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The Photovoltaic and Maximum Power Point Tracking Methods

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ABSTRACT
The arrival of the photovoltaic(PV)technology in the electric power sector has given rise toa significant clean, low carbon footprint powerprovision with the associated environmental sustainability. The growth and utilization of this technology hashowever been hindered by low efficiency as a result of its non-linear operational characteristics, the inherent low efficiency of the solar cell and the environmental variability that affects the maximum power generation of the system. The application of maximum power point concept to the PV system for tracking and extracting the maximum power produced by the photovoltaic system has been looked into.Several maximum power point tracking(MPPT) methods using different algorithms to extract the maximum power have been developed and implemented by the application different PV technologies. In a nutshell, some of these MPPT methods perform extremely well under rapidly changing environmental conditionswhereas the others prefer constant environmental behaviour. This paper looks at each of the MPPT methods, their operational concepts, performanceand the attendant issues as well as the merit and demerit in each implementation.

KEY WORDS*: Photovoltaic, Maximum Power point, MPPT,carbon footprint*

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I. INTRODUCTION

The continuous exploration and use of conventional energy resource create negative impact that endangers the environment. As a result of this threat the development and utilisation of renewable energy resources has been accelerated. Among the various renewable resources solar energy has proven to be the most promising due to its environmental sustainability as well as its wild range of applications using photovoltaic (PV) technologies [1]. Even with these favourable benefits and applications, photovoltaic solar technologies still have many challengingissues. As a result of the non-linear characteristics and metrological dependent nature of the PV technologies, it is difficult for PV cell to generate and supply constant power to load. Solar technologies are also expensive compared to conventional based electricity generation. Also, the conversion efficiency of the PV system is low due to many factors such as the manufacturing process, nature of PV materials, operating temperature etc. [2-3]. These and many other factors are some of the obstacles that are currently plaguing the exponential growth of solar electricity utilization in many areas.

Current research trend on PV power generation has identified specific operating point on the PV characteristic curve that yields the maximum power for any given environmental condition.This has also systematically focused on tracking this maximum power point at different metrological variations particularly temperature and irradiancein order to ensure relatively constant electricity power generation and supply. The tracking concept, involves the use of smart controller called the Maximum Power Point Tracking (MPPT) system, which harvest the maximum power of the PV module or array by varying the duty ratio of the converter. This concept is very unique and has been identified as the most economical way of improving the power produced as well as the overall efficiency of the PV system [4].

Several MPPT methods have been proposed, designed, developed and implemented [5 – 13]. These methods, although performing the same function of tracking the maximum power point, employ different techniques and algorithms in extracting power in the PV system.Several issues such as the cost of the system, the energy loss, range of effectiveness, type of implementation, tracking speed and efficiency etc., are some of the key considerations in the design of these MPPT systems. These systems differ considerable from one method to the other in terms of complexity, sensor, type of circuitry and hardware implementation [14 – 15].

Thus, these MPPT methods display different degrees of accuracy and performance, and as such several modifications have also been proposed and implemented in order to address those issues as well as improve efficiency [16 – 18].

There is no doubt that the availability of different MPPT methods has added unique options in moving the operation to the maximum power point region and thereby improve the performance of the system. However, it is worth mentioning that these PV MPPT algorithms developed and implemented are tested on different PV system, with different rating, and size, and under different metrological factors. Thus it is difficult to ascertain the best technique to adopt as all these method have their unique characteristics. However, in orderto clearly identify the merits and demerits of these systems, it is necessary to carry out systematic comparative performance analysis of each individual MPPT system. Therefore, the aim of this study is to review various MPPT methods used for photovoltaic system.

II. THE MPPT CONCEPT

The concept of MPPT is explained by examining the current – voltage (I-V) characteristics and power – voltage (P-V) curve of a single solar cell shown in figure 1; which indicates that the solar PV can give maximum power (Pmax) only at a single point. This point, which is referred to as the maximum power point (MPP) of the solar cell occurs at a particular operating voltage (Vmpp) and current (Impp) under a given temperature and insolation [19]. However, temperature and insolation vary continually in the natural environment and these variations alter the I – V and P – V characteristics by varying the PV cell current, voltage and power generated unit per time. These continuous changes in the solar cell characteristic causes the operating point as well as the MPP that delivers the Pmax of the PV system to vary throughout the day, and these affect the performance and the overall efficiency of the PV system. In order to operate the solar cell at a MPP for any given environmental variation, the MPPT system is required in order to shift the operating point to the maximum power point where the Pmax value is achieved as shown in figure 1.

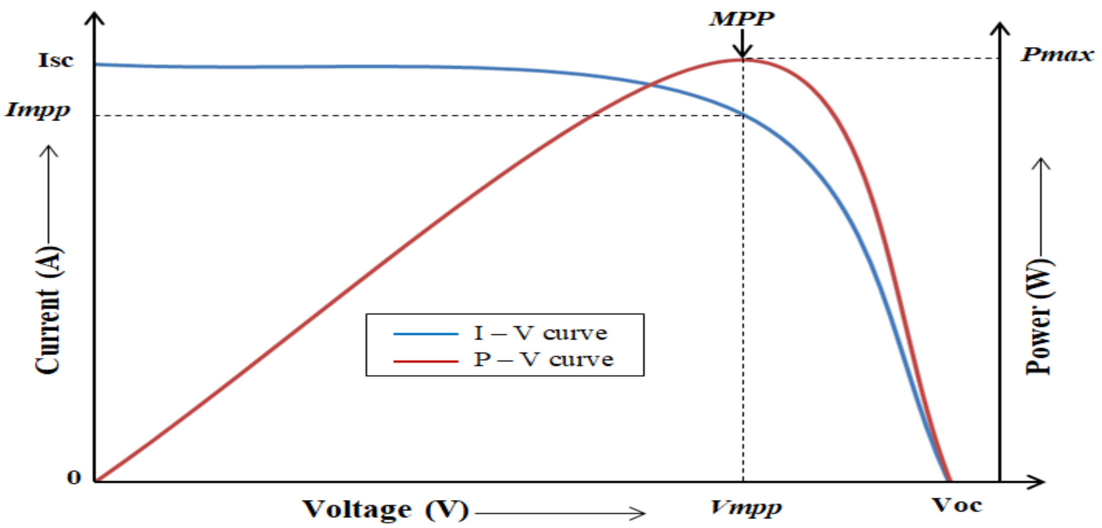

Figure 1: Solar cell I – V and P – V characteristics

II.i. MPPT Methods

These techniques are based on the I –V characteristics and the P – V curves as shown in figure 1 where the operating region that produces the maximum power point (MPP) keeps changing with both irradiance and temperature. In order toadjust to the MPP position, any variant of the maximum power point tracking with power conversion system is used The MPPT system searches and tracks the specific location of the MPP using an algorithm. Several algorithms have been developed for MPPT however, some of these algorithms suffer from slow tracking to low efficiency, and these issues have in one way or the other, impacted negatively on the implementation of some MPPT methods and as a result, provided other platforms for modifications and development of improved version of MPPT method. However, a general survey of these MPPT methods and their MPP tracking operations for PV system is required, and in this review, the MPPT methods are presented in two categories – classified as Conventional methods and Artificial Intelligence method

II.i.i. Conventional Methods

This class is well established, easy to implement and shows a good performance in tracking the maximum power point (MPP) under uniform solar irradiance. However, it exhibits relatively low tracking response and efficiency when compared with the artificial intelligence class. Under rapidly changing environment and partial shading condition, the conventional class fails to track the maximum power point [20]. The conventional method includes but not limited to the following: Perturbation and Observation (P&O) [21 – 22], Hill Climbing (HC) [20], Incremental Conductance (IC) [23 – 24], Fractional Open Circuit Voltage [25], Fractional Short Circuit Current [26], etc.

II.i.ii.Perturbation and Observation

Perturbation and Observation method is a computational approach that uses periodic perturbation of PV operating voltage in determining the operating point of the photovoltaic system. The output power based on the perturbation is observed in order to predict the next perturbation direction that will drive the operating point to the MPP; where change in power with respect to voltage is zero. Based on the analysis; if the change in power (ΔP) due to the perturbation is positive, the system will continue to increase the operating voltage towards the MPP and the subsequent perturbation step will be generated in the same direction. Conversely, if the ΔP is negative, it means the system operating point is farther away from the MPP thus; the perturbation size needs to be reduced in order to bring the operating point back to the MPP [20], [27]. This process continued until MPP region is reached as shown in figure 2.

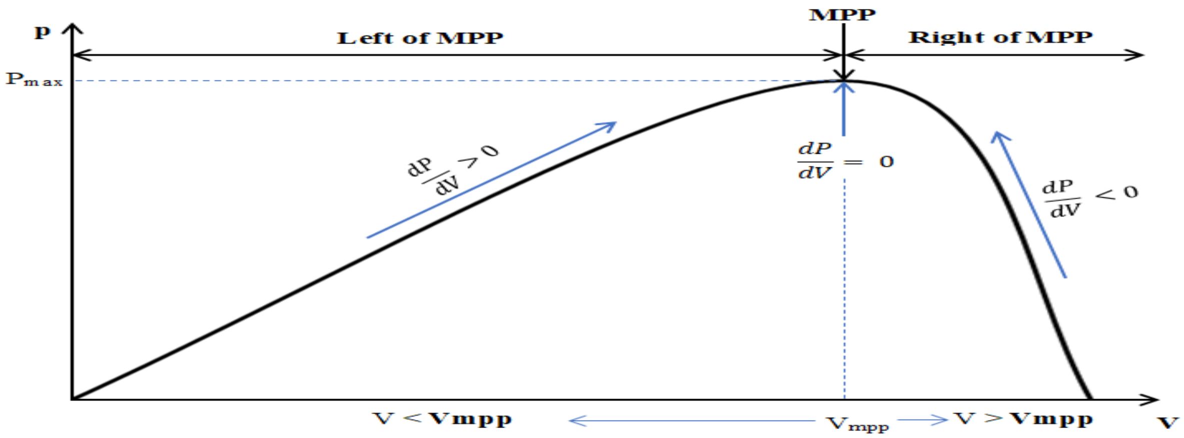

Figure 2: Operating Principle of perturbation and observation in P-V curve

This method is one of the most commonly used methods because of its low cost, simple implementation and good performance under a steady environmental condition. However, under a rapidly varying atmospheric condition, the algorithm exhibit lower coverage speed, drift and high oscillation around the maximum power point [22]. This is due to its inability to relate the changes in the PV power to the changes in the atmospheric condition and these challenges have on occasions led to the tracking of MPP in the wrong direction resulting to energy losses as well as reducedtracking efficiency[28 – 29]. Several improvements of the P&O algorithm have been proposed. Among them are the use of instantaneous PV array voltage and current instead of the average [16], fixed and adaptive step perturbation size [28], and improved variable step perturbation size [30 – 32]. These modifications do improve the efficiency of the system by providing dynamic response in tracking speed to compensate for the drawbacks of the P&O.

II.i.iii.Hill Climbing (HC) Method

The operational principle of this method focuses on perturbation in duty cycle of its converter to achieve MPP. The perturbation direction is based on the initial and calculated value of the power. If the change in power is positive the operating point is move towards the MPP otherwise it is reversed. As a result of this operation the switching duty – cycle converter keeps changing until the operating power reached the MPP [33]. Fundamentally, this principle is the same with the Perturbation and Observation method. Both employ perturbation process in tracking the MPP but operationally, the perturbation focused is different. While the P&O perturbs the operating voltage of the PV system, the Hill Climbing perturbation focuses on changes in the duty cycle as stated earlier [34 – 35]. Though both methods enjoy the same advantages, they also face the similar challenges of inability to track the MPP under rapidly changing environmental conditions.

Hence, improved versions, based on the same principle have been developed to minimise the drawbacks and improve the tracking performance. Among them is the introduction of a digital hill climbing method incorporating bi-directional current mode power cell. This has been implemented in space application [36] and review [37]. In another study [38], HC is used in a parallel connected MPPT system for stand-alone PV power generation. The proposed structure reduces the negative influence of dc–dc converter losses, hence increasing the efficiency of power generation

II.i.iv.Incremental Conductance (IC) Method

The quest for improved efficiency of the MPPT system has led to the development of incremental conductance and the algorithm is based on the derivative of the power gradient ($\frac{dP}{dV}$) from the power-voltage curve; which is zero at the maximum power point, greater than zero at region before the MPP and less than zero at region after the MPP as shown in figure 2. Operationally, this method measures and compares instantaneous conductance $\left(\frac{I}{V}\right)$ with incremental conductance $\left(\frac{\Delta I}{\Delta V}\right)$ at different voltage operating points until both are equal. At that point MPP is achieved, the operating voltage equals the voltage at MPP and the algorithm will stop operation. However, if a change is detected in $\left(\frac{\Delta I}{\Delta V}\right)$ due to environmental variations then, the algorithm will re-calculate until optimal point is obtained [20]. How fast the MPPT algorithm searches for the MPP is a function of the incremental size. Large incremental size reduces the duration of the tracking process; however, this will make the system to oscillate around the MPP. The incremental conductance algorithm is derived from the following equations:

$$\frac{dP}{dV} = \frac{d(IV)}{dV} = I\frac{dV}{dV} + V\frac{dI}{dV} = I + V\frac{dI}{dV} \quad (1)$$

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

Then, $I + V\frac{dI}{dV} = 0$ (2)

Therefore, $\frac{dI}{dV} \cong \frac{\Delta I}{\Delta V} = -\frac{I}{V}$ at MPP (3)

$\frac{\Delta I}{\Delta V} > -\frac{I}{V}$ left of MPP

$\frac{\Delta I}{\Delta V} < -\frac{I}{V}$ right of MPP

Where; $\frac{\Delta I}{\Delta V}$ is the incremental conductance while $\frac{I}{V}$ represent the instantaneous conductance. Although generally, this method has better performance and less oscillation around the MPP compared to the P&O and HC methods. However, the complexity of the algorithms and the high system cost as well as the compulsory measurement of PV current and voltage are limiting factors. Several modifications in the area of advanced IC, improved variable step size IC, control circuitry incremental conductance, etc., have been introduced based on the Power (P) - Voltage (V) curve [34] [36] [37] [39 - 40]. However, these modifications are considered insufficient solutions for addressing all of these problems.

II.i.v.Artificial Intelligent Methods

The artificial intelligent methods were introduced to solve practical problems in different areas which include the challenges of conventional method in tracking the maximum power of PV system under any given atmospheric condition, including partial shading. These methods have shown improved performance in tracking efficiency compared to the convention methods. The artificial intelligence method involves the use of artificial intelligent technology, such as Genetic Algorithms (GA) [15], Particle Swam Optimism (PSO) [41], Neural Networks (NN) [42], Fuzzy Logic (FL) [14], etc.

II.i.vi.Artificial Neural Network (ANN)

Artificial Neural Network is a computational network model that is capable of modeling non-linear relationship that exists between input and output within systems. The network structure usually consists of three layers (input, hidden and output) with processing elements that are interconnected. An example of ANN is shown in figure 3; the input variables for PV array may include temperature, rate of solar irradiance and short-circuit current or open-circuit voltage. The system processes the data in the hidden layer to achieve the MPP and output the expected result which could be voltage or signal that can be used to drive the power converter to operate at MPP [43]. Thenumbers of nodes in each layer as well as the input variables varies and are user defined; the performance of the system is based on the number of hidden layers as well as the nodes in each layer [44]. The algorithm used by the hidden layer as well as the knowledge of the trained user determine how close the operating point gets to the MPP

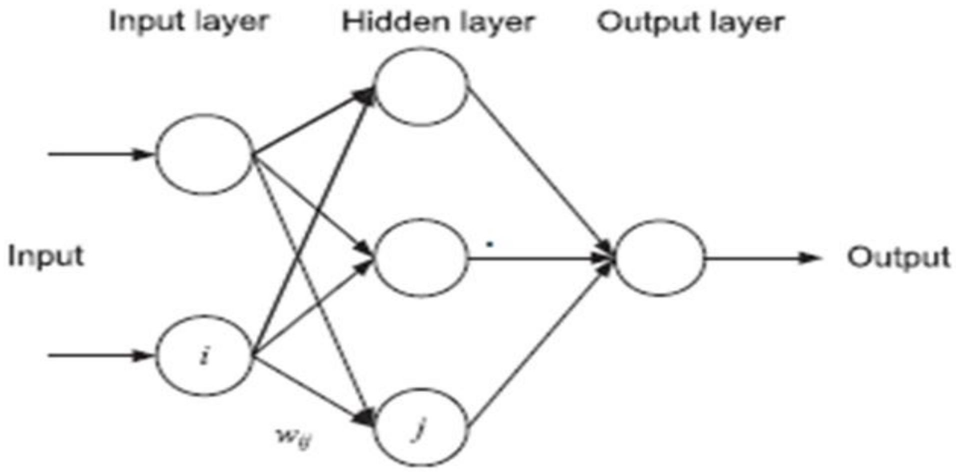

Figure 3: The three layers of ANN structure [43]

The main disadvantage of this MPPT technique is the fact that the data needed for the training process has to be specifically acquired for every PV array and location, as the characteristics of the PV array vary depending on the model, the atmospheric conditions and location. These characteristics also change with time, so the neural network has to be periodically retrained. However, the uncertainties posed by solar irradiance, ambient temperature and electrical load characteristic in PV systems are compensated in the ANN MPPT algorithm using neural network compensator [45]. Several other authors have equally proposed different ways to enhance the performance of the system for improving the MPPT. An improved efficiency MPPT based on artificial neural network suitable for solving non-linear relation has been proposed [46]. The proposed ANN-MPPT is compared to the conventional perturbation & observation algorithm. The comparison shows that ANN-MPPT outperforms the traditional P & O MPPT in term of efficiency and the reduction of the output oscillations around the MPP. One of the major improvement of this method is in the implementation of variable step size neural network MPPT controller, the system reached MPP very rapidly in fast changing environmental conditions and show reduction in the energy losses and oscillation in the steady state [47]. In addition, there are other research works on the application of ANN with other algorithm methods like P&O, IC, Fuzzy Logic Controller (FLC) and these combinations improved the MPPT performance [4], [48 – 49].

II.i.vii.Fuzzy Logic Controller (FLC)

Fuzzy logic control method has been identified as one of the most commonly used MPPT methods according to several authors [50 – 52] and this is largely due to the advantage of using imprecise input which does not require accurate mathematical model [16]. This technique benefits from the concept of linguistic mapping of membership function of the variable, expert rather than technical knowledge applicationand systematic application of fuzzy logic for tracking MPPT. The simplicity of design, improved microcontroller processing power as well as the ability to model nonlinear and complex system gives the FLC an added advantage in tracking maximum power point under varying atmospheric conditions [16]. Generally, fuzzy logic controlsystem structure consists of four blocks: fuzzification, rule base, inference and defuzzification, as shown in figure 4. These blocks respectively involved the conversion of the crisp input variable of the system into linguistic variable based on defined membership function through the fuzzification process, this is followed by the formation of rulesbased on the system control behavior, the operational application of the rule base to compute the activation of each linguistic variation is performed by the inference engine and finally, the defuzzification block converts these linguistic output results back to crisp variable using different defuzzification methods. This defuzzification stage provides output control signal that drives the operating point to the MPP. The efficiency of the system depends on the number of linguistic variable used in the system, and the number of linguistic variable applied for both inputs determines the number of maximum rules require for tracking the MPPT in the system. Sample of membership function for seven linguistic variable are depicted in figure 5 and these variables are expressed as Positive Big (PB), Positive Medium (PM), Positive Small (PS), Zero (Z), Negative Big (NB), Negative Medium (NM) and Negative Small (NS). More stable and accurate results are produced with increasing number of linguistic variable [53– 54].

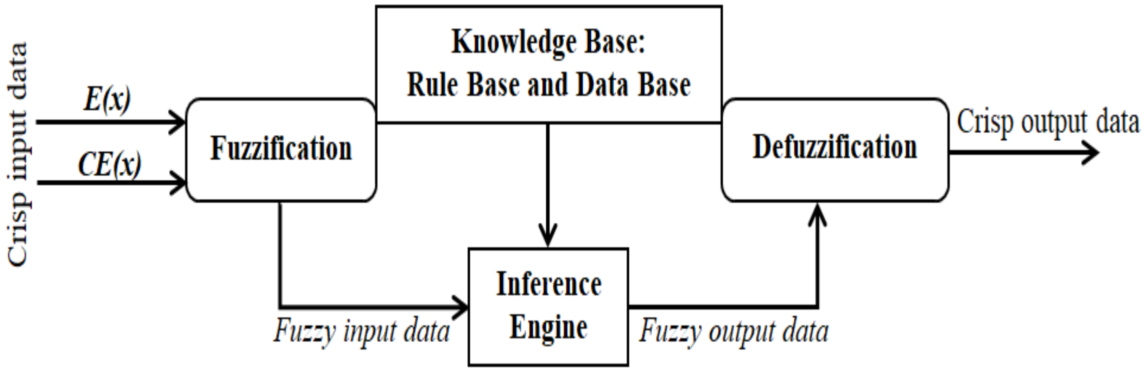

Figure 4: The Structure of a fuzzy logic control system

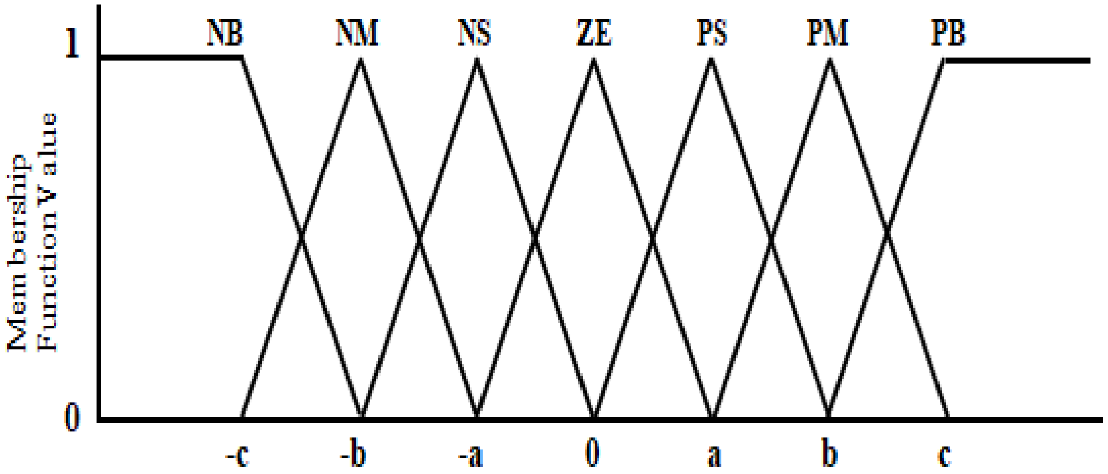

Figure 5: Sample of membership function

Several different PV variable such as power, voltage, current, irradiance and temperature or the derivative of power with respect to either voltage or current [55] are used for the computation of fuzzy logic control inputs which are usually referred to as error (***E***) and change in error (***CE***). It has been shown that the derivative of PV Power with respect to voltage is used as error input while the change in error as a result of change in derivative is used as change in error input as shown in equation 4 and 5 respectively [44].

$$\boldsymbol{E}(x) = \frac{dp}{dv} = \frac{P(x) - P(x-1)}{V(x) - V(x-1)} \qquad (4)$$

$$\boldsymbol{CE}(x) = E(x) - E(x-1) \qquad (5)$$

Where, x is the sampling time while P and V are the instantaneous power and corresponding voltage of the PV system. The error and change in error indicate the operating point and direction of the operating point in the system respectively. The system operational condition for extracting the maximum power is such that the operating point has to always be at the MPP when the input error is zero [36]. However, for the input error value greater or less than zero, incremental and non-incremental changes will take place in the duty cycle based on the rule base until the MPP is reached. A sample of the rule base is shown in table 1 and clearly states the rules that govern the error and change in error computations during the MPPT tracking. The rule states that if the error ***E*** is NB and change in error ***CE*** is PS THEN duty cycle is NB. This implies that if the operating point is far to the right of MPP (error value is negative big) and the direction of operation point is further away to the left of the MPP (change in error value is positive big), then the controller output from the duty cycle will be decreased greatly in order to moves the operating point towards then MPP. The number of rule generated in any designed system is a function of the number of linguistic variable used for both the error and change in error input as shown in table 1.

Table 1: Sample of Rule Base

CE→ / E↓	NB	NM	NS	ZE	PS	PM	PB
NB	ZE	ZE	ZE	NB	NB	NB	NB
NM	ZE	ZE	ZE	NM	NM	NM	NM
NS	NS	ZE	ZE	NS	NS	NS	NS
ZE	NM	NS	ZE	ZE	ZE	PS	PM
PS	PM	PS	PS	PS	ZE	ZE	ZE
PM	PM	PM	PM	ZE	ZE	ZE	ZE
PB	PB	PB	PB	ZE	ZE	ZE	ZE

Fuzzy logic control based MPPT method has robust performance with fast convergence, fast tracking under highly variable environmental change, improved MPPT efficiency, superior performance and minimal oscillation around the MPP [44] with comparedallthe other methods [54] [56 – 57]. Although, the effectiveness of FLC MPPT system depends on the skill of the designer in error computation and, formulation of appropriate rule-base based on the membership function. However, several optimization and modifications of FLC MPPT which include adaptive FLC [54], scaling factor and switching pulses [58 – 60] have been implemented to further enhance the performance and efficiency of the system.

III. CONCLUSION

The MPPT systems have been reviewed to show that the conventional methods although simple to design unlike the artificial intelligent methods, perform poorly under rapidly changing operating variables. On the other hand, the artificial intelligent methods performed exceedingly well; in tracking the MPP and extracting the maximum power from PV system, under rapidly changing environmental condition. However, any comparison can only be meaningful if the tests were carried out under identical conditions.

REFERENCES

[1]. Christopher A. O, George N. N, Cyrus W. W. A Neural Fuzzy Based Maximum Power Point Tracker for a Photovoltaic System. IEEE AFRICON, 2009.

[2]. Roman E, Alonso R, Ibanez P. Intelligent PV module for grid-connected PV systems. IEEE Trans Ind Electron 53(4):1066-1073, 2006.

[3]. Achara N, Adikankwu H. O. Temperature Characterization of Solar Module Voltage Generation. International Journal of Science and Research, Vol 6, Issue 6, June 2017

[4]. Zainal S, Jubaer A, Benny S. The application of soft computing methods for MPPT of PV system: A technological and status review. Applied Energy 107 pp: 135–148, 2013.

[5]. Chao K. H, Chang L.Y, Liu H. C. Maximum power point tracking method based on modified particle swarm optimization for photovoltaic systems. International Journal of Photoenergy. Article ID 583163, 6 pages, 2013.

[6]. Mahamudul H, Saad M, Ibrahim Henk M. Photovoltaic system modeling with fuzzy logic based maximum power point tracking algorithm. International Journal of Photoenergy. Article ID 762946, 10 pages, 2013.

[7]. Arulmurugan R,Suthanthiravanitha N. Improved fractional order VSS Inc-Cond MPPT algorithm for photovoltaic scheme. International Journal of Photoenergy. Article ID128327, 10 pages, 2014.

[8]. 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. vol. 26, no. 4, pp. 1010–1021, 2011.

[9]. Tey K. S, and Mekhilef S. Modified incremental conductance MPPT algorithm to mitigate inaccurate responses under fast changing solar irradiation level. Solar Energy, vol. 101, pp. 333–342, 2014.

[10]. Adly M, Ibrahim M, El Sherif H. Comparative study of improved energy generation maximization techniques for photovoltaic systems. In Proceedings of the Asia-Pacific Power and Energy Engineering Conference (APPEEC '12), pp. 1–5, Shanghai, China, March 2012.

[11]. Yu G. J, Jung Y. S, Choi J. Y, Choy I, Song J. H, Kim G.S. A novel two-mode MPPT control algorithm based on comparative study of existing algorithms.In Proceedings of the Conference Record of the 29th IEEE Photovoltaic Specialists Conference, pp. 1531–1534, IEEE, May 2002.

[12]. Al Nabulsi A, Dhaouadi R, Rehman H. Single Input Fuzzy Controller (SFLC) based maximum power point tracking. In Proceedings of the 4th International Conference on IEEE Modeling, Simulation and Applied Optimization (ICMSAO '11), pp. 1–5, Kuala Lumpur, Malaysia, April 2011.

[13]. Patel A, Kumar V, Kumar Y. Perturb and observe maximum power point tracking for Photovoltaic cell. Innovative Systems Design and Engineering vol. 4, no. 6, pp. 9–15, 2013.

[14]. Seyedmahmoudian M, Horan B, Soon T. K, Rahmani R, Than A.M, Mekhilef S. State of the art artificial intelligence-based MPPT techniques for mitigating partial shading effects on PV systems - a review. Renew Sustain Energy Rev 64:435-455. 2016.

[15]. Bechouat M, Soufi Y, Sedraoui M, Kahla S. Energy storage based on maximum power point tracking in photovoltaic systems: a comparison between GAs and PSO approaches. Int J. Hydrogen Energy 40(39): 13737-13748, 2015

[16]. Mohamed A. E, Zhengming Z. MPPT techniques for photovoltaic applications. Renewable and Sustainable Energy Reviews, 25: 793–813, 2013.
[17]. Sadeq D. A, Maysam F. A, Hamed S. A. A novel maximum power point tracking technique based on fuzzy logic for photovoltaic systems.International journal of hydrogen energy 43: 14158 – 14171, 2018.
[18]. Bendib B, Belmili H, Krim F. A survey of the most used MPPT methods: Conventional and advanced algorithms applied for photovoltaic system. Renewable and Sustainable Energy Reviews 45: 637–648, 2015.
[19]. Singh S. C. Solar photovoltaics: fundamentals, technologies and applications. New Delhi: PHI Learning Pvt. Ltd, 2011
[20]. Kamarzaman N. A, and Tan C. W. A comprehensive review of maximum power point tracking algorithms for photovoltaic systems. Renewable and Sustainable Energy Reviews 37: 585–598, 2014.
[21]. Femia N, Petrone G, Spagnuolo G, and Vitelli M. A technique for improving P & O MPPT performances of double-stage grid-connected photovoltaic systems. IEEE Trans Ind. Electron, 56(11): 4473–4482, 2009.
[22]. Souza N. S. D, Lopes L. A. C and Liu X. Comparative study of variable size perturbation and observation maximum power point trackers for PV systems. Elec. Power Syst. Res., 80: 296-305 2010.
[23]. Safari A, and Mekhilef S. Simulation and hardware implementation of incremental conductance MPPT with direct control method using cuk converter. IEEE Trans Ind. Electron, 58(4):1154–1161, 2011.
[24]. Elgendy M. A, Zahawi B, and Atkinson D. J. Assessment of the incremental conductance maximum power point tracking algorithm. IEEE Trans Sustain Energy 4(1):108-117, 2013.
[25]. Ahmad J. A. Fractional open circuit voltage based maximum power point tracker for photovoltaic arrays. Software Technology and Engineering (ICSTE), 2nd International Conference on San Juan, PR, pp. 247 – 250, 2010.
[26]. Reza R. A, Mohammad H. M., and Shahriar J. Classification and comparison of maximum power point tracking techniques for photovoltaic system: A review. Renewable and Sustainable Energy Reviews, 19: 433–443, 2013.
[27]. Onat N. Recent developments in maximum power point tracking technologies for photovoltaic systems. Int. J. Photo-energy, pp:1–10, 2010.
[28]. Khaehintung N, Kunakorn A, and Sirisuk P. A novel Fuzzy logic control technique tuned by particle swarm optimization for maximum power point tracking for a photovoltaic system using a current-mode boost converter with bifurcation control. Int. J. Control Autom. Syst. :289–300, 2010.
[29]. Saleh E. B, Matthew A, Volker P. Overview of Maximum Power Point Tracking Control Methods for PV Systems. Journal of Power and Energy Engineering, 2, 59-72, 2014.
[30]. Dorin P, Toma P, Stefan D, Cristina M, Brian M. A Novel Maximum Power Point Tracker Based on Analog and Digital Control Loops. Solar Energy, 85: 588-600, 2011.
[31]. Housheng Z, Suling Li, Haidong Li. Maximum Power Point Tracker for Solar Cells Based on Boost Converter. 2010 2nd International Conference on Computer Engineering and Technology(ICCET), V4-665-V4-668, 2010.
[32]. NoppadolK, Theerayod W,Phaophak S. FPGA implementation of mppt using variable step-size p&o algorithm for pv applications. In Communications and Information Technologies, ISCIT'06. International Symposium, pages 212–215. IEEE, 2006
[33]. SubudhiB and Pradhan R. A comparative study on maximum power point tracking techniques for photovoltaic power systems. Sustainable Energy, IEEE transactions on, 4(1), 89-98, 2013.
[34]. Sarah L. L. A Simulated Annealing Global Maximum Power Point Tracking Method for Photovoltaic Systems Experiencing Non-Uniform Environmental Conditions", (PhD Thesis), 2015.
[35]. Verma D, Nema S, Shandilya A. M, Soubhagya K. D. Maximum power point tracking (MPPT) techniques: Recapitulation in solar photovoltaic systems. Renewable and Sustainable Energy Reviews 54: 1018–1034, 2016.
[36]. Teulings W. J. A. et al. A new maximum power point tracking system. In: Proceeding 24th annual. IEEE power electron spec conf., pp. 833-838, 1993.
[37]. Muthuramalingam M, Manoharan P. S. Comparative analysis of distributed MPPT controllers for partially shaded standalone photovoltaic systems. Energy Convers Manag., 86: 286-299, 2014.
[38]. Gules, De Pellegrin Pacheco J, Hey H. L, Imhoff J. A maximum power point tracking system with parallel connection for PV stand-alone applications.Industrial electronics. IEEE Transactions on 55: 2674–2683, 2008.
[39]. Xiao W and Dunford W. G. A modified adaptive hill climbing MPPT method for photovoltaic power systems. In: Presented at the proceedings of 35th annual IEEE power electron spec conf., 2004.
[40]. Koutroulis E, Kalaitzakis K, and Voulgaris N. C. Development of a microcontroller- based, photovoltaic maximum power point tracking control system, power electronics. IEEE Transactions on 16: 46–54, 2001.
[41]. Koad R. B. A, Zobaa A. F, and El-Shahat A. A novel MPPT algorithm based on particle swarm optimization for photovoltaic systems. IEEE Trans Sustain Energy 8(2):468 – 476, 2017.
[42]. Duman S, Yorukeren N, and Altas I. H. A novel MPPT algorithm based on optimized artificial neural network by using FPSOGSA for standalone photovoltaic energy systems. Neural Comput. Appl. 29(1):257 – 278, 2018.
[43]. EsramT and Chapman P. L. Comparison of photovoltaic array maximum power point tracking techniques. IEEE Transaction on Energy Conversions, 22, No 2, 2007.
[44]. Awang J, Tole S, Tan K. G, Saad M. A Review on Favourable Maximum Power Point Tracking Systems in Solar Energy Application. TELKOMNIKA, Vol.12, No.1, pp. 6-22. ISSN: 1693-6930, 2014.
[45]. Sabir M, Abdelghani H, Abdelhamid L. A new variable step size neural networks MPPT controller: Review, simulation and hardware implementation. Renewable and Sustainable Energy Reviews 68: 221–233, 2017.
[46]. Tsai M. F, Tseng C. S, Hong G. D, and Lin S. H. A novel MPPT control design for PV modules using neural network compensator. IEEE, 2012
[47]. Yong Z, Hong L, Liqun L and Xiao Feng G. The MPPT control method by using BP neural networks in PV generating system. In: Proceedings of the 2012 international conference on industrial control and electronics engineering, 2012.
[48]. Jinbang X, Shen A, Yang C, Rao W, Yang X. ANN based on Inc-Cond algorithm for MPP tracker. In: Bio-inspired computing: theories and applications (BIC-TA), 2011. Sixth international conference on; p. 129–134, 2011.
[49]. Veerachary M, Senjyu T, Uezato K. Neural-network-based maximum power point tracking of coupled-inductor interleaved-boost-converter supplied PV system using fuzzy controller. IEEE Trans Ind Electron 50(4):749–58, 2003.
[50]. Aashoor F.A.O, and Robinson F.V.P. A variable step size perturbs and observe algorithm for photovoltaic maximum power point tracking. In Universities Power Engineering Conference (UPEC), 47th International pp. 1-6, 2012.
[51]. Ishaque K and Salam Z. A review of maximum power point tracking techniques of PV system for uniform insolation and partial shading condition.Renewable and Sustainable Energy Reviews, 19, 475-488, 2013
[52]. Saravanan S and Babu N. R. Maximum power point tracking algorithms for photovoltaic system-A review. Renewable and Sustainable Energy Reviews, 57, 192-204, 2016.

[53]. Syafaruddin, etal. Artificial neural network-polar coordinated fuzzy controller based maximum power point tracking control under partially shaded conditions. IET Renew Power Gener., 3: 239–253, 2009.
[54]. Patcharaprakiti N, Premrudeepreechacharn S. Maximum power point tracking using adaptive fuzzy logic control for grid-connected photovoltaic system. In: Proceedings of IEEE power engineering society winter meeting; .p.372–377, 2002.
[55]. Algazar M. M, AL-monier H, EL-halim HA, El Kotb Salem M. E. Maximum power point tracking using fuzzy logic control. Electrical Power and Energy Systems 39: 21–28, 2012.
[56]. Rebhi M, BenatillahA, Sellam M, Kadri B. Comparative study of MPPT controllers for PV system implemented in the south-west of Algeria. Energy Procedia 36:142–153, 2013.
[57]. Lalouni S, Rekioua D. Optimal Control of a grid connected photovoltaic system with constant switching frequency. Energy Procedia 36:189–199, 2013.
[58]. Gupta N, Garg R. Tuning of asymmetrical fuzzy logic control algorithm for SPV system connected to grid. Int. J. Hydrogen Energy 42(26):16375-16385, 2017.
[59]. Ali B. S, Moulahoum S, Benkercha R, Taghezouit B, Saim A. M5P model tree based fast fuzzy maximum power point tracker. Sol Energy 163:405-424, 2017.
[60]. Subiyanto S, Mohamed A, Hannan M. A. Intelligentmaximum powerpoint tracking for PV system using Hopfield neural network optimized fuzzy logic controller. Energy Build 51:29-38, 2012.

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