produced 5.2MW at the highest capacity, which made it the largest set of arrays in existence. When oil returned to popularity, these plants fell into disorder and displayed the ability of making solar energy generation a commodity (www.solarpowerauthority.com). A patent was filed in 1995 by Thomas Faludy; which was retractable awning with integrated solar cells as the research for solar energy continued to spread to other business sector. Recreational vehicles used solar cells during that time. At present, this structure is a common method to supply electricity to recreational vehicles. During the year 1994, there was a creation of a new solar cell from gallium indium phosphide and gallium arsenide that has efficiency conversion of 30% by the National Renewable Energy Laboratory. Thin-film solar cells that transformed 32% of sunlight it acquired into energy capable of being used were later designed by the Laboratory. Recently, solar power for residential areas has gained popularity as efficiency and of solar cells has increased. Every New Year that passes, the DIY solar panels began to dominate after reaching the market in 2005. At the moment, solar panels have different ways of construction, from assembling a panel to array planning (Zainudin *et al.*, 2010). Nowadays, industrial printer can produce solar cells as thin as paper and embedded into goods such as roofing tiles. The residential solar energy cost reduced drastically as one strip could generate up to 50W/m² due to the power conversion efficiency of 20% (Benneth *et al.*, 2012). However, since the strips are easy to bend and not costly to produce; it is a welcome development for the large number people living in progressing countries. Discovery of new attributes of Nano materials by investigation group from California University, Berkeley and National University in Australia emerged. It has a property known as Magnetic Hyperbolic Dispersion, meaning when warmed up, the material emits light (Abdalla *et al.*, 2011)). It has the ability to change heat to electrical power without sunlight when combined with thermo photovoltaic cells.

2.0 REVIEW OF PREVIOUS RELATED WORKS

Research on solar PV systems has displayed tremendous growth in the last few years, making them commercially achievable. Comprehending how the systems works is based on the numerical modeling which has proven to be a worthy tool. In literatures, Matlab/Simulink models have been the major objective. (Tsai *et al.*, 2010) recommended four distinct types of generalized MATLAB designs to ascertain the outcome of temperature and irradiance; and to make efficient the generalized design. (Nema *et al.*, 2010) carried out a Matlab/Simulink based research of PV module, PV array and PV cell subjected to various conditions of operations. (Hernanz, *et al.* 2010) created a finished design to simulate PV system electrical

operation by analyzing how solar cells perform. (Kumari and Babu, 2012) similarly performed simulation and modeling of mathematically PV cell in Matlab/Simulink workspace to obtain the non-linear I-V equation parameters by modifying the curve at three conditions of operation: maximum power, open circuit and short circuit positions. (Bhatt and Thakker, 2011) carried out research on PV Array characteristics and have been acquired as a function of temperature. (Alsayid and Jallad, 2011) compared a 50W solar panel with a Simulink simulation of PV array, module and cell. (Mohammed, 2011) attempted to carry out Matlab/Simulink based designs of modules with 60W and 64W power output. (Richhariya and Pachori, 2011) made a simple solar cell using parameters such as cell temperature and irradiance as input and had it proven by using Matlab/Simulink. (Hernanz *et.al.*, 2012) assessed the similarities and differences between two PV simulation designs in functions of time by using matlab/Simulink to obtain an I-V curve comparable to the data sheet provided by the manufacturer. Nevertheless, numerous adoptions accompanied these models, whereby some of them are inaccurate. (Venkateswarlu and Raju, 2013) expressed that studying PV systems in a thorough way needs a straight learning of I-V and P-V curves of PV modules. (Vajpai and Khyani, 2013) revealed the progress of Matlab/Simulink design for solar PV array, module and cell.

2.1 Fundamental Principle of PV Cell

Between N-type and P-type regions, a diode is formed and such diode is a P-N junction diode where PV cells are crucially part of the whole system (Christopher *et al.*, 2013). The incident energy can be transformed into electricity when sunlight hits PV cells. Subsequently, free electrons are excited from lower energy level to a free higher energy level when transmitted light is sucked up within the semiconductor. Excess electron-hole pairs are produced by luminance through the material at the instance a PV cell is lighted up, and hence, current flows while the p-n junction is electrically shorted. Initial cost of installation for PV systems is very high, thus utilizing this energy from the PV panels is quite expensive. (Abdelsalam *et al.*, 2011).

2.2 Maximum Power Point Tracking (MPPT)

The process whereby an algorithm is fixed in charge controllers for drawing highest power possible from a PV array at varying atmospheric state is known as Maximum Power Point Tracking (www.leonics.com). Maximum Power Point (MPP) or Peak Power Voltage is the voltage at which the PV array can generate the highest power.

2.21 Irradiance

This can be described as a measurement of solar power, and it is defined as the speed at which energy from the sun falls on a surface. It is measured in power per unit area typically given as W/m^2 i.e. watt per square meter.

2.2.2 Fill Factor

This is a quantity often used to characterize the output performance of PV module. It is the ratio of the maximum point power to the product of open circuit voltage, V_{oc} and short circuit current, I_{sc} . Fill factors around 70–75% for crystalline silicon solar modules are typical, while for multi junction amorphous-Si modules, it is closer to 50–60%.

$$\text{Fill Factor} = \text{Power at MPP} / V_{oc} \times I_{sc} \quad 1.0$$

3.0 MAXIMUM POWER POINT TRACKING TECHNIQUES (MPPT)

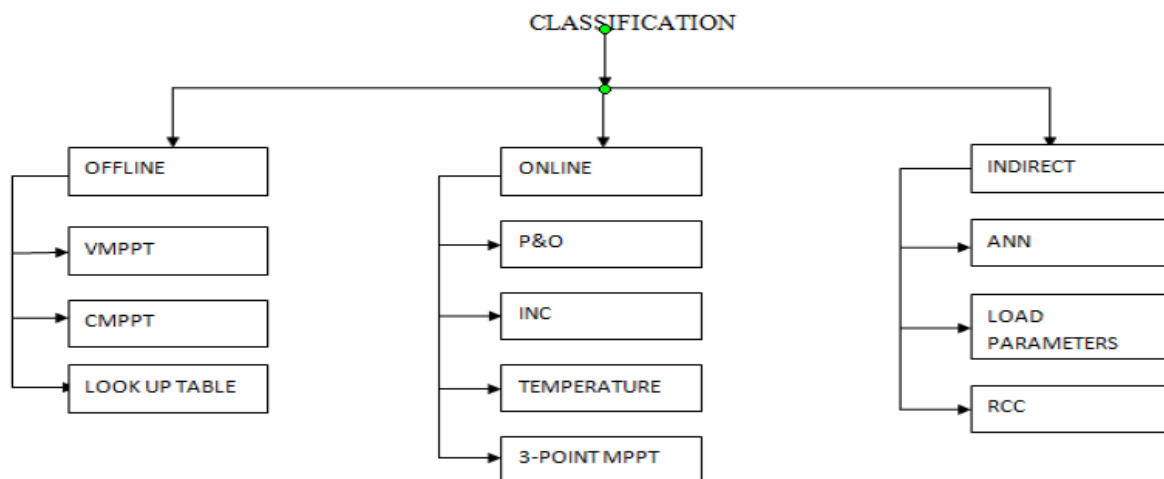


Fig. 3.1: Categories of MPPT Techniques (Source: Priety *et al*, 2014).

Offline, online and hybrid methods are various MPPT techniques which have been developed and implemented. Open circuit voltage, short circuit current, temperature and irradiation are the solar panel values that solar cell models use in offline techniques (Priety *et al*, 2014). Figure 3.1 shows various categories of MPPT techniques.

3.1 Offline Open Circuit Voltage (VOC) MPPT Technique

This is the easiest offline technique which uses approximate linear connection between open circuit voltage (V_{oc}) and maximum power point voltage (V_{mpp}) under varying atmospheric state as shown in equation 3.1,

$$V_{mpp} \approx K_{vf} \cdot V_{oc} \quad 3.1$$

Where V_{mpp} = maximum power point voltage, V_{oc} = open circuit voltage and K_{vf} = range of constant voltage factor which is from 0.75 to 0.9 and depends on distinctive feature of the PV system. Now, to ascertain the quantity of open circuit voltage between converter and panel, a switch is placed in series. PV system current is rapidly set to zero by the MPPT and equation 2.1 is computed when the circuit is opened and V_{oc} measured (Ahmed *et al*, 2011). To get maximum power, at intervals, this process is repeated. With relative ease in implementation and low cost, VOC technique suffers from two major setbacks: Initial measurement of V_{oc} needs periodic load shedding. Secondly, correct maximum power point may not be tracked which cause more power losses. However, trial cell is used to control these power losses and also method to measure the irradiance and temperature and estimation of the V_{oc} based on the stated MPPT technique. Worthy of note is that since insolation does not vary, this technique is suitable for satellite (Abdelsalam *et al*, 2011). Figure 2.2 shows a flowchart of the open circuit voltage MPPT technique.

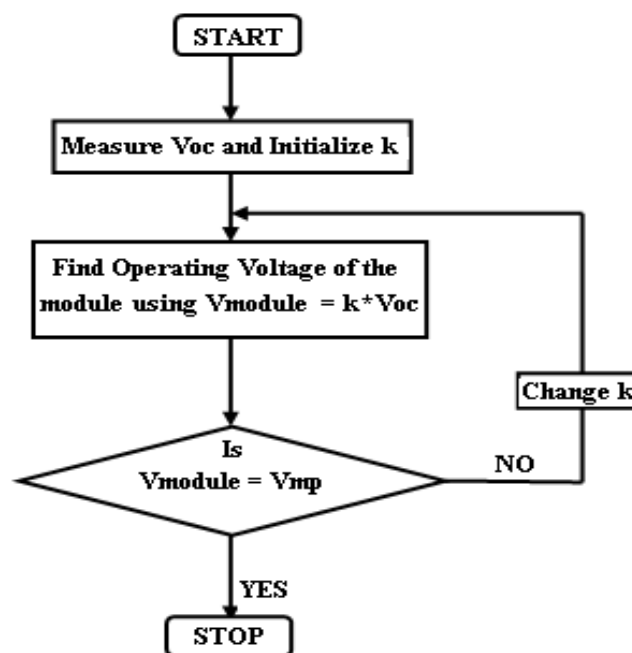


Fig. 3.2: Flow chart of Open Circuit Voltage (V_{oc}).

3.2 Offline Short Circuit Current (S_{CC}) MPPT Technique

S_{CC} is another offline technique same as V_{oc} and also uses the approximate linear relationship between the highest power point current and PV system current, as stated in equation 3.2

$$I_{mpp} \approx K_{if} \cdot I_{sc} \quad 3.2$$

Where I_{mpp} = maximum power point current, I_{sc} = short circuit current and K_{if} = constant current factor, which varies from 0.7 to 0.8. The switch converter can be used as a PV system

short circuit where the boost converter is employed. However, the cost to carry it out is higher though it is a more efficient and exact technique. Worthy of note is that like V_{OC} technique, power losses associated with load interruption can be controlled if measuring the irradiance and temperature is used to estimate the S_{CC} based on the main technique equation and same enhancement can be applied to the S_{CC} technique. Failure of delivery of highest output power by both V_{OC} & S_{CC} occurs owing to the following reasons: The first is that tracking of MPP would not be correct. Secondly, when I_{sc} or V_{oc} is measured, interference of load occurs (Kumar *et al*, 2015).

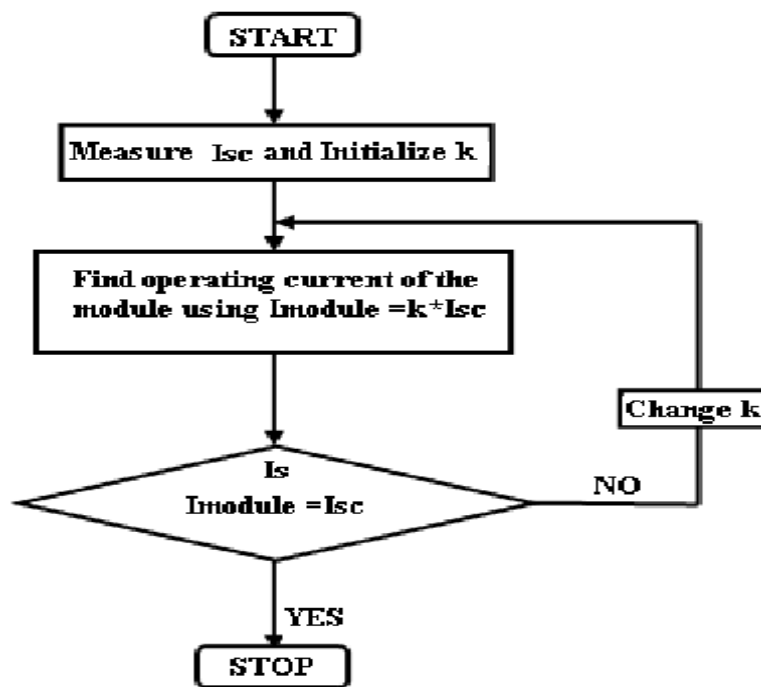


Fig. 3.3: Flow chart of Short Circuit Current (S_{cc}).

3.3 Offline Look-up Table MPPT Technique

This is also one of the offline techniques to track MPP. Panel distinctive features, learning of PV system technical data and materials are needed and stored at varying environmental conditions before using this method. Then, computation and comparison of power with those stored values to track MPP and at the new MPP, operating point is shifted after the output current I and output voltage V of PV system are sensed. Due to the system becoming hard for changing atmospheric conditions, the system needs larger capacity to store prior data. However, its speed is slow and it is also not an accurate technique since more number of sensors is required (Priety *et al*, 2014).

3.4 Perturb and Observe (P&O) MPPT

This is one of the hybrid techniques of MPPT. According to Yue and Tolbert, in 2010, when the irradiation vary slowly, Perturb and Observe (P&O) method is employed but it displays unsteady behavior for swiftly varying irradiance level that causes erroneous or slow tracking of power. However, because of its ease of implementation, this technique is most common MPPT algorithm. In other words, the current power is computed and compared with previous value to ascertain its variation after one perturb operation. So, the system raises the voltage of operation until the power in the output begins to reduce when the cell voltage increases the cell power output. Then, the voltage is reduced to get back the highest power output once this happens. Hence, this process is continually repeatedly until MPP is reached (Hun *et al.*, 2011). However, steady state oscillations and slow speed are the two major problems of P&O technique. When small steps are chosen, the dynamics will slow down; on the other hand, efficiency reduces and steady state oscillations increases if large steps are chosen and the dynamics are larger. Modified P&O algorithms are used to overcome this setback in this case.

3.4.1 Perturb & Observe MPPT Algorithm

In this method, voltage from the solar array is adjusted in bits by the MPPT controller and the power is measured. If there is an increase in power, it is adjusted further in that direction until there is no more increase in power. It also relies on the theory that the output power derivative (P) with respect to panel voltage (V) equals zero at maximum power point. The P&O algorithm is employed in MPPT charge controllers as its feedback is a simple arrangement and parameters measured are small. P&O MPPT controls the time interval of DC-DC converter to change the terminal voltage of PV array at maximum power point. Before each perturbation, the array output power is tracked every interval and compared to the initial value. The time interval is altered in the same direction if any alteration (whether negative or positive) in the time interval of the DC-DC converter makes the output power to rise up. Similarly, it reverses to the other direction if it makes the output power to reduce. Perturbation size (Δd) of the converter switching time interval determines the algorithm's performance. Large perturbations yield large fluctuations of the power output around the maximum power point whereas small perturbations reduce the speed of the algorithm. The algorithm flow chart is shown in figure 3.4a. The graphical representation of P&O MPPT is described in Figure 3.4b.

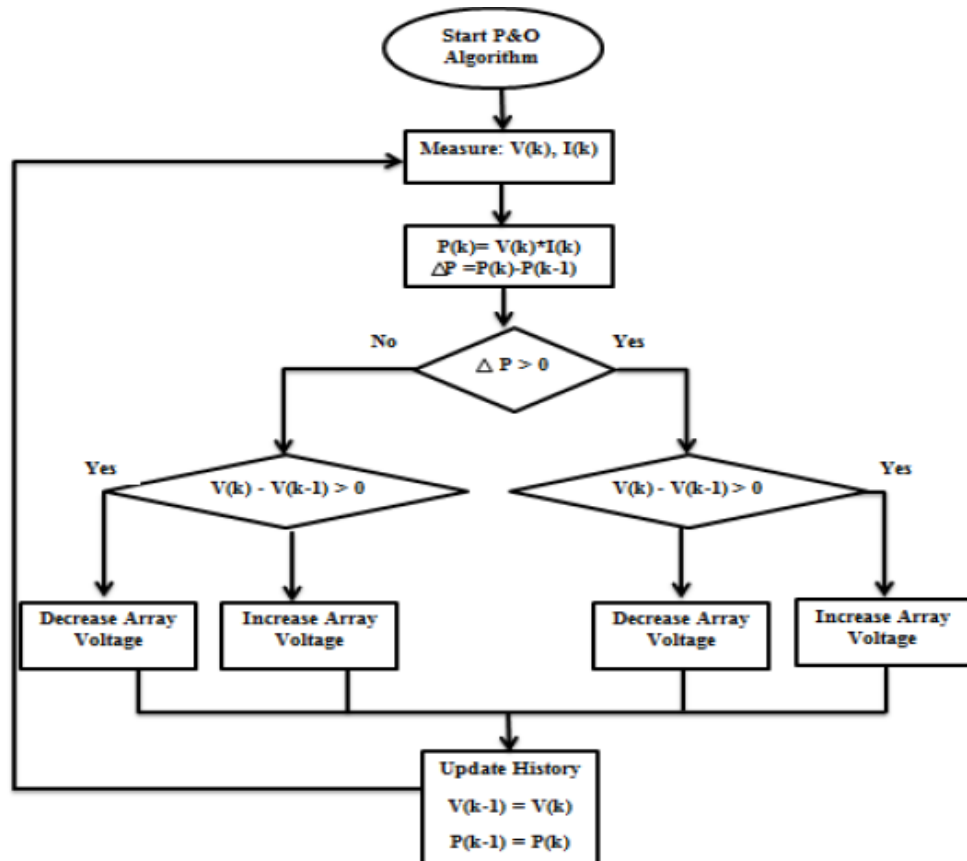


Fig. 3.4a: Flow Chart Algorithm of P&O MPPT (Sachin *et al.*, 2015).

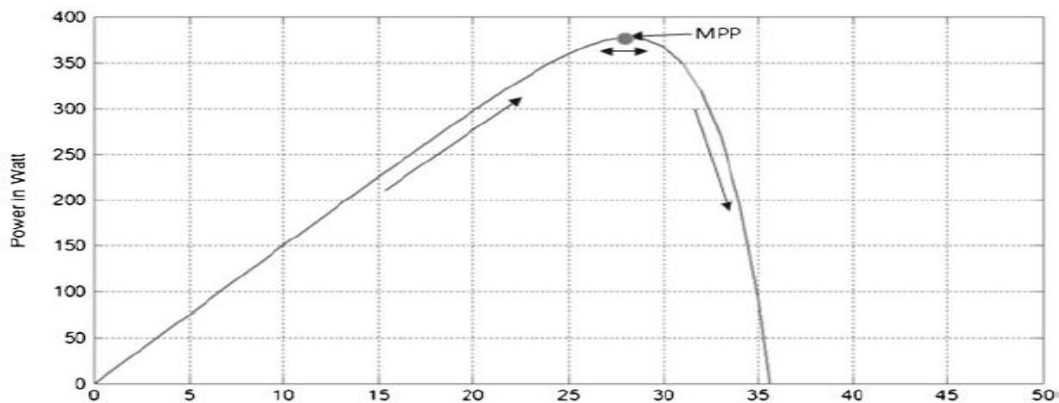


Figure 3.4b: Power Curve of P&O MPPT (Source: Sachin *et al.*, 2015).

3.5 Incremental Conductance (INC) MPPT

This is another form of hybrid MPP technique. Incremental Conduction method is employed in getting the highest power during frequent changes in atmospheric condition where P&O technique fails (Shimi *et al.*, 2013). Tracking accurate maximum power point with INC technique is obtained by comparing instantaneous conduction (I/V) with INC ($\Delta I/\Delta V$) of photovoltaic array. However, because of its high tracking speed, better efficiency and ease of implementation, this method of tracking is advantageous over other conventional techniques.

Note that at maximum power point, summation of $\Delta I/\Delta V$ and $I/V =$ zero, if positive then the maximum power point is to the left side and if negative, then on right side of maximum power point (Priety *et al.*, 2014).

Where I_{pv} = PV current, V_{pv} = PV voltage, I_o = Output current, V_o = Output voltage, R_L = Resistive load. Table 3.1 made comparisons and characteristics between different MPPT techniques.

Table 3.1: Different MPPT Techniques & Their Characteristics (Rohit *et al.*, 2017).

MPPT Technique Used	CHARACTERISTICS			
	Complexity/Implementation	Periodic Tuning	Speed of Convergence	Parameters Sensed
INC	Medium	No	Varies	Voltage, Current
P&O	Low	No	Varies	Voltage
FLC	High	Yes	Fast	Varies
Fractional I_{sc}	Medium	Yes	Medium	Current
Fractional V_{oc}	Low	Yes	Medium	Voltage
Neural Network	High	Yes	Fast	Varies

3.5.1 Incremental Conductance MPPT

In this method, increase in PV voltage and current is measured by the charge controller to state the result of change in voltage. It calculates the maximum power point by comparing the incremental conductance, $\Delta I/\Delta V$ with the array conductance, I/V . When both are similar, the voltage at the output is called the Maximum Power Point voltage. Incremental Conductance (INC) method corrects the oscillations around highest power point of P&O MPPT method to monitor or track the maximum power when the atmospheric condition changes rapidly. When the MPPT has reached the highest power point, INC will observe that and cease the perturbation. The direction of the MPPT point of operation is perturbed with the connection between $\Delta I/\Delta V$ and $-I/V$ if this requirement is not satisfied. When the MPPT is on the right side curve of the maximum power point, $\Delta P/\Delta V$ is negative and it is positive when it is on the left side curve of the highest power point. Where P&O swings back and forth, INC ascertains when the MPPT has attained its maximum power point and that is its major advantage. High complexity is the disadvantage of INC but it can monitor and track fast rising and falling irradiation conditions with exactness better than the P&O method.

For a PV array, the power equation is given as;

$$P = IV \quad 3.3a$$

Where P = Module Power, I = Module Current and V = Module Voltage

Differentiating equation (3.3a) with respect to V yields;

$$\frac{dP}{dV} = I + (V \times \frac{dI}{dV}) \tag{3.3b}$$

Equation 3.7b defines the algorithm and at highest power point,

$$\frac{dP}{dV} = 0 \text{ and } \frac{dI}{dV} = -\frac{I}{V} \tag{3.3c}$$

If the point of operation is to the right of the power curve, then;

$$\frac{dP}{dV} < 0 \text{ and } \frac{dI}{dV} < \frac{I}{V} \tag{3.4a}$$

If the point of operation is to the left of the power curve, then;

$$\frac{dP}{dV} > 0 \text{ and } \frac{dI}{dV} > \frac{I}{V} \tag{3.4b}$$

The flow chart of INC is described in Figure 3.5a.

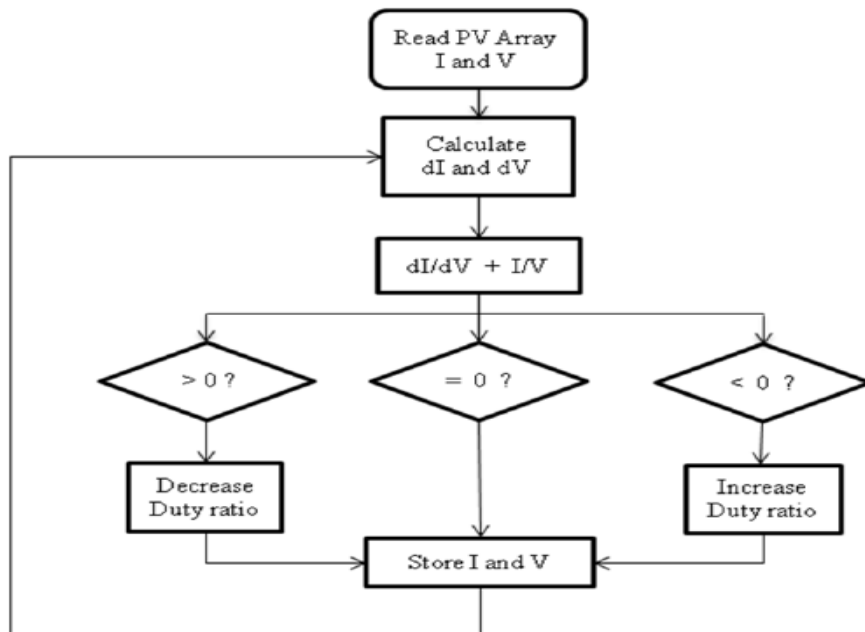


Figure 3.5a: Flow Chart Algorithm of INC MPPT (Source: Christopher *et al*, 2013).

The graphical representation of INC MPPT is shown in Figure 3.5b.

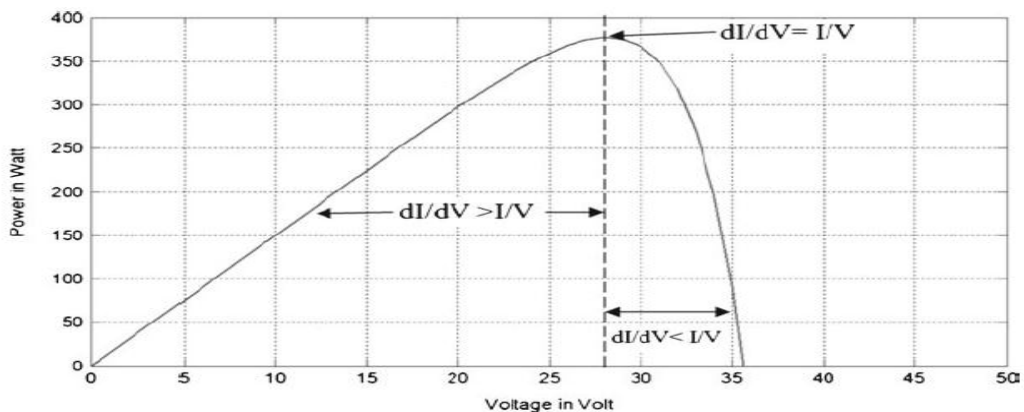


Fig. 3.5b: Power Curve of INC MPPT (Source: Sachin *et al*, 2015).

The block diagram of MPPT controlled system is described in Figure 3.6 while the circuit diagram is as shown in figure 3.7.

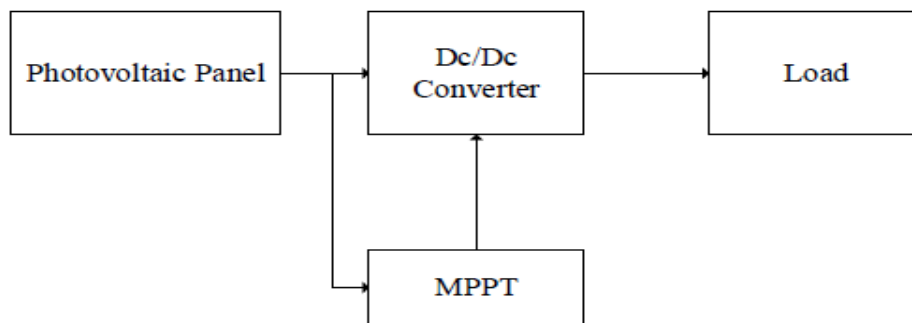


Fig. 3.6: Block Diagram of MPPT System.

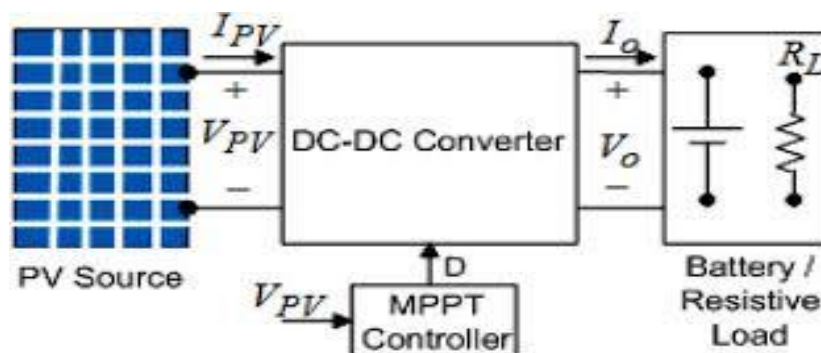


Fig. 3.7: Circuit Diagram of MPPT system (Source: google.com/mppt).

3.6 Three Point MPPT

This technique compares the power at three points on the P-V curve for MPP. In this technique, there are three points that are powered at current operating point P_x , previous point P_{x-1} and next point P_{x+1} . So, if it is positive perturbation, then $P_{x+1} \geq P_x$ otherwise it is a negative perturbation power. Subsequently, positive perturbation is given if power at $P_{x+1} \leq P_x$. Then, these points are compared and duty cycle is altered after each perturbation. Hence, oscillation problem is avoided in this technique which makes it advantageous over other conventional techniques (Priety *et al*, 2014).

3.7 Temperature Based MPPT

This technique is very simple to implement as maximum power point is tracked with temperature sensor. However, in short circuit, current changes with change in irradiance level whereas the voltage of PV cell changes with change in cell temperature in open circuit as discussed in offline techniques (Kumar *et al*, 2015). This technique has some disadvantages of non-uniformity in photovoltaic system temperature and also inaccurate tracking caused by calibration of temperature sensor leading to error in precision measurement.

3.8 Artificial Intelligence (AI) Controlling MPPT

A widely accepted technique employed to find answers to difficult problems in many aspect is the Artificial intelligence (AI). It is highly technical and specialized and divided into small field that often fails to communicate with each other (Poornima *et al*, 2013).

3.9 The Fuzzy Logic Control (FLC) MPPT

According to (Bendib *et al*, 2015), machine control application in industry makes use of the Fuzzy logic controller. In other words, to control the system, linguistic labels from the output of the controller by the fuzzy are transformed into a sharp solution. Note that FL based MPPT algorithms develops the characteristics of PV system.

4.0 CONCLUSION AND RECOMMENDATION

This paper reviewed MPPT techniques and its applications to PV systems for the main purpose of power generation. High financial cost needed for energy generation is a significant setback of PV systems as it cannot be compared to that generated by common power production systems or other renewables like wind power. To get an efficient power, MPPT which is an electronic DC - DC converter is used as it enhances the solar arrays matching. Simply put, to charge batteries, they transform high voltage DC output from solar system to a lower voltage required. In essence, since winter is the time more energy is required from the PV system; temperatures of the panel are quite low during that period and tend to generate more energy. A digital controller (MPPT) is employed in controlling the converter. To obtain an exact matching with the panels and batteries, the tracker is a high frequency DC - DC converter that collects the input from the PV system, changes it to high frequency AC, and changes it back to a separate DC voltage current. It should be worthy of note that the operating range of MPPT IS approximately BETWEEN 20khz to 85 khz.

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REFERENCES

1. Abbasi, T., & Abbasi, S., Renewable energy sources: Their impact on global warming and pollution. PHI Learning, 2010.

2. Abdalla, I., Zhang, L., and Corda, J., “Voltage-Hold Perturbation & Observation Maximum Power Point Tracking Algorithm (VH-P&O MPPT) for Improved Tracking over the Transient Atmospheric Changes,” presented at Power Electronics and Applications (EPE 2011) of the 2011-14th European Conference, 2011; 1–10.
3. Abdelsalam A. K, Massoud A. M., Ahmed S, Enjeti P.N., High-performance adaptive perturb and observe MPPT technique for photovoltaic-based microgrids. *IEEE Transactions on Power Electronics*, 2011; 26(4).
4. Alsaid, B. and Jallad, J., “Modelling and Simulation of Photovoltaic Cells/Modules/ Arrays”, *International Journal of Research and Reviews in Computer Science (IJRRCS)*, 2011; Vol. 2, No. 6,
5. Bhatt, H.G and Thakker, R.A. (2011). Matlab Based Simulation of Photovoltaic Solar Cell and its Array at Different Temperature Values“, *National Conference on Recent Trends in Engineering & Technology, B.V.M. Engineering College, Gujarat*, PP. 1-4, 2011.
6. Bendib, B & Belmili, Hocine & Krim, Fateh. (2015). A survey of the most used MPPT methods: Conventional and advanced algorithms applied for photovoltaic systems. *Renewable Sustainable Energy Rev.* 45. 637-648. 10.1016/j.rser.2015.02.009
7. Bennett, T., Zilouchian, A., Messenger, R. (2012). ‘Photovoltaic model and converter topology considerations for MPPT purposes’, *Sol. Energy*, 2012, 86, pp. 2029–2040.
8. Christopher W. and Ramesh R. (2013). *American Journal of Engineering Research (AJER)* e-ISSN : 2320-0847 p-ISSN : 2320-0936 Volume-02, Issue-12, pp-402-408 www.ajer.org
9. Hernanz, R. Martín,C. Belver, Z. Lesaka, L., Guerrero, Z. and Perez, P.(2010). “Modelling of Photovoltaic Module”, *International Conference on Renewable Energies and Power Quality (ICREPQ'10) Granada (Spain)*, 2010.
10. Hernanz, J.A.R Campayo, J.J Larranaga, J. Zulueta, E. Barambones, O. Motrico, J. Gamiz, U.F and Zamora, I.(2012) “Two Photovoltaic Cell Simulation Models in MATLAB/Simulink”, *International Journal on Technical and Physical Problems of Engineering (IJTPE)*, Vol. 4, No.1, pp. 45-51, 2012.
11. Hun W. N, Yue W. M, Gua S. and Heng C. S. (2011). Study on characteristics of photovoltaic cells based on MATLAB simulation. *Power and energy engineering conference Asia- Pacific*, 2011.

12. Kumari, S. and Babu,S. „Mathematical Modelling and Simulation of Photovoltaic Cell using MATLAB/Simulink Environment“, *International Journal of Electrical and Computer Engineering (IJECE)* Vol. 2, No.1, PP. 26-34, 2012.
13. Mohammed, S.S (2011). “Modelling and Simulation of Photovoltaic Module using MATLAB/Simulink”, *International Journal of Chemical and Environmental Engineering* Vol. 2, No. 5, , pp. 350- 355, 2011.
14. M. Kumar, S. R.Kapoor, R. Nagar and A. Verma (2015). “Comparison between IC and Fuzzy Logic MPPT Algorithm Based Solar PV System using Boost Converter”, *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, Vol. 4, Issue 6, pp. 4927-4939, 2015
15. Nema, S., Nema, R.K and Agnihotri, G.(2010). “MATLAB/Simulink Based Study of Photovoltaic Cells /Modules/Array and their Experimental Verification”, *International Journal of Energy and Environment* Vol.1, No. 3, pp.487-500, 2010.
16. Poornima M., Prasad N. Enjeti, Robert S. Balog (2013). *Electrical and Computer Engineering*, “Texas A&M University Analysis and Design of Smart PV Modules”,pp. 83-86
17. Priety (2014). “International Journal of Engineering & Science Research”_Shiau, *IJESR/May 2014/ Vol-4/Issue-5/320-330*, e-ISSN 2277-2685, p-ISSN 2320-976
18. Richhariya, G. and Pachori, A.(2011) “Modelling of Solar Cell” *International Journal of Wind and Renewable Energy (IJWRE)*, Vol., No.1, , pp. 31-34, 2011.
19. Rohit K. (2017). *International Journal of Advanced Research in Computer Science and Software Engineering*. Volume 7, Issue 4, April 2017 ISSN: 2277 128X
20. Sachin V. R. and Vivek J. (2015). Simulation and comparison of perturb and observe and incremental conductance MPPT algorithms for solar energy system connected to grid. *Sadhana* Vol. 40, Part 1, February 2015, pp. 139–153._c Indian Academy of Sciences
21. Shimi, S. L., Thilak Thakur, Jagdish Kumar, S Chatterji, and Dnyaneshwar Karanjkar (2013). "MPPT based solar powered cascade multilevel inverter", 2013 Annual International Conference on Emerging Research Areas and 2013 International Conference on Microelectronics Communications and Renewable Energy.
22. Tsai, H.L, Tu, C.S and Su, Y.J (2010) “Development of Generalized Photovoltaic Model Using MATLAB/Simulink”, *Proceedings of the World Congress on Engineering and Computer Science (WCECS'10)* San Francisco (USA). 2010 Available at: <http://www.iaeng.org/publication/WCECS2010/WCECS2010>

23. Vajpai, J. and Khyani, H.K., “Mathematical Modelling and Experimental Validation of Performance Characteristics of Solar Photovoltaic Modules” *International journal of application or Innovation in engineering and management (IJAIEEM)* Vol.2, No.11, pp. 295-301, 2013.
24. Venkateswarlu G. and Raju P. S., “SIMCAPE Model of Photovoltaic Cell” *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering* Vol. 2, No. 5, PP.1766-1772. 2013.
25. www.leonics.com.
26. www.solarpowerauthority.com
27. Yue Cao and L.M.Tolbert (2010). “Multilevel DC-AC Converter Interfaced with Solar Panels”, *Journal of Undergraduate Research at the University of Tennessee*, Vol 1, 2010.
28. Zainudin Hairul Nissah and Saad Mekhilef (2010). “Comparison Study of Maximum Power Point Tracker Techniques for PV Systems”, *Proc. 14th International Middle East Power Systems Conference (MEPCON’10)*, Cairo University, Egypt, 2010, 750-755.