International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056
Volume: 04 Issue: 01 | Jan -2017 www.irjet.net p-ISSN: 2395-0072

Maximum Power Point tracking algorithms for solar power system-Review

P.Sudheer[1], Dr.Ch.Chengaiah[2],

[1]*Research Scholar, S.V.U. College of Engineering, S. V. University, Tirupati* ,Andhra Pradesh ,*India*
[2]*Professor, S.V.U. College of Engineering, S.V. University, Tirupati* ,Andhra Pradesh ,*India*

* * *

Abstract-*Past lessons, present situations and future demands of energy leads a man step towards renewable energy sources very fastly especially in solar energy because of its more advantages such as abundant availability, no pollution, lack of greenhouse gas emission, low maintenance costs, fewer limitations in site selection ,absence of mechanical noise etc. However these solar systems are having its own drawbacks mainly less conversion efficiency with varying solar irradiance and temperatures. To draw maximum power in those conditions, tracking maximum power point is more essential for the Photovoltaic systems. Upto now in research field so many maximum power point tracking methods have been proposed and implemented. This paper intended to present different maximum power point tracking methods with its behaviour, performance etc to serve as a convenient reference for future maximum power point tracking users in Photovoltaic systems.*

Keywords- Maximum power point Tracking, Photovoltaic system, performance,oscillations

I.INTRODUCTION

The demand of PV generation systems seems to be increased for both ON-GRID and OFF-GRID applications[1-3]. Attainment of maximum power involves load-line adjustment under variations in irradiation level and temperature. The maximum power point tracking, MPPT not only enables an increase in the power delivered from the PV module to the load, but also enhances the operating lifetime of the PV system [4]. A variety of MPPT methods have been developed and implemented [5,6]. Therefore, an efficient maximum power point tracking technique is necessary that is expected to track the maximum power point at all environmental conditions and then force the Photovoltaic system to operate at that maximum power point. More number of MPPT techniques are developed for both applications. Users always getting confuse while selecting an MPPT technique for a their application. It is necessary to prepare a review that includes all the different efficient MPPT techniques for future work. We referred around major 50 papers pertaining to MPPT methods published up to the date of this publication. We apologize if an any technique or advancement was left out.

2.MPPT CLASSIFICATION

Different MPPT methods can be categorized into offline methods, which depends on solar cell models, online methods which does not depends on modelling of the solar cells, and hybrid methods which are a combination of the both above methods. The offline and online methods can also be named as the model-based and model-free methods, respectively. Offline methods requires solar panel values, such as the open circuit voltage (V_{OC}), short circuit current (I_{SC}), temperature and irradiation. These values are useful to generate the control signal which is necessary for driving the solar cell to its maximum power point (MPP).In online methods, usually the instantaneous values of the PV output voltage or current are used to generate the control signals. The control signal is applied to the PV system along with a small methodical and premeditated perturbation in voltage or current or duty cycle (control signal) and the resulting output power is determined.

2.1.Curve-Fitting Technique

Modelled PV panel[7][8] gives P-V characteristics, from this, power and voltage samples in different intervals to determine values of coefficients like a,b,c,d which was used in third-order polynomial function to get accurate P-V curve fitting .

$$p = av^3 + bv^2 + cv + d \quad \text{-----------------} \quad (1)$$

Differentiation of (1) gives

$$\frac{dP}{dV} = 3av^2 + 2bv + c \quad \text{-----------------} \quad (2)$$

At MPP $\frac{dP}{dV} = 0$ ----------------- (3)

Thus, the voltage at MPP can be calculated as

$$V_{mpp} = \frac{-b \pm \sqrt{b^2 - 3ac}}{3a} \quad \text{-----------------} \quad (4)$$

In this technique a,b,c,d , repeatedly sampled in a span of few milliseconds using mathematical equations defined in [8] and then V_{mpp} is calculated.

2.2.Fractional Short-Circuit Current (FSCI) Technique

Based on V-I Characteristics this method calculates I_{mpp} using following equation when V_{mpp} is known to get P_{mpp} .

$$I_{mpp} \approx K_{SC} I_{SC} \quad \text{--------------} \quad (5)$$

The value of K_{sc}generally varies between 0.64 and 0.85 [9].

iii.Fractional Open-Circuit Voltage (FOCV) Technique

In this technique, V_{mpp} can be calculated from the following relationship when I_{mpp} is known to get P_{mpp} .

$$V_{mpp} \approx K_{OC} V_{OC} \quad \text{--------------} \quad (6)$$

the value of K_{OC} varies between 0.78 and 0.92.[9][10]. Repeating this process is V_{OC} sampled repeatedly in every few seconds and value of V_{mpp} is updated.

2.3.Look-up Table Technique

In this technique, for each probable environmental condition the MPP is calculated and stored in the memory device of MPPT's control system. During the operation, the corresponding MPP for a particular condition is selected from that memory and implemented [11][12].

2.4.One-Cycle Control (OCC) Technique

This method involves the use of a single-stage inverter where the output current can be adjusted according to the voltage of the PV array to extract the maximum power from it [13]–[15]. The OCC system is shown in Fig.1. The values of L,C should be properly tuned to get better accuracy.

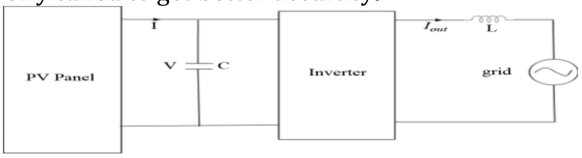

Fig:1.Block diagram of One-Cycle Control method

2.5.Differentiation Technique

For tracking MPP, this technique requires a high capacity processor to solve the complex MPP equation [16] .This technique determines MPP by solving the following equation:

$$\frac{dP}{dt} = \frac{d(IV)}{dt} = I\frac{dV}{dt} + V\frac{dI}{dt} = 0 \qquad \text{----------------} (7)$$

2.6.Feedback Voltage or Current Technique

This method is used in no battery systems, by using a simple controller bus voltage(or current) is fixed as a reference [5]and the panel feedback voltage(or current) taken as a actual voltage(or current) and by adjusting duty ratio of dc – dc converter it operates as close as to the MPP[17]which is shown if fig.2.

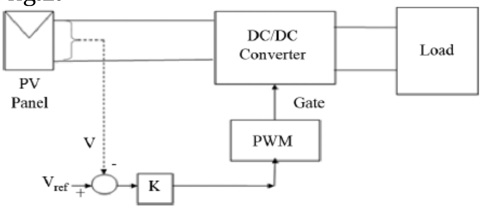

Fig:2. Block diagram of Feedback Voltage method

2.7.Feedback of Power Variation With Voltage method

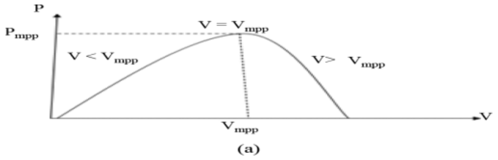

Fig:4(a) P–V curve explaining feedback variation of power with voltage.

This method is same to that of feedback voltage method, but the only difference is power variation with voltage $\frac{dP}{dV}$. Maximum power control is achieved by making $\frac{dP}{dV} = 0$ under power feedback control. A common procedure in power feedback control is to measure and maximize the power at the load terminals [18].In this method, power to the load is maximized not the power from the solar array because of power-loss in the converter. the high performance converter design is required[19] to avoid this losses.

2.8.Feedback of Power Variation With current method

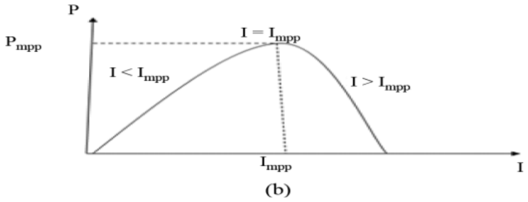

Fig:4(b) P–V curve explaining feedback variation of power with current.

This method [Fig. 4(b)] is taken feedback of power variation with current upto MPP.MPP will get by varing the duty cycle till $\frac{dP}{dI} = 0$ [20].

2.9.Perturb and Observe (P&O)Methods

In this technique perturbing the voltage and the current of the PV regularly, and power from it compares with the previous power to decide the next variation. According to that variation it will move to the next position to find the MPP. Here mainly three Perturb & Observe (P&O) Methods are discussed.

a).Conventional P&O with fixed Perturb

Because of the simplicity, this method will work with few sensors. The sensor will senses the operating voltage. The operating voltage is sampled and the P&O algorithm changes the operating voltage towards the MPP by perturbing PV array voltage. Perturb means either increase or decrease. If the PV array voltage is increased, power of PV array increases. Hence in the next perturbation also voltage is increased. This process is continued till power reaches Maximum Point. At maximum point if voltage is increased further PV array power decreases. Hence perturbation is made negative at this point that means voltage is decreased

.In this manner, the operating point of the system reaches the MPP. This method is not appropriate for different irradiation conditions. The block diagram of P&O method is shown in Fig.5.

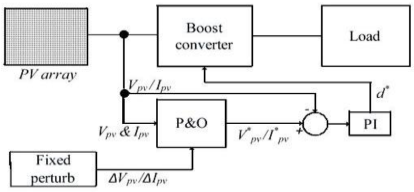

Fig:5. Block diagram of P&O MPPT

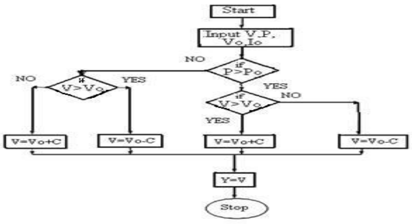

Fig.6 . Flowchart of Conventional P&O algorithm .

b).Conventional P&O with Adaptive Perturb

The conventional P&O involves perturbation in the array operating voltage or current [21]. The system oscillates at this maximum point. To reduce these oscillations the perturbation size is decreased but this smaller perturbation size slows down the system. Hence speed versus oscillations problem exists with conventional P&O method with fixed Perturb value. To avoid this problem adaptive perturb method is used. The block diagram of Adaptive P&O Technique is shown in Fig.7.

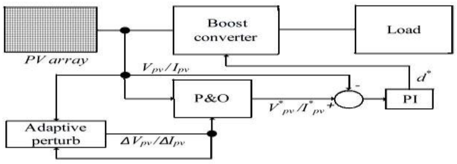

Fig:7. Block diagram of Adaptive P&O Technique

c).Modified Adaptive P&O MPPT Technique

In this method converter duty ratio is used as a perturb signal instead of using array voltage or current. The block diagram and flow chart of MAP&O are shown in Fig.8 and Fig.9 respectively. This method decides perturb value by using automatic parameters tuning. In modified P&O with fixed perturb trade off problem exists between dynamic response and steady state performance .Generally Duty cycle incremental size should be high during transient stage and small in steady state. Automatic tuning of duty cycle perturb value is found by following expression

$$a(k) = M * \frac{\Delta P}{a(k-1)} \quad \text{----------} \ (8)$$

Where $a(k)$ = perturb value of duty cycle

$a(k-1)$ = historic value of *a(k)*

$$\Delta P = P(k) - P(k-1) \quad \text{------------}(9)$$

At the beginning of the process power change is high so the tuner will give high value of 'a' from the above equation. This large value of 'a' satisfies the quick response requirement. At steady state condition, power change is small so the tuner will tune the controller to give small value of 'a' which is used to reduce steady state oscillations and to satisfy dynamic response requirements [22]. In this manner adaptive value of duty cycle is generated which satisfies both fast response and low oscillation requirements[23-25].

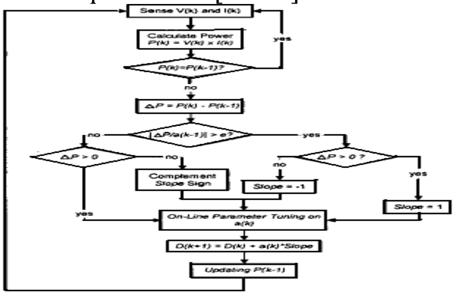

Fig.8.Flowchart of Modified Adaptive P&O Technique

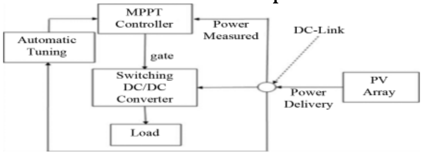

Fig.9. Block diagram of Modified Adaptive P&O Technique

In some particular cases, like variations in insolation the traditional P&O method makes the operating point to deviate from the optimal point. This problem also overcome by switching control algorithm [26-29] which is shown in flow chart Fig.8,where"P" and "D" represent the PV power level and the duty cycle value respectively. $\frac{\Delta P}{a(k-1)}$ is the switching criterion.If the solar insolation causes power variation then the controller indicates the value of $\frac{\Delta P}{a(k-1)}$ is greater than the threshold "e", then the increment of duty cycle is in the same direction as ΔP. The perturbation direction is represented by "Slope" in the flow chart (Fig.8). The system is in stead state when $\frac{\Delta P}{a(k-1)}$ value is small.

The output of MPPT is given to boost converter.

2.10. Forced Oscillation Technique

This technique is based on injecting a small-signal sinusoidal perturbation into the switching frequency and comparing the ac component and the average value of the panel terminal voltage as shown in Fig.10. Here, the switching frequency is varied and V_i (input voltage) is sensed. Scaling down the value of β and comparing β V_i with V_{ref}, the duty cycle of converter is set at MPP [30].

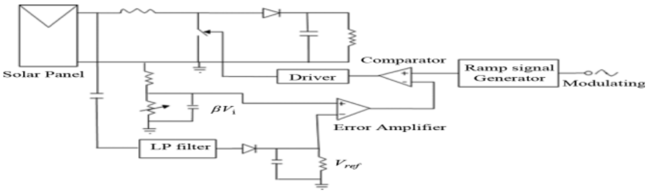

Fig:10. Block diagram of forced-oscillation technique

2.11. Ripple Correlation Control (RCC) Technique

Converter switching action imposes voltage and current ripple on the PV array. In this RCC technique [31], the ripple is utilized by the PV system to perform MPPT. As, Here no artificial perturbation is required because the ripple is naturally available by the switching converter . RCC correlates dp/dt with either di/dt or dv/dt and hence using (10.1) and (10.2) the value of voltage and current of PV system are renowned whether more or less than that of MPP. The aim of RCC method is to force the ripple to zero and ultimately drag the PV panel voltage and current to that of MPP.

$$\frac{dv}{dt} > 0 or \frac{di}{dt} > 0 \,\&\, \frac{dp}{dt} > 0 \Rightarrow V < V_{mpp} or I < I_{mpp} \quad \text{--(10.1)}$$

$$\frac{dv}{dt} > 0 or \frac{di}{dt} > 0 \,\&\, \frac{dp}{dt} < 0 \Rightarrow V > V_{mpp} or I < I_{mpp} \quad \text{--(10.2)}$$

The adjustment of current I can be done by using a boost converter. Here, the inductor current i_L is equal to the array current. At a given temperature and irradiance, i_L is adjusted together with $P = vi_L$. When there is any change in environmental condition, MPP is also shifted. Then referring to Fig. 7, (10.1)–(10.2) can be modified as follows:

$$\frac{di_L}{dt}\frac{dp}{dx} > 0 \Rightarrow i_L < I_{mpp} \quad \text{------------(11.1)}$$

$$\frac{di_L}{dt} > \frac{dp}{dt} < 0 \Rightarrow i_L > I_{mpp} \quad \text{------------ (11.2)}$$

Adjusting the duty ratio d the value of i_L can adjusted and it is find by the following equation

$$d = k\int \frac{di_L}{dt}\frac{dp}{dt}dt \quad \text{-----------------(12)}$$

where k is a constant.

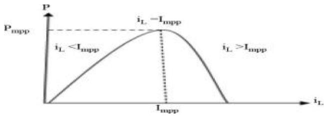

Fig.11. PV array power versus average inductor current.

2.12. Current Sweep Technique

The current sweep technique[32] uses a sweep waveform for the PV array current such that the I–V characteristic of the PV array is obtained and updated at a constant time interval. The V_{MPP} can then be computed from the characteristic curve at the same interval. The function for the current sweep waveform is directly proportional to its derivative as

$$i(t) = k_1\frac{di}{dt} \quad \text{------------------- (13)}$$

The solution of (13) is

$$i(t) = k_2 e^{t/k_1} \quad \text{----------------- (14)}$$

Here, k_2 is taken as I_{mpp} at MPP. Again at MPP

$$\frac{dp(t)}{dt} = \frac{d(v(t)i(t))}{dt} = i(t)\frac{dv(t)}{dt} + v(t)\frac{di(t)}{dt} = 0 \quad \text{-----(15)}$$

Using (13) in (15)

$$\frac{dp(t)}{dt} = \left(k_1\frac{dv(t)}{dt} + v(t)\right)\frac{di(t)}{dt} = 0 \quad \text{------------(16)}$$

where $i(t)$ can be calculated using (14), followed by V_{mpp} using (16). Here, the reference point is frequently updated in a fixed time interval and hence the technique yields accurate results if proportionality coefficients k_1 and k_2 are properly chosen.

2.13.Estimated-Perturb-Perturb (EPP) Technique

It is an extended P&O method. This technique has one estimate mode between two perturb modes. The perturb process conducts the search over the highly nonlinear PV characteristic and the estimate process compensates for the perturb process for irradiance-changing conditions. The technique is complex but its tracking speed is faster and more accurate than that of P&O method [33].

2.14. Incremental Conductance technique

In this algorithm the PVarray voltage gets modified based on the instantaneous and Incremental Conductance value of PV module. As the tracking of control variable is done rapidly it helps to overcome the disadvantage of the P&O method which fails to track the peak control variable under fast varying conditions. The PV characteristic equation is obtained as Eq. (17).The slope of the PV array power curve is zero at the MPP, positive when the operating point is on the left of MPP, and negative when the operating point is on the right of MPP

$$\frac{dp}{dv} = 0 \quad at\ Mpp$$

$$\frac{dp}{dv} > 0\ left\ to\ Mpp \quad \text{-----------------------------(17)}$$

$$\frac{dp}{dv} < 0\ right\ to\ Mpp$$

Eq. (17) can be expressed as:

$$\frac{dp}{dv} = \frac{d(IV)}{dv} = I + V\frac{dI}{dv} = I + V\frac{\Delta I}{\Delta v} \quad \text{---------------------(18)}$$

On comparing (17) and (18), Eq. (17) is rewritten as,

$$\frac{\Delta I}{\Delta v} = -\frac{I}{v} \quad at\ Mpp$$

$$\frac{\Delta I}{\Delta v} > -\frac{I}{v}\ left\ to\ Mpp \quad \text{-----------------------------(19)}$$

$$\frac{\Delta I}{\Delta v} < -\frac{I}{v}\ right\ to\ Mpp$$

The operating point tracks MPP by comparing the immediate conductance (I/V) to the Incremental Conductance (ΔI/ΔV. Vref is the voltage reference at which the PVarray is forced to operate. The control algorithm increments or decrements the Vref to track the new MPP [34]. The main disadvantage of this system is its perturbation size and complex control circuits [35–37]. To over come the disadvantage of perturbation size, improved Incremental Conductance methods were proposed by various researchers in the literature [38–45] and they are discussed below.

a. Modified INC

This technique is used to track the global maximum point under both partial shading condition and load variation with fast response in tracking .It operates based on multi duty cycle control method that efficiently uses the periodic PV characteristics [46]. From the characteristics multiple peaks are obtained during partial shading condition and the algorithm will separate the peak into GMP and LMP [47]. In this algorithm converter duty cycle step size value acts as a control variable and its selection is made with permitted error value and error tolerance on the MPP's of PVarray is maintained around7%.Eq. (7) ensures that the operating point of the PV system lies around the GMP,

$\frac{dI}{dv} + \frac{I}{v} < D$ --------------------------------(20)

where D is the permitted error used to stop the oscillation during the steady state condition and improve the efficiency of a PV system [48].

b.Variable step size INC

This method is used to track the maximum power point of PV array with automatically adjusting step size. It is used to reduce the oscillation present in both steady state and dynamic condition and improves the tracking position. The MPPT is used to control the converter duty cycle as given in Eq. (21).

$D(k) = D(k-1) \pm N * \frac{p(k)-p(k-1)}{v(k)-v(k-1)}$ --------------------- (21)

where D(k) is the actual duty cycle of controller, D(k-1) is the previous duty cycle of controller, N is the scaling factor (range from 0.06 to 0.12 is used to adjust step size), P(k) is the actual power, P (k-1) is the previous power, V(k) is the actual voltage and V(k-1) is the previous voltage [48]. The automatic tuning is employed to adjust the step size according to the PV characteristics. The con-stant voltage tracking (CVT) is used to initiate a smooth tracking process.

c. Improved variable step size INC [51]

This algorithm works under the combination of variable step size along with Incremental Resistance(INR)so as to improve the response speed and accuracy of the MPPT in the PV system. This paper uses the current as a control variable and achieves faster response in tracking the MPP. Also this method makes the MPP trackings simple and efficient even under dynamic conditions [49]. The step size modes of INR can be switched with larger values of a threshold function C as $C = p^n * \left|\frac{dp}{dI}\right|$ --------------------------(22)

where n is an index, Pn is the PV array output power and |dP/dI| is the fixed value of the power derivative. The INR based MPPT is operating in both fixed and variable step size modes based on the following conditions

$\frac{\Delta C}{\Delta I} \geq 0$ Fixed variable step size mode left of MPP
$\frac{\Delta C}{\Delta I} \leq 0$ Fixed variable step size mode right of MPP
$\frac{\Delta C}{\Delta I} < 0$ Variable step size mode left of MPP
$\frac{\Delta C}{\Delta I} > 0$ Variable step size mode right of MPP

where ΔC/ΔI is the increment of the threshold function

d.Power increment based INC [50]

This paper describes the INC algorithm which operates under variable frequency constant duty control (VFCD)or constant fre- quency variable duty control (CFVD) and threshold tracking zone (TTZ) for obtaining the reference point. In this technique the MPP was tracked in both left hand side and right hand side of PV curve using appropriate threshold tracking zone. The TTZ is divided as conductance threshold zone (CTZ) and power threshold zone (PTZ). The conductance increment (ΔC) measured for CTZ in two phase approach of power increment (PI) based INCMPPT is given

2.15.PSO based P&O

A combination of P&O and Particle Swarm Optimization(PSO) algorithms to track the MPP under partial shading condition of the PV system is proposed in [51]. Initially the P&O algorithm is operating to track the Local Maximum Point(LMP)and during partial shading condition the PSO is used to track the Global Maximum Point(GMP) [52]. The main drawback of PSO is its larger iteration time. By combining P&O and PSO algorithm, the iteration time has been reduced to track the MPP and also the searching space of the PSO gets reduced.

2.16.P&O based hybrid MPPT

A combined hybrid P&O algorithm and the open circuit voltage method for the improved MPPT technique has been proposed in [53]. In this methodology set point approximation is made using the open circuit voltage method and then exact maximum power point is tracked using P&O algorithm. As this procedure utilizes two different loops for its operation, the frequency changes the disturbances addressed effectively, and it exhibits good performance of the proposed algorithm. A new hybrid MPPT methodology combining offline and online duty cycle estimation for converter is proposed in [54].

2.17. Artificial bee Colony

ABC algorithm follows the foraging behavior exhibited by the bee colonies, from which collective intelligence emerges for maximizing the nectar amount in the hive. In the ABC algorithm, a possible solution vector of the difficulty is treated as the position of a nectar source and the nectar amount of a food source corresponds to quality (fitness) of associated solution. In a real bee colony, there are three types of functional groups namely 1) employed bee; 2) onlooker bee; and 3) scout bee. Half of the colony consists of the employed bees, and another half consists of the onlookers [56].

2.18. Firefly algorithm

The firefly algorithm (FA) is a meta-heuristic algorithm, inspired by the flashing behavior of fireflies and was developed by Xin-She Yang [58-60]. The performance of the firefly algorithm is depends on the updating function. In the updating function considers the randomized parameter. Therefore, the optimal results are obtained while using the optimum randomized parameter. For various MPPT algorithms the comparison table was tabulated in the table.1.as shown in below.

Table.1.Comparison table of various MPPT methods

MPPT Method/Properties	P&O	INC	VMPPT	CMPPT	RCC	Curve Fitting	Forced ShortCircuit Current	Forced OpenCircuit Voltage	Look Up Table	EstimatedPerturb Perturb	ForcedOscillation	ANN	FL	Current sweep
PV Array dependence	NO	NO	YES	YES	NO	NO	YES	YES	YES	NO	NO	YES	YES	YES
Sensors/Sensed parameters	V&I	V&I	V	I	V&I	V	V&I	V&I	V&I	V&I	V&I	V&I	V&I	V&I
Tracking accuracy	M	H	L	L	L	L	L	L	L	M	M	V.H	V.H	L
Application	B	B	OFG	OFG	ONG	OFG	OFG	OFG	OFG	OFG	OFG	ONG	B	ONG
Cost	E	E	IE	IE	E	IE	IE	IE	IE	E	E	E	E	E
Hardware	C	C	S	S	C	S	S	S	S	C	C	C	C	C
Analog/Digital	B	D	D	A/D	A	D	B	B	D	B	A	D	D	D
Convergence speed	V	V	M	M	H	H	M	M	M	Varies	M	H	H	L
Implementation Complexity	C	C	S	S	S	S	S	S	S	C	C	M	M	C
Periodic tuning	NO	NO	NO	NO	NO	NO	YES	YES	YES	NO	NO	YES	YES	YES
Parameter tuning	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES
Circuitry	B	D	D	A/D	A	D	B	B	D	B	A	D	D	D

L-Low M-Medium H-High V.H-Very High B-Both A-Analog D-Digital C-Complex S-Simple OFG-OffGrid ONG- OnGrid E-Expensive IE-Inexpensive V-Varies

3. CONCLUSION

This paper tried to present the various maximum power point tracking techniques existed at one place for better reference purpose with comparison table. This will be one of the source for better understanding of MPPT techniques to the beginners in this area of study. Here various conventional MPPT methods was illustrated and it was moved to optimization algorithms also, which is using for tracking the maximum power. In the comparison table various algorithms and parameters are compared for speedy reference.

REFERENCES

[1] Wu TF, Chang CH, Liu ZR, Yu TH. Single-stage converters for photovoltaic powered lighting systems with MPPT and charging features. In: Proc. IEEE APEC;, pp. 1149–1155, 1998.

[2] De Broe AM, Drouilhet S, Gevorgian. V. A peak power tracker for small wind turbines in battery charging applications. IEEE Transactions on Energy Conversion 1999;14(4):1630–5.

[3] M. Ameli, S. Moslehpour, and M. Shamlo, "Economical load distributionin power networks that include hybrid solar power plants," *Elect.Power Syst. Res.*, vol. 78, no. 7, pp. 1147–1152, 2008.

[4]BahgatABG,HelwabNH,AhmadbGE,ElShenawybET.Maximumpowerpoint tracking controller for PVsystems using neural networks. Renewable Energy 2005;30:1257–68.

[5] SalasV,Olı _as E,Barrado A. ALazaro Review of the maximum power point tracking algorithms for stand-alone photovoltaic systems. Solar Energy Materials &SolarCells2006;90:1555–78.

[6]EsramT,ChapmanPL.Comparisonofphotovoltaicarraymaximumpowerpointtrackingtechniques.IEEETransactionsonEnergyConversion2007;22:2.

[7] T. T. N. Khatib, A. Mohamed, N. Amin, and K. Sopian, "An efficient maximum power point tracking controller for photovoltaic systems using new boost converter design and improved control algorithm,"*WSEAS Trans. Power Syst.*, vol. 5, no. 2, pp. 53–63, 2010.

[8] J. C. H. Phang, D. S. H. Chan, and J. R. Phillips, "Accurate analytical method for the extraction of solar cell," *Electron. Lett.*, vol. 20, no. 10, pp. 406–408, 1984.

[9] M. A. S. Masoum, H. Dehbonei, and E. F. Fuchs, "Theoretical and experimental analyses of photovoltaic systems with voltage and current based maximum power point tracking," *IEEE Trans. Energy Conv.*,vol. 17, no. 4, pp. 514–522.2002.

[10] B. Subudhi and R. Pradhan, "Characteristics evaluation and parameter extraction of a solar array based on experimental analysis," in *Proc.9th IEEE Power Electron. Drives Syst.*, Singapore, Dec. 5–8, 2011.

[11] J.-A. Jiang, T.-L. Huang, Y.-T. Hsiao, and C.-H. Chen, "Maximum power tracking for photovoltaic power systems," *Tamkang J. Sci. Eng.*,vol. 8, no. 2, pp. 147–153, 2005.

[12] Y. Chen, K. Smedley, F. Vacher, and J. Brouwer, "A new maximum power point tracking controller," in *Proc. 18th Annu. IEEE Conf. Appl.Power Electron. Conf. Expo.*2003.

[13] N. Femia, D. Granozio, G. Petrone, G. Spagnuolo, andM. Vitelli, "Optimized one-cycle control in photovoltaic grid connected applications for photovoltaic power generation," *IEEE Trans. Aerosp. Electron.Syst.*vol. 42, no. 3, 954–972 2006.

[14] Y. Chen and K. Smedley, "A cost-effective single-stage inverter with maximum power point tracking," *IEEE Trans. Power Electron.*, vol.17, no. 4, pp. 1289–1294, Sep. 2002.

[15] W. L. Yu, T.-P. Lee, G.-H. Yu, Q. S. Chen, H. J. Chiu, Y.-K. Lo, and F. Shi, "A DSP-based single-stage maximum power point tracking pv inverter," in *Proc. 25th IEEE Annu. Conf. Appl. Pow. Electr.*, China,Jun. 12–15, 2010, pp. 948–952.

[16] S. Jain and V. Agarwal, "A new algorithm for rapid tracking of approximate maximum power point in photovoltaic systems," *IEEE Power Electron. Lett.*, vol. 2, no. 1, pp. 16–19, Mar. 2004.

[17] O. L-Lapeña,M. T. Penella, andM. Gasulla, "A newMPPTmethod for low-power solar energy harvesting," *IEEE Trans. Ind. Electron.*, vol.57, no. 9, pp. 3129–3138,. 2010.

[18] V. Salas, E. Olias, A. Lazaro, and A. Barrado, "Evaluation of a new maximum power point tracker applied to the photovoltaic stand-alone systems," Solar Energy Mater. Solar Cells, vol. 87, no. 1–4, pp.807–815, 2005.

[19] C. Hua and C. Shen, "Study of maximum power tracking techniques and control of DC/DC converters for photovoltaic power system," inProc. Power Electron. Specialist Conf., Japan, May 17–22, 1998.

[20] L. Li-qun and W. Zhi-xin, "A rapid MPPT algorithm based on the research of solar cell's diode factor and reverse saturation current,"WSEAS Trans. Syst., vol. 7, no. 5, pp. 568–579, 2008.

[21] Ahmed K. Abdelsalam, Ahmed M. Massoud , Shehab Ahmed, and Prasad N. Enjeti, "High-Performance Adaptive Perturb and Observe MPPT Technique for Photovoltaic-Based Microgrids" IEEE Transactions on Power Electronics, Vol. 26, No. 4, April 2011.

[22] W. Xiao and W. G. Dunford, "A modified adaptive hill climbing MPPTmethod for photovoltaic power systems," in Proc. IEEE 35th Annu. Power Electron. Spec. Conf., Jun. 20–25, 2004, vol. 3, pp. 1957–1963.

[23] G. de Cesare, D. Caputo, and A. Nascetti, "Maximum power point tracker for photovoltaic systems with resistive like load," *Solar Energy*,vol. 80, no. 8, pp. 982–988, 2006.

[24] V. Salas, E. Olias, A. Lazaro, and A. Barrado, "New algorithm using only one variable measurement applied to a MPPT," *Solar Energy Mater. Solar Cells*, vol. 87, no. 1–4, pp. 675–684, 2005.

[25] Y. H. Lim and D. C. Hamill, "Simple maximum power point tracker for photovoltaic arrays," *Electron. Lett.*, vol. 36, no. 11, pp. 997–999,2000.

[26] F. Liu, Y. Kang, Y. Zhang, and S. Duan, "Comparison of p&o and hill climbing MPPT methods for grid-connected PV generator,"in *Proc.3rd IEEE Conf. Industrial Electron.*2008.

[27] W.Xiao andW. G. Dunford, "Amodified adaptive hill climbingMPPTmethod for photovoltaic power systems," in *Proc. 35th Annu. IEEEPower Electron. Conf.*, Achan,2004.

[28] L. Piegari and R. Rizzo, "Adaptive perturb and observe algorithm for photovoltaic maximum power point tracking," *IET Renew. Power Gener.*, vol. 4, no. 4, pp. 317–328, 2010.

[29] N. Femia, D. Granozia, G. Petrone, G. Spagnuolo, andM. Vitelli, "Predictive and adaptive MPPT perturb and observe method," *IEEE Trans.Aerosp. Electron. Syst.*, vol. 43, no. 3, pp. 934–950, Jul. 2007.

[30] K.K. Tse,M. T.Ho,H. S.-H. Chung, and S.Y.Hui, "Anovelmaximum power point tracker for PV panels using switching frequency modulation,"*IEEE Trans Power Electron.*, vol. 17, no. 6, pp. 980–989, Nov.2002.

[31]T. Esram, J. W. Kimball, P. T. Krein, P. L. Chapman, and P. Midya, "Dynamic maximum power point tracking of photovoltaic arrays using ripple correlation control," *IEEE Trans. Power Electron.*, vol. 21, no. 5, pp. 1282–1291, Sep. 2006.

[32]T. Noguchi and H. Matsumoto, "Maximum power point tracking method of photovoltaic using only single current sensor," in *Proc. 10th Eur. Conf Power Electron. Applicat.*, Toulouse, France, Sep. 2–4, 2003.

[33]C. Liu, B. Wu, and R. Cheung, "Advanced algorithm for MPPT control of photovoltaic systems," in *Proc. Canadian Solar Build. Conf.*, Mon-treal, QC, Canada, Aug. 20–24, 2004.

[34] SaravananS, RameshBabuN. Incremental conductance based MPPT for PV system using boost and SEPIC converter.ARPNJEngApplSci2015;10(7):2914–9.

[35] KuoYeong-Chau,LiangTsorng-Juu,ChenJiann-Fuh. Novel maximum-power- point-tracking controller for photovoltaic cenergy conversion system.IEEE Trans Ind Electron 2001; 48(3):594–601.

[36]IrisawaKei,SaitoTakeshi,Takanolchiro,SawadaYoshio.Maximumpower point tracking control of photovoltaic generation system under non-uniform insolation by means of monitoring cells.In:ProceedingsoftheIEEEcon-ference on photovoltaic specialist;2000.p.1707–1710.

[37] WuWenkai, PongratananukulN, QiuWeihong, RustomK, KasparisT, Batarseh I. DSP-based multiple peak power tracking for expandable power system. In: Proceedings ofthe 18thAnnualIEEEconferenceonaappliedpowerelectro- nics; 2003.p.525–530.

[38]SoonTeyKonMekhilefSaad.Modifiedincremental conductance algorithm for photovoltaic system under partial shading conditions and load variation .IEEE Trans Ind Electron 2014;61(10):5384–92.

[39] Hiren Patel, Vivek Agarwal. Maximum power point tracking scheme for PV systems operating under partially shaded conditions. IEEE Trans Ind Electron 2008;55(4):1689–98.

[40] Weidong Xiao, Dunford WilliamG ,Palmer PatrickR, Antoine Capel. Applica- tion of centered differentiation and steepest descent to maximum power point tracking. IEEE Trans Ind Electron2007;54(5):2539–49.

[41] Fangrui Liu, Shanxu Duan, FeiLiu, BangyinLiu, YongKang.A variable step size INC MPPT method for PV systems. IEEE Trans Ind Electron 2008;55(7):2622–8.

[42]PandeyAshish,Dasgupta Nivedita, Mukerjee AshokK. Design issues in imple- menting MPPT for improved tracking and dynamic performance .In: Proceedings of the IEEE conference on industrial electronics,2006.p.4387–4391.

[43] Qiang Mei, Mingwei Shan, Liying Liu, Guerrero JosepM. A novel improved variablestep –size incremental-resistance MPPT method for PVsystems. IEEE Trans Ind Electron 2011;58(6):2427–34.

[44] TanCheeWei,GreenTimC,Hernandez-Aramburo CarlosA. Animproved maximum power point tracking algorithm with current-mode controlfor photovoltaic applications. In :Proceedings of the IEEE international conference PEDS; 2005.p.489–494.

[45] Hsieh Guan-Chyun,Hung-IHsieh,TsaiCheng-Yuan, Wang Chi-Hao. Photovoltaic power-increment-aided incremental-conductance MPPT with two- phased tracking. IEEE Trans Power Electron2013;28(6):2895–911.

[46] FarajiRasoul, Fadaeinedjad Roohollah, Chavoshian MohammedReza.FPGA-

basedrealtimeincrementalconductance maximum power point tracking controller for photovoltaic systems.IET Power Electron 2014;7(5):1294–304.

[47] Petrone Giovanni, Spagnuolo Giovanni, Vitelli Massimo. Analytical model of mismatched photovoltaic fields bymean so flambert W-function. Sol Energy Mater Sol Cells 2007;91 (18):1652–7.

[48] Kwon Jung-Min,NamKwang-Hee, KwonBong-Hwan. Photovolatic power conditioning system with line connection.IEEETransIndElectron2006;53 (4):1048–54.

[49] Lin Chia-Hung,HuangCong-Hui,DuYi-Chun,ChenJian-Liung.Maximum photovoltaic powertracking for the PVarray using the fractional-order incremental conductance method. Appl Energy2011;88(12):4840–7.

[50]AbdulRahmanNH,OmarAM,MatSaatEH.Amodification ofvariablestepsize INC MPPTin PVsystem.In: Proceedingsof theI EEE7thinternationalcon-ference on power engineering and optimization;2013.p.340–345.

[51] Lian KL ,Jhang JH, Tian IS "A maximum power point tracking method based on perturb-and-observe combined with particles warm optimization". IEEEJ Photovolt2014;4(2):626–33.

[52] Ishaque Kashif, Zainal Salam."A deterministic particle swarm optimization maximum power point tracker for photo voltaic system under partial shading condition." IEEE Trans Ind Electron2013;60(8):3195–206.

[53] Moradi MH, Reisi A R. "A hybrid maximum power point tracking method for photo voltaic systems. SolEnergy 2011; 85: 2965–76.

[54] Moradi MH, Tousi SMR, Nemati M,Basir NS,Shalavi N. "A robust hybrid method for maximum power point tracking in photo voltaic systems.Sol Energy 2013;94:266–76.

[55]Kinattingal Sundareswaran, Peddapati Sankar, P. S. R. Nayak, Sishaj P. Simon, and Sankaran Palani, Enhanced Energy Output From a PV System Under Partial Shaded Conditions Through Artificial Bee Colony, ieee transactions on sustainable energy, vol. 6, no. 1, january 2015.

[56] W. Gao, S. Liu, and L. Huang, "A novel artificial bee colony algorithm based on modified search equation and orthogonal learning," *IEEE Trans.Cybern.*, vol. 43,pp.1011–1024,2013.

[57] Kinattingal Sundareswaran, Sankar Peddapati and Sankaran Palani, "MPPT of PV Systems under Partial Shaded Conditions Through a Colony of Flashing Fireflies" IEEE Transactions on Energy Conversion, Vol.29,pp.463-472, 2014.

[58] Iztok Fister, Matjaz Perc, Salahuddin M. Kamal and Iztok Fister, "A review of chaos-based firefly algorithms: Perspectives and research challenges", Applied Mathematics and Computation, Vol. 252, pp. 155–165, 2015

[59] P. Sarmila Devi and S. Bharath, "Firefly Algorithm Based Approach for Stability Enhancement in Interconnected Power System Using PSS", International Journal of Emerging Technology and Advanced Engineering, Certified Journal, Vol. 5, No. 4, April 2015

[60] Eisa Bashier M Tayeb, "Faults Detection in Power Systems Using Artificial Neural Network", American Journal of Engineering Research (AJER), Vol. 02, No. 06, pp-69-75, 2013.