IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676,p-ISSN: 2320-3331, Volume 13, Issue 4 Ver. I (Jul. – Aug. 2018), PP 01-13
www.iosrjournals.org

A Review of Maximum Power Point Tracking Algorithm for Solar Photovoltaic Applications

Jiwajyoti Mahanta[1], Bijoyendra Sharma[1], Nabin Sarmah[2]
[1, 1, 2] Department of Energy, Tezpur University
Corresponding Author:Jiwajyoti Mahanta

Abstract: *The world's large dependency on conventional energy sources has not only posed a threat to the environment but also they are non-renewable. Therefore, a huge interest is put upon renewable sources of energy. Amongst them, solar technology has become a rapid growing industry for power generation. This paper briefly reviews the technological challenges of maximum power point (MPP) tracking of photovoltaic (PV) energy obtained from solar cells. The paper describes the evolution of several MPP techniques that are popular commercially and presents their basic working, utilisation ability in different scenarios, cost of implementation and new research performed to find better techniques. The study also includes incorporation of soft computing in solar MPP tracking. It is observed that, the MPP tracking techniques are rapidly evolving from simple to complex methods, as per the demands dictates. The simpler methods like perturb and observe are cost effective and have simpler design, but are highly inefficient in terms of efficiencies under drastically changing environment. They find application in streetlights and solar lanterns. The incorporation of soft computing methods like ANNs, FLCs, can drastically increase efficiency, but are cost ineffective. Such techniques find place where efficiency matters the most. In large PV plants, these systems prove to be highly efficient.*

Keywords: *Photovoltaics; MPPT; Perturb and observe; Incremental Conductance; FLC; ANN*

Date of Submission: 25-06-2018 Date of acceptance: 10-07-2018

❖ MPP	Maximum Power Point.	❖ V_{mpp}	Voltage at maximum power point.
❖ MPPT	Maximum Power Point Tracking.	❖ q	Charge of electron.
❖ PV	Photovoltaic.	❖ A	Diode ideality factor.
❖ I_0	Dark saturation current.	❖ P&O	Perturb and Observe.
❖ I_L	Light generated current.	❖ D	Duty Cycle.
❖ V	Output voltage of solar cell.	❖ IC	Incremental Conductance.
❖ R_s	Series Resistance.	❖ FLC	Fuzzy logic controller.
❖ R_{sh}	Shunt Resistance.	❖ ANN	Artificial neural network.
❖ P_{max}	Maximum power of a PV panel.		
❖ P_{MPP}	Power at maximum power point		
❖ V_{oc}	Open circuit voltage.		
❖ V_{ref}	Reference voltage		

I. Introduction

The current trend in energy usage suggests that, annually almost about 92 million barrels of oil and natural gas and about 3.8 billion toe coal are consumed per day [1]. These data show us our dependency on non-conventional sources of energy and the figures are expected to rise in the coming years. This massive dependency of fossil fuel is creating serious environmental problems, and these fuels are not going to last forever. It has been estimated that the world has consumed about 40% of the oil present in the earth's crust and the remaining will run out in about 50 years from now.To meet the growing energy demand, a lot of focus has been bestowed upon the renewable sources of energy. These sources include solar energy, wind, hydro-energy and biomass. These resources are clean, i.e. they have very less to negligible environmental effects and also they are not exhausted over time. Sun is the primary source of renewable energy, others (wind, hydro and biomass) being the indirect application of it [2]. The sun causes uneven heating of earth surface and the air mass above it. This creates pressure difference as land and water-bodies have different heating and cooling rates and due to rotation of earth, wind flows [3].

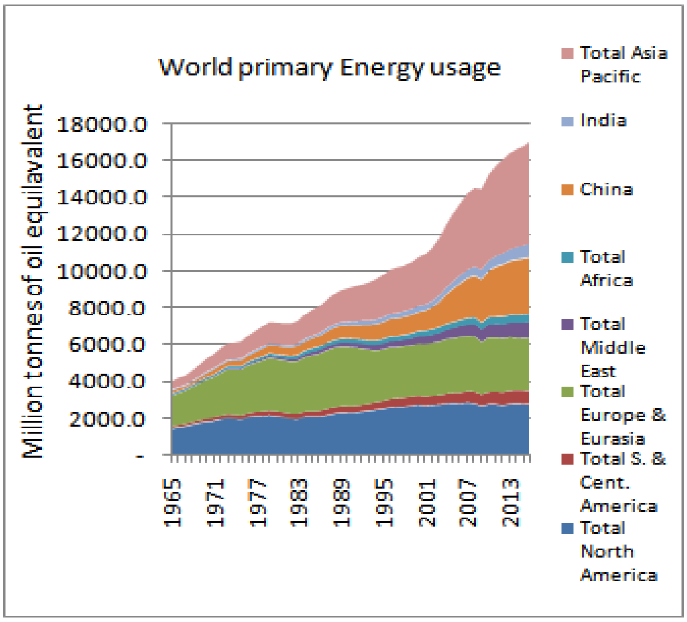

Fig 1: World primary Energy usage [1]

The sun also causes water from seas to evaporate and form clouds. These clouds are carried by the wind and distributed throughout the earth's atmosphere. As they cool down, they form rain and maintain the water cycle in rivers, lakes and springs. Solar energy is also captivated by plants to produce food, their leaves work like biological solar panels which absorbs radiation to reduce CO_2 to form glucose [4]. Thus, all the earth renewable sources are indirectly dependent on the sun.

However, renewables provide only about 15% of the world's energy demands. The architecture of the established technology i.e. our present energy conversion devices, are designed to primarily work on non-conventional sources of energy. The renewables have a promising future but the problems associated with them mainly include availability, storage and long distance transmission with minimum losses.

Mostly utilised renewable resources today are Wind, Hydro and Solar. In most countries there is abundance of wind power which can be utilised to generate electricity. Highest globally installed wind power capacity is seen in Asia with a cumulative capacity of 203,643 MW followed by Europe and North America with 161,330MW and 97,611MW respectively [5]. But availability of utilisable wind is specific to zones i.e. they are mostly available in coastal regions. Solar energy is becoming a hot topic in recent years. A lot of investment is done upon solar P.V. technology. During 2016, additional 75 GW of solar PV capacity was installed thereby increasing the total world production to 303 GW. In 2016, China installed additional 35.5GW thereby increasing their installed capacity up to 74GW which is the highest capacity among other countries. The top 10 countries to have installed solar power generation plants are Germany, China, U.S. Italy, U.K. India, France, Australia and Spain. India recently installed about 4.1 GW (up from 2 GW in 2015) thereby increasing the capacity to 9.1 GW. Tamil Nadu (with nearly 1.6 GW) overtook Rajasthan (1.3 GW), followed by (1.1 GW) Andhra Pradesh and Gujarat (1 GW) for cumulative capacity [6]. Thus, we may conclude that as the energy demand is rising most of the countries are switching to renewable energy for power generation as they prove to environmental friendly sources which provide green energy to the world.

The most promising fact about solar photovoltaic technology is that electricity generation is free; i.e. the panel will provide electricity as long as it receives radiation with no environmental side-effects. Unlike wind or biomass, solar energy is sufficiently available therefore, most of the countries are heavily investing in this technology [7]. Before installation of a solar plant, radiation data for that area must be statistically reviewed. Solar radiation data is collected using devices like pyrheliometer (for direct radiation measurements) [8], Pyranometers (for irradiance measurements) [9]. Radiation data is averaged over a period of time to determine the feasibility of a particular site for solar power generation [10]. Conversion of solar radiation to electricity and its distribution or utilization, involves a complex series of conversions and includes various devices. This means that the terminals of a solar panel can't directly be connected to a load. This is because of the fact that each solar cell in the panel, behaves as a direct current (D.C.) source. When solar cells are connected in series, the voltage of each cell gets added up, while in parallel, their currents gets added up. Therefore, devices like maximum power point tracker (MPPT), inverters, power converters etc. must be used in conjunction in order to utilise the electricity obtained from the solar panels [11]. The most common PV configurations includes solar panels connected in series and parallel to give the desired voltage and current, a centrally connected inverter for converting the D.C output of the panels to A.C. and grid connection, a battery is used which works like a buffer to provide sufficient power during unavailability of solar radiation [12]. But there are certain effects like shading and temperature effects which decrease the overall efficiency of a centrally connected inverter PV system.

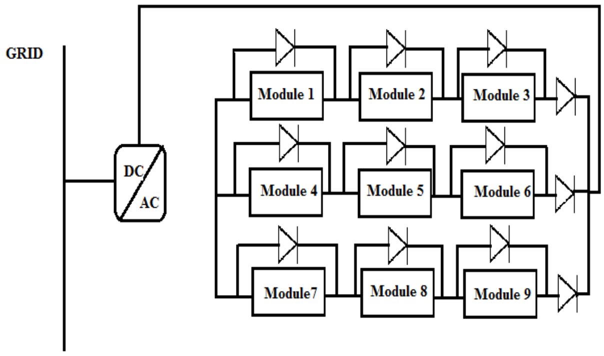

Fig 2: Schematic diagram of a centrally connected PVarray

Fig 2 represents the schematic diagram of a centrally connected PV array; the diodes are introduced to account for the shading effect which is caused when unequal amount of solar radiation falls on one of the modules of that array. In this case, the module consumes power acting as a high resistance rather than a power source. The diodes restrict power flow within the branches of the array. However, these types of configurations tend to have more losses as each module may not be working at the maximum power point due the obligatory series diodes inserted in each parallel branch of the structure and centralised MPPT algorithm [13].

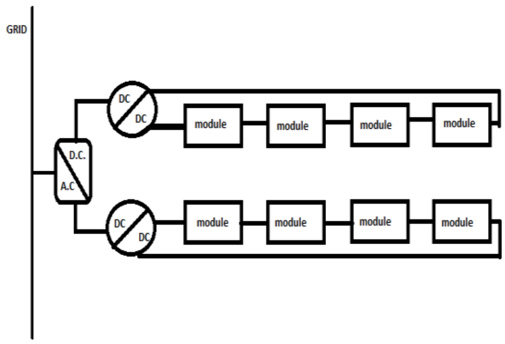

Fig 3: Schematic representation of grid connected PVsystem with independent power converters in each branch

With advancement in electronic technology, a smarter way of connecting the branches of a PV array has surfaced. Fig 3 represents the schematic representation of modified configuration which is more efficient. In this case each branch is connected to a micro-inverter which accounts for the series diodes as well as each branch of the array can have its dedicated algorithm for maximum power generation [14].

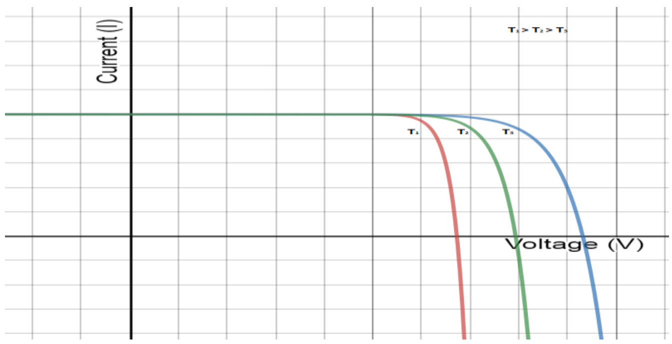

Fig 4: I vs. V characteristics of PV module under varyingtemperature (T)

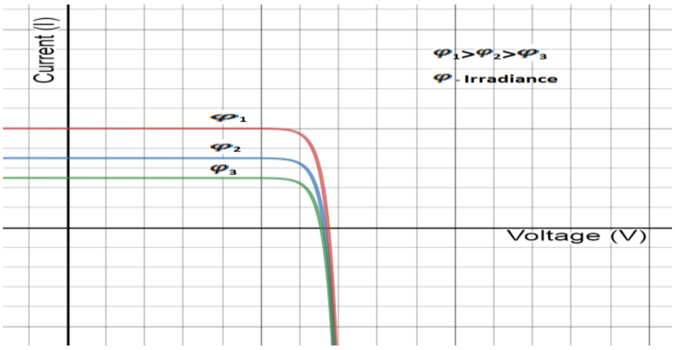

Fig 5: I vs. V characteristics of PV moduleunder varyingRadiation (∅)

The non-linear behaviour of solar panel is associated with irradiance and temperature. The equivalent circuit representation is shown in figure b2, and its current equation is given as:

$I = I_L - I_0(e^{\frac{q(V-IRs)}{AKT}} - 1) - \frac{V-IRs}{R\omega}$……… *(i)*

Where I is the total output current, $I_0$is the dark saturation current, I_L is the light generated current, V is the output voltage, R_s is the series resistance and $R_{sh}$is the shunt resistance, K is the Boltzmann constant, T is the temperature (in Kelvins) q is the charge of electron and A is the diode ideality factor. The variation of open circuit voltage and short circuit current with variation in temperature and irradiance are shown in Fig 4 and Fig 5 respectively. The total output power depends upon radiation or irradiance. It is evident from the characteristic curve [Fig 6] of a PV module that for maximum power transfer, the solar panel must operate at its maximum voltage and current available at a particular radiation and temperature. There are several methods for tracking the maximum power point (MPP) [12]. Among them, Perturband Observe (P&O), Incremental Conductance (IC) [15] and Hill Climbing (HC) [16, 17] are the most popular. These methods arewidely applied in several commercial dc–dc converters (for battery chargers) and dc–ac inverters (for grid-tied). For cheap circuitry such as street lamps, simpler methods such as the Fractional Open Circuit Voltage [18] Fractional Short Circuit Current [19] and RippleCorrelation Control [20] are employed. These MPPTs techniques require only a few sensors so they are cheap, but their accuracy is very low. Other methods include Current Sweep [21], DC-link CapacitorDrop Control, Load Current and Load Voltage Minimization, dP/dV or dP/dI Feedback Control [22], Linear Current control, State-based MPPT [23], Best Fixed Voltage algorithm [24], LinearReoriented Coordinate [25] and Slide Control method [26]. But these methods are more research oriented and has not reached a matured level for commercialisation.

Perturb and observe method

For extracting maximum power from solar panel the duty cycle of the power converters is adjusted with the dynamic behaviour of solar radiation. In order to do so, the power conditioning unit of any solar photovoltaic plant contains a maximum power point controller which regulates the duty cycle according to changes in irradiance and temperature [27]. The Perturb and Observe (P&O) method is most commonly mentioned in many conference papers and journals [27-29]. Basically the voltage and current outputs are measured for a particular irradiance. The power vs. voltage curve for the module varies as described in figure (c) for a given value of irradiance.

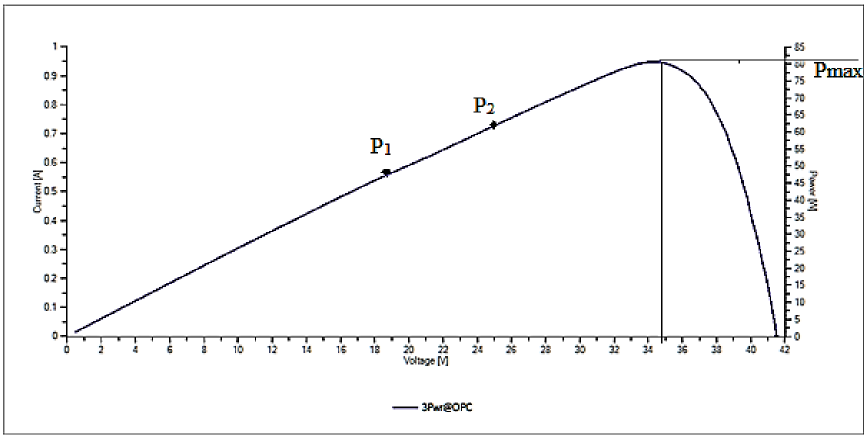

Fig 6: Power vs Voltage curve of a PV modu

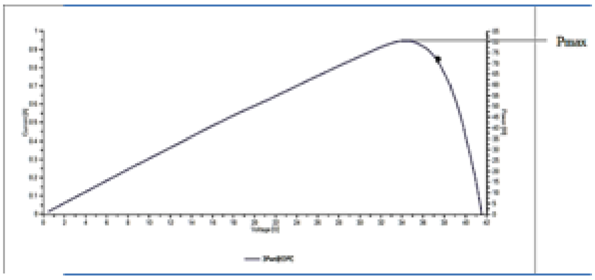

Fig 7: Maximum power point tracking of PV module

In P&O method the maximum power point is tracked along the power vs voltage curve. This is done by an algorithm that icrementally increases the voltage to its maximum power point region. With each increment in voltage, the tracker compares the power before and after incrementation. If there is increase in power, this implies that maximum power is not reached and the voltage needs to be increamented more as shown in Fig 6. If the incrementation leads to decrese in power, then the voltage must be reduced to achieve the maximum power point as shown in Fig 7 [30].

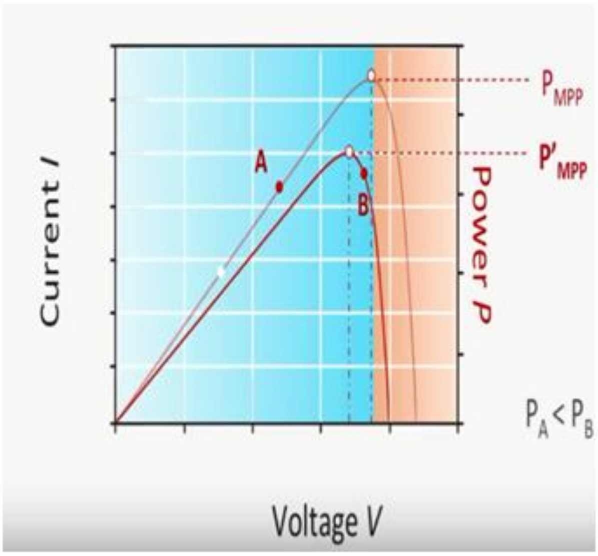

Fig 8: MPP tracking in changing radiation

However, there are certains limitations to this technique [31]. Consider a case where the irradiance has changed at the instant of two sampling. This case is illustrated in Fig 8 where according to the latest pertubation the algorthm has determined that the maximum power point is achieved after incrementing the voltage, i.e. the MPP lies to the right. However at that instant radiation changes and the new MPP shifts down (from P_{MPP} to P'_{MPP} as illustrated in Fig 8 before any new pertubation. In this case, the algorthm thinks that the maximum power is towards right while it is to the left. Hence, drastic changes in weather conditions affects the accuracy of the system. In order to improve the accuracy and make the system run smoothly in dynamic condition, new adaptive pertub methods are being researched [32]. In another approach, a theoretical study has been carried out allowing the optimal choice of the two main parameters characterizing the P&O algorithm has been carried out. The idea behind the expected optimization method resides in the customization of the P&O MPPT parameters to the dynamic behaviour of the whole PV system. In this technique, one parameter which is suggested to be adjusted is the amplitude of the duty cycle and the other is the sampling interval [33], but this system implementation requires whole knowledge of the system, and is not a versatile one. In [34], hardware based analog version system of P&O oriented algorithm method is developed in which the measured values of voltage and power from the PV panel is differentiated with respect to time using a differentiator, this differentiated signals are passed through two comparators which gives a positive high output if the input signals are greater than zero, otherwise gives negative output.

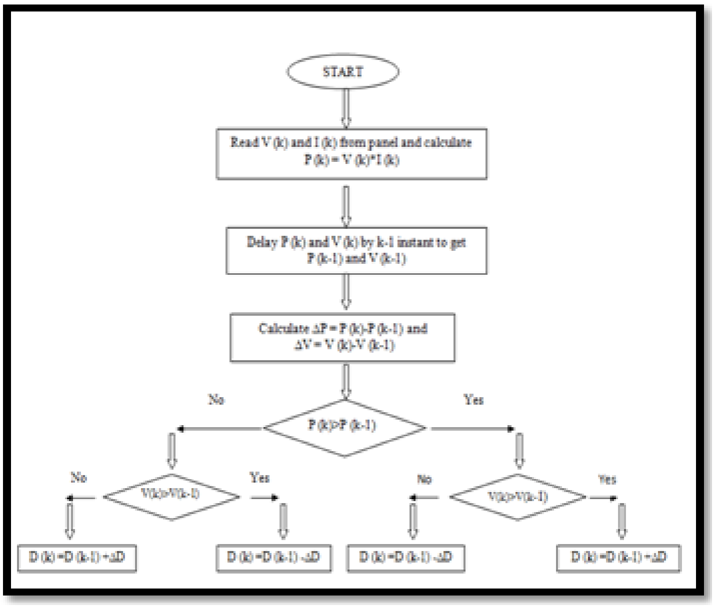

Fig 9: Flow chart of P&O method

The outputs of the two comparators are further multiplied using an analog multiplier and compared if the multiplied value is greater than or less than zero. At the later stage, the final output of the system is multiplied with a gain factor and then integrated to generate a reference voltage signal. The system claims to have an efficiency of 99.99% and fast response time in MPP tracking even in drastic change in insolation. In [35, 36] a more cost efficient P&O method has been innovated which employs a novel algorithm. In order to track MPP, this algorithm uses current obtained from the PV panel for calculation of duty-cycle (D) for the power converters, where the current serves as the reference signal.

Incremental Conductance method

A more smarter aproach to tackle the problem associated with P&O method, is the measure of instantaneous conductance of the PV array for tracking maximum power point [37]. The conductance is the ratio of current (I) to voltage (V) or is the reciprocal of resistance. From Fig 10 and Fig 11 we can relate that the slope of power vs. voltage curve is positive upto the MPP Voltage (V_{mpp}), at the V_{mpp} the slope becomes zero and beyond it, slope becomes negative.

We know that,

Power (P) = V (voltage)×I (current)

Therefore,

$\frac{dP}{dV} = \frac{d(V.I)}{dV}$ ……….(ii)

$\frac{dP}{dV} = I + V\frac{dI}{dV}$ ……..(iii)

Now, at maximum power $\frac{dP}{dV} = 0$

Therefore,

$I + V\frac{dI}{dV} = 0$ ………(iv)

$\frac{dI}{dV} = -\frac{I}{V}$ = C(conductance)………..(v)

Thus if the value of $\frac{dI}{dV} > -\frac{I}{V}$ then voltage must be incremented to find the MPP, otherwise if $\frac{dI}{dV} < -\frac{I}{V}$, then the voltage must be decremented. Equation (iv) is considered to be the error signal (e), which is zero at MPP. The algorithm exploits these properties to find out the MPP. An advantage of this method to the previous one is that only the instantaneous conductance is to be observed and compared to the icremental conductance to track the MPP [38].

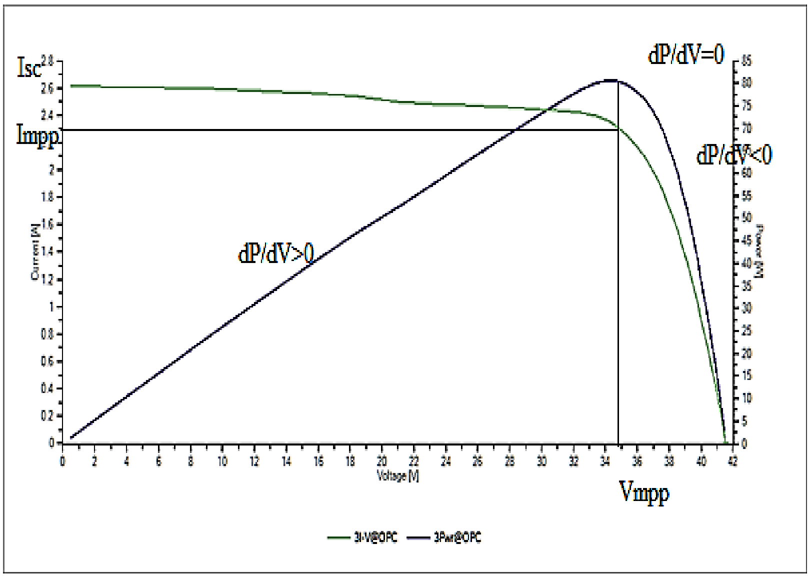

Fig 10: MPP tracking using IC method

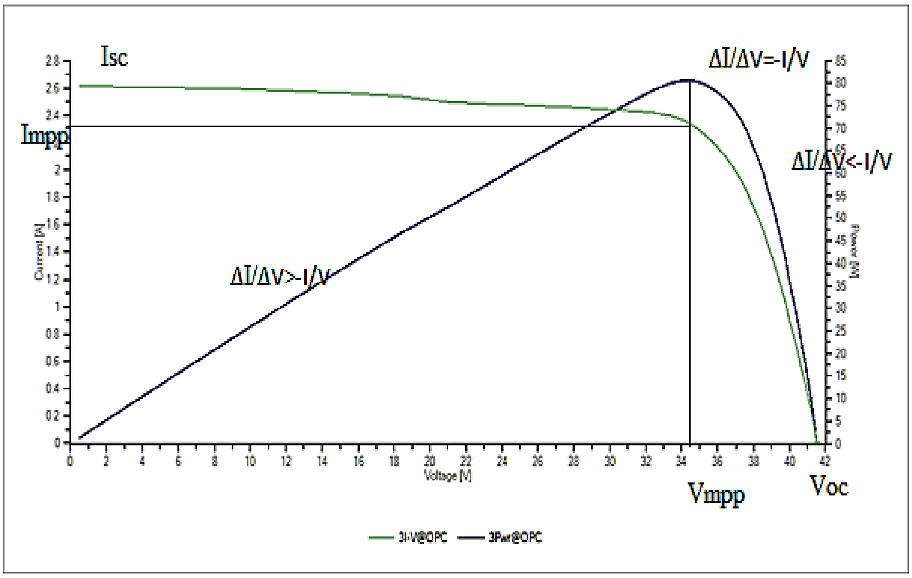

Fig 11: Comparision of measured value of conductanceand change in output power

In [39], the variable-step-size Incremental Conductance method is compared with the fixed-step-size one. The variable step size with constant-voltage-tracking start-up system has a performance of 99.2%. In [40] a study was conducted to introduce a smart algorithm which eliminates the necessity of the PI controller. However, this method also has a very basic problem, the values $\frac{dI}{dV}$and $\frac{I}{V}$ must be measured with high precision and the method is too slow for dynamic radiation changes [41]. Mostly, the incremental conductance method is integrated with soft computing methods for system versatility and improved efficiency [42].

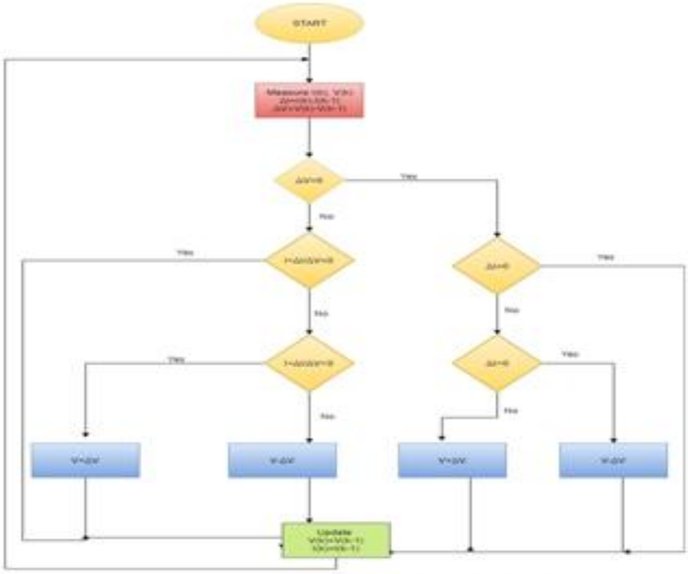

Fig 12: Flow-chrart of IC method

Introduction to soft computing methods for MPP tracking:

Introduction of soft computing methods like Fuzzy logic (FL) in MPP tracking in a solar panel can help improve the tracking efficiency and solve the problem of slow response of MPPT in dynamic weather conditions. MPPTs based on FLC, does not need the understanding of the specifications of the PV model [43, 44]. Generally there are three stages of control: fuzzification, decision making and de-fuzzification. In the first stage, i.e. in fuzzification, the input crisp variables are converted to linguistic variables of a membership functions. In the second stage, the rules operating are specified by IF-THEN statements which define the controller operation. The rules that designate this step are in the form of linguistic variable belonging to a fuzzy set. In the third stage, i.e. the de-fuzzification step, the fuzzy logic controller output is converted from a linguistic variable to a numerical variable still using a membership function, providing an analog signal which controls the duty cycle of the power converter drives the operating point to the MPP [45]. The FL-based MPPT in [43] has two inputs and one output. The two input variables are error (e) which is the difference between power at i^{th} and $(i-1)^{th}$ instant and the change in error (Δe) i.e. difference in the error signal at two instants, at the i^{th} sampled time are defined as:

$$e(i) = \frac{P(i)-P(i-1)}{V(i)-V(i-1)} \text{.......vi}$$

$$\Delta e\,(i) = e\,(i) - e\,(i\text{-}1) \text{......... vii}$$

The fuzzy inference is carried out by using Mamdani’s method and the de-fuzzification uses the centre of gravity to compute the output (duty cycle) of this fuzzy logic-based MPPT [46]. The process in which the FLC performs the calculation is called rules inference. In a fuzzy controller, the input current and voltages from the solar panel is converted to the linguistic variables of a membership function. For example in the following figure below (Fig 13), five fuzzy variables namely NB (Negative Big), NS (Negative Small), ZE (Zero), PS (Positive Small), PB (Positive Big) are used. More number of fuzzy variable leads to better efficiency as the range of input data gets divided into more intervals. This leads to improved efficiency of the overall system.

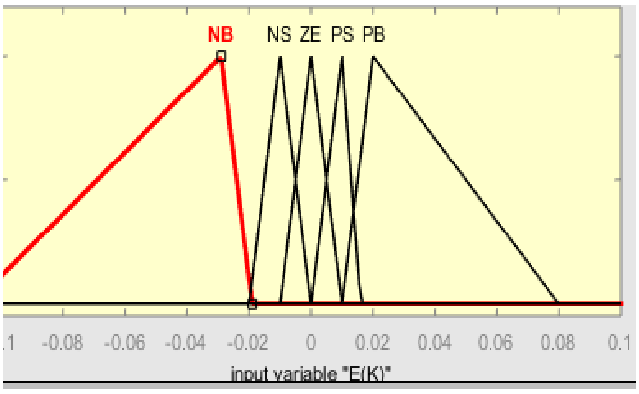

Fig 13(a)

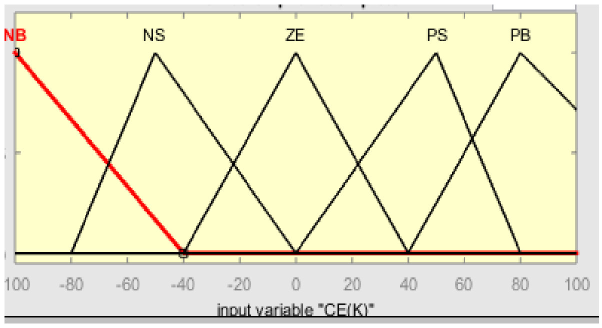

Fig 13(b)

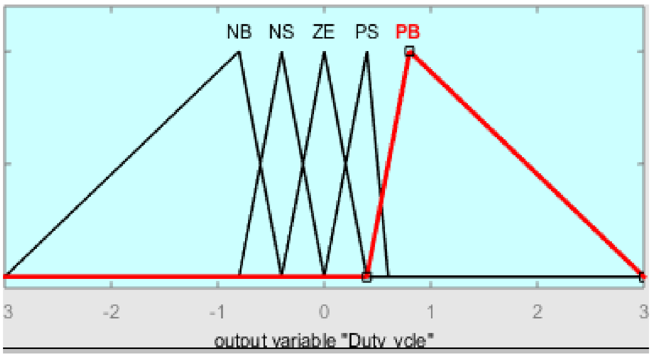

Fig 13(c)

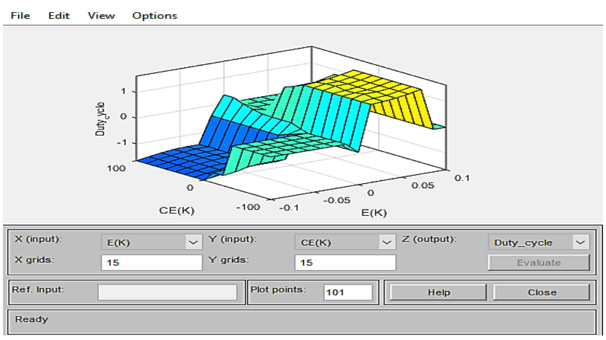

Fig 13(d)

Fig 13: (a) Membership function of error, (b)Membership function of change in error, (c) Membership function of duty cycle,(d) Surface view of input and output variables in FLC

In [47] an intelligent control mode is proposed for the maximum power point tracking (MPPT) of a photovoltaic system subjected to fluctuating temperature and insolation situations. This particular mode employs a fuzzy logic controller integrated to a DC-DC converter. The system claims to have a smoother signal for tracking MPP and faster response time. In [48] a method of maximum power point tracking using adaptive fuzzy logic control over traditional FL-Cs for grid-connected photovoltaic systems is developed. The system is capable of delivering power to a utility with low power and high power factor. In [49] a fuzzy controller based feed forward maximum power (MP) point tracking scheme is made for the interwoven dual boost (IDB) converter oriented photovoltaic (PV) system. The primary object of the tracking algorithm is to changes the duty ratio of the converter such that the solar cell array (SCA) voltage and the voltage corresponding to the MP point are same at that solar insolation. This is achieved by, generating an error signal by the feed forward loop and thereby comparing the instantaneous array voltage and reference voltage. This reference voltage is given by an artificial neural network. In [50] a fuzzy logic controller (FLC) based single-ended primary-inductor (SEPIC) converter for maximum power point tracking (MPPT) operation of a photovoltaic (PV) system is developed. The FLC utilises the convergent distribution of the membership function rather than the regular than the symmetrically distributed membership functions thereby resulting in quicker response.

Thus incorporation of FL based controllers has drastically improved the effectiveness of MPP trackers. The main advantage of FL based controllers is that it doesn't require information of the whole system. Furthermore, it is highly responsive to the dynamic changes in the environment. In the coming sections we will encounter models incorporating FL controllers with artificial neural networking, which are more efficient in MPP tracking.

Artificial Neural Networks

A collection of several electrical neurons, connected on the basis of various topologies is called an "Artificial Neural Network" [51]. Such type of networks if employed in MPP tracking for solar modules will improve accuracy, response time and overall efficiency [52]. ANN and FL based MPP trackers are successfully implemented nowadays for its robustness and flexibility [53-58]. Implementation of ANN in a PV system involves identification and modelling of the system using non-linear complex functions. The prediction of the duty-cycle is done using measured values of voltage and current. The inputs to the neural network can be the short circuit current I_{sc} or open circuit voltage V_{oc} or irradiance value or temperature value or a combination of all [59]. ANNs are capable of self-learning which is why they have a fast response time. Different weights are assigned to the input variables which are assigned during the learning process of the ANN. This is why PV panels are tested over a long period of time so that the relationships between the input variables and output power can be properly determined for the suitable selection of the weights to be assigned by the ANN [60]. Hiyama et al. were the first to propose use of ANN for MPPT [53]. Their method utilises only the open circuit voltage V_{oc} obtained from the PV panel to drive the solar panel to MPP using a PI controller.In [61], an offline ANN is used along with a FL controller for seeking optimal voltage required for MPP tracking. Their system consists of a data acquisition system which is designed with an ANN and a FL controller. The ANN is fed with insolation data which then generates a reference signal. This reference signal is then compared with the voltage obtained from PV panel and the signal is fed to the fuzzy logic controller for MPP tracking. In [62] an innovative model has been developed that takes into account the effects of solar irradiance, atmospheric temperature, wind speed and variability of load. The model can conjecture the MPP current and voltage under mutable atmospheric and load conditions. In [63] an offline based ANN is used where insolation data and temperature data is fed. The ANN generates a reference voltage which is compared with the instantaneous output voltage of the panel to generate an error signal. This error signal is fed to a PI controller for adjustment of the duty cycle for MPP tracking. In [64] a smart algorithm is used to account for the partial shading problem. The system uses the traditional IC algorithm, but with an extra loop where the shading effect is taken into account. If there is no shading, the reference voltage is calculated by V_{ref} by multiplying the open circuit voltage with a constant K which depends upon the properties of the solar cell and ranges from 0.73 to 0.8. If there is shading then the reference voltage is set by an ANN. In [65] an ANN is trained using the commonly adopted back-propagation (BP) algorithm with the Levenberg–Marquardt optimization method. This system claims to have fast adaptability in dynamic environments.

Use of ANN in MPP tracking has proven to be very efficient due to its high accuracy. But the only problem an ANN based tracker faces is that it needs a big database for prediction of the reference voltage signals and for different systems, unique neural networks are required to be trained. Hence long term testing is essential before ANN implementation in a system.

II. Conclusion

Collection of several technologies for maximum power point tracking of solar PV energy is presented in this paper. This work shows the evolution of MPP tracking techniques from simple ones to complex in a concise manner. The technology dedicated to maximum power point tracking for solar cells is changing drastically from simple electronics to incorporation of soft-computing methods. With advancement in semiconductor electronics, numerous techniques of MPP tracking has surfaced which differ in circuitry, implementation and operation and costs. Different techniques are used based on user demands. In this paper different techniques for MPP searching are listed along with their advantages, dis-advantages and latest research done. It is clear from this review that simple techniques like P&O method are best suited for cheap and stand-alone system. In most of the common applications, this method is used. Another common method of MPP tracking is the incremental conductance method. But for generation in Giga scale, sophisticated techniques like Fuzzy Logic, Artificial neural network may be incorporated which considerably lowers the losses thereby increasing efficiency and faster response time under dynamic weather conditions. However sophisticated techniques are costlier and hence may be used in large solar power plants. Numerous research is going on in the field of MPP techniques, some of which are also presented in this paper in concise manner.

References

[1]. BP Statistical Review of World Energy, June 2017 (66th edition). London: BP.

[2]. Dincer, Ibrahim. "Renewable energy and sustainable development: a crucial review." Renewable and sustainable energy reviews 4, no. 2 (2000): 157-175.

[3]. Manwell, J. F., McGowan, J. G., & Rogers, A. L. (2010). Wind energy explained: theory, design and application, page no 25.John Wiley & Sons.

[4]. Hatch, M. D., & Slack, C. R. (1970). Photosynthetic CO2-fixation pathways. Annual review of plant physiology, 21(1), 141-162.

[5]. Council, G. W. E. (2016). Global Wind Statistics 2015. 2016.

[6]. Adib, R., Murdock, H. E., Appavou, F., Brown, A., Epp, B., Leidreiter, A., & Farrell, T. C. (2016). Renewables 2016 Global Status Report. Global Status Report RENEWABLE ENERGY POLICY NETWORK FOR THE 21st CENTURY (REN21), 272.

[7]. De Brito, M. A., Sampaio, L. P., Junior, L. G., & Canesin, C. A. (2011, September). Research on photovoltaics: review, trends and perspectives. In Power Electronics Conference (COBEP), 2011 Brazilian (pp. 531-537). IEEE.

[8]. Iqbal, M. (2012). An introduction to solar radiation. Elsevier. Page no 339

[9]. Iqbal, M. (2012). An introduction to solar radiation. Elsevier. Page no 354

[10]. Tomson, T., Russak, V., & Kallis, A. (2008). Dynamic behavior of solar radiation. In Modeling Solar Radiation at the Earth's Surface (pp. 257-281). Springer, Berlin, Heidelberg.

[11]. F. Schimpf, L. E. Norum. "Grid connected Converters for Photovoltaic, State of the Art, Ideas for Improvement of Transformerless Inverters", in Proc. of NORPIE, 2008, pp. 1-6.

[12]. [12] 2002, pp. 1995-2000.

[13]. P. C. Loh, et al. "Topological Development and Operational Analysis of Buck-Boost Current Source Inverters for Energy Conversion Applications", in Proc. of PESC, vol. 37, 2006, pp.1-6

[14]. I. J. Balaguer, et al. "Survey of Photovoltaic Power Island Detection Methods", in Proc. of IECON, vol.34, 2008, pp.2247-2252.

[15]. H. P. Desai and H. K. Patel, "Maximum power point algorithm in PV generation: An overview," in Proc. 7th Int. Conf. Power Electron. DriveSyst. Nov. 27–30, 2007, pp. 624–630.

[16]. Jainand S, Agarwal V. A new algorithm for rapid tracking of approximate maximum power point in photovoltaic systems. IEEE Power Electron Lett 2004; 2(1):16–9.

[17]. Xiao W, Dunford WG. A modified adaptive hill climbing MPPT method for photovoltaic power systems. In: Proc 35th annu IEEE power electron spec conf; 2004. p. 1957–63.

[18]. Bazzi, A. M., & Krein, P. T. (2011). Concerning "maximum power point tracking for photovoltaic optimization using ripple-based extremum seeking control". IEEE Transactions on Power Electronics, 26(6), 1611-1612.

[19]. Jainand S, Agarwal V. A new algorithm for rapid tracking of approximate maximum power point in photovoltaic systems. IEEE Power Electron Lett2004; 2(1):16–9.

[20]. Xiao W, Dunford WG. A modified adaptive hill climbing MPPT method for photovoltaic power systems. In: Proc 35th annu IEEE power electron spec conf; 2004. p. 1957–63.

[21]. Bazzi, A. M., & Krein, P. T. (2011). Concerning "maximum power point tracking for photovoltaic optimization using ripple-based extremum seeking control". IEEE Transactions on Power Electronics, 26(6), 1611-1612.

[22]. Masoum MAS, Dehbonei H, Fuchs EF. Theoretical and experimental analyses of photovoltaic systems with voltage and current-based maximum power-point tracking. IEEE Trans Energy Convers 2002; 17(4):514–22.

[23]. Arcidiacono V, Corsi S, Lambri L. Maximum power point tracker for photovoltaic power plants. In: Proc IEEE photovoltaic spec conf; 1982. p. 507–12

[24]. Bodur M, Ermis M. Maximum power point tracking for low power photovoltaic solar panels. In: Proc 7th Mediterranean electrotechnical conf; 1994. p. 758– 61.

[25]. Sugimoto H, Dong H. A new scheme for maximum photovoltaic power tracking control. In: Proc IEEE power conv conf; 1997. p. 691–6

[26]. Solodovnik EV, Liu S, Dougal RA. Power controller design for maximum power tracking in solar installations. IEEE Trans Power Electron 2004;19(5):1295–304

[27]. De Carvalho PCM, Pontes RST, Oliviera Jr DS, Riffel DB, De Oliviera RGV, Mesquita SB. Control method of a photovoltaic powered reverse osmosis plant without batteries based on maximum power point tracking. In: Proc IEEE PES transmiss distrib conf & expo. Latin, America; 2004. p. 137–42.

[28]. Rtiz-Rivera EI, Peng F. A novel method to estimate the maximum power for a photovoltaic inverter system. In: Proc 35th annu IEEE power electron spec conf; 2004. p. 2065–9.

[29]. Zhang M, Wu J, Zhao H. The application of slide technology in PV maximum power point tracking system. In: Proc 5th world congr intell contr automat; 2004. P. 5591–4.

[30]. Jainand S, Agarwal V. A new algorithm for rapid tracking of approximate maximum power point in photovoltaic systems. IEEE Power Electron Lett 2004; 2(1):16–9.

[31]. Femia N, Petrone G, Spagnuolo G, Vitelli M. Optimization of perturb and observe maximum power point tracking method. IEEE Trans Power Electron 2005;20(4):963–73

[32]. NSD' Souza LAC, Lopes XJ. Liu. Comparative study of variable size perturba- tion and observation maximum power point trackers for PV systems. Electric Power Systems Research 2010;80:296–305.

[33]. P. Midya, P. Krein, R. Turnbull, R. Reppa, and J. Kimball, “Dynamic maximum power point tracker for photovoltaic applications,” in Proc.27th Annu. IEEE Power Electronics Specialists Conf., vol. 2, Jun. 1996, pp. 1710–1716.
[34]. C. Hua and J. R. Lin, “DSP-based controller application in battery storage of photovoltaic system,” in Proc. IEEE IECON 22nd Int. Conf. Ind.Electron., Contr. Instrum., 1996, pp. 1705–1710.
[35]. M. A. Slonim and L. M. Rahovich, “Maximum power point regulator for 4 kWsolar cell array connected through invertor to the AC grid,” in Proc.31st Intersociety Energy Conver. Eng. Conf., 1996, pp. 1669–1672.
[36]. A. Al-Amoudi and L. Zhang, “Optimal control of a grid-connected PV system for maximum power point tracking and unity power factor,” in Proc. Seventh Int. Conf. Power Electron. Variable Speed Drives, 1998, pp. 80–85.
[37]. Ahmed, J., & Salam, Z. (2015). An improved perturb and observe (P&O) maximum power point tracking (MPPT) algorithm for higher efficiency. Applied Energy, 150, 97-108.
[38]. Esram, T., & Chapman, P. L. (2007). Comparison of photovoltaic array maximum power point tracking techniques. IEEE Transactions on energy conversion, 22(2), 439-449.
[39]. Abdelsalam, A. K., Massoud, A. M., Ahmed, S., & Enjeti, P. N. (2011). High-performance adaptive perturb and observe MPPT technique for photovoltaic-based microgrids. IEEE Transactions on Power Electronics, 26(4), 1010-1021.
[40]. Liu, B., Duan, S., Liu, F., & Xu, P. (2007, November). Analysis and improvement of maximum power point tracking algorithm based on incremental conductance method for photovoltaic array. In Power Electronics and Drive Systems, 2007. PEDS'07. 7th International Conference on (pp. 637-641). IEEE.
[41]. F. Liu, S. Duan, F. Liu, B. Liu, and Y. Kang, “A variable step size INC MPPT method for PV systems,” IEEE Trans. Ind. Electron., vol. 55, no. 7, pp. 2622–2628, Jul. 2008.
[42]. Safari, A., & Mekhilef, S. (2011). Simulation and hardware implementation of incremental conductance MPPT with direct control method using cuk converter. IEEE transactions on industrial electronics, 58(4), 1154-1161.
[43]. Enrique, J. M., Andújar, J. M., & Bohorquez, M. A. (2010). A reliable, fast and low cost maximum power point tracker for photovoltaic applications. Solar Energy, 84(1), 79-89.
[44]. SalasV,Olı´asE,La´zaro.A,BarradoA.Newalgorithmusingonlyonevariablemeasurementappliedtoamaximumpowerpointtracker.Solar Energy Material SolarCells2005;1–4:675–84.
[45]. SalasV,Olı´as E,La´ zaro A,BarradoA.Evaluationofanewmaximumpower point tracker(MPPT)appliedtothephotovoltaicstand-alonesystems.Solar Energy MaterialSolarCells2005;87(1–4):807–15.
[46]. A. Mathew and A. I. Selvakumar, “New MPPT for PV arrays using fuzzy controller in close cooperation with fuzzy cognitive network,” IEEE Trans. Energy Conv., vol. 21, no. 3, pp. 793–803, Sep. 2006.
[47]. C.-S. Chiu, “T-S fuzzy maximum power point tracking control of solar power generation systems,” IEEE Trans. Energy Conv., vol. 25, no. 4, pp. 1123–1132, Dec. 2010.
[48]. Salah CB, Ouali.Comparison M. of fuzzy logic and neural network in max- imum power point tracker for PV systems. Electric Power Systems Research 2011; 81:43–50.
[49]. Subudhi, B., & Pradhan, R. (2013). A comparative study on maximum power point tracking techniques for photovoltaic power systems. IEEE Transactions on sustainable energy, 4(1), 89-98.
[50]. Esram, Trishan, and Patrick L. Chapman. "Comparison of photovoltaic array maximum power point tracking techniques." IEEE Transactions on energy conversion 22, no. 2 (2007): 439-449.
[51]. Patcharaprakiti, N., Premrudeepreechacharn, S., & Sriuthaisiriwong, Y. (2005). Maximum power point tracking using adaptive fuzzy logic control for grid-connected photovoltaic system. Renewable Energy, 30(11), 1771-1788.
[52]. Veerachary, M., Senjyu, T., & Uezato, K. (2002). Feedforward maximum power point tracking of PV systems using fuzzy controller. IEEE Transactions on Aerospace and Electronic Systems, 38(3), 969-981.
[53]. El Khateb, A., Rahim, N. A., Selvaraj, J., & Uddin, M. N. (2014). Fuzzy-logic-controller-based SEPIC converter for maximum power point tracking. IEEE Transactions on Industry Applications, 50(4), 2349-2358.
[54]. Khanaki, R., Radzi, M. A. M., & Marhaban, M. H. (2013, November). Comparison of ANN and P&O MPPT methods for PV applications under changing solar irradiation. In Clean Energy and Technology (CEAT), 2013 IEEE Conference on (pp. 287-292). IEEE.
[55]. S. Weerasooriya and M. A. El-Sharkawi: Laboratory implementation of a neural network trajectory controller for a dc motor, IEEE Transaction on Energy Conversion, Vol. EC-8, No. 4, pp. 107-113, March 1993.
[56]. Hiyama T, Kouzuma S, Imakubo T. Identification of optimal operating point of PV modules using neural network for real time maximum power tracking control. IEEE Transactions on Energy Conversion 1995; 10(2):360–7.
[57]. Hiyama T, Kitabayashi K. Neural network based estimation of maximum power generation from PV module using environmental information. IEEE Transactions on Energy Conversion 1997; 12:241–7.
[58]. Giraud F, Salameh ZM. Analysis of the effects of a passing cloud on a grid- interactive photovoltaic system with battery storage using neural networks. IEEE Transactions on Energy Conversion 1999; 14(4):1572–7.
[59]. Al-moudi A, Zhang L. Application of radial basis function networks for solar- array modeling and maximum power point prediction. IEE Proceedings 2000, 147(5), 310–316.
[60]. Hussein A, Hirasawa K, Hu J, Murata J. The dynamic performance of photovoltaic supplied dc motor fed from DC–DC converter and controlled by neural networks, In: Proc. Int. Joint Conf. Neural Netw; 2002, pp. 607–612.
[61]. Sun X, Wu W, Li X, Zhao Q. A research on photovoltaic energy controlling system with maximum power point tracking, In: Proc. Power Convers. Conf.; 2002, pp. 822–826. [27] Hilloowala RM, Sharaf AM
[62]. Veera chaw Mummadi and Narri Yadaiah: ANN based .oeak n.ower tracking far PV supplied DC motors, Solar Energy, Vol. 69, No. 4. pp. 343-350, April 2000.
[63]. Ali Reza Reisi, Mohammad Hassan Moradi, Shahriar Jamasb. (2013). Classification and comparison of maximum power point tracking techniques for photovoltaic system: A review. Renewable and Sustainable Energy Reviews,19, 433–443
[64]. Veerachary, M., Senjyu, T., & Uezato, K. (2003). Neural-network-based maximum-power-point tracking of coupled-inductor interleaved-boost-converter-supplied PV system using fuzzy controller. IEEE Transactions on Industrial Electronics, 50(4), 749-758.
[65]. Rai, Anil K., N. D. Kaushika, Bhupal Singh, and Niti Agarwal. "Simulation model of ANN based maximum power point tracking controller for solar PV system." Solar Energy Materials and Solar Cells 95, no. 2 (2011): 773-778.
[66]. Ramaprabha, R., & Mathur, B. L. (2011). Intelligent controller based maximum power point tracking for solar PV system. International Journal of Computer Applications, 12(10), 37-41.
[67]. Punitha, K., Devaraj, D., & Sakthivel, S. (2013). Artificial neural network based modified incremental conductance algorithm for maximum power point tracking in photovoltaic system under partial shading conditions. Energy, 62, 330-340.

[68]. Liu, Y. H., Liu, C. L., Huang, J. W., & Chen, J. H. (2013). Neural-network-based maximum power point tracking methods for photovoltaic systems operating under fast changing environments. Solar Energy, 89, 42-53.

IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE) is UGC approved Journal with Sl. No. 4198, Journal no. 45125.

Jiwajyoti Mahanta "A Review of Maximum Power Point Tracking Algorithm for Solar Photovoltaic Applications." IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE) 13. 4 (2018): 01-13.