MPPT Methods for PV Systems Review Based on Tracking Nature

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Abstract: *An efficient maximum power point tracking (MPPT) method plays an important role to improve the efficiency of a photovoltaic (PV) generation system. This study provides an extensive review of the current status of MPPT methods for PV systems which are classified into eight categories. The categorization is based on the tracking characteristics of the discussed methods. The novelty of this study is that it focuses on the key characteristics and eleven selection parameters of the methods to make a comprehensive analysis, which is not considered together in any review works so far. Again, the pros and cons, classification and immense comparison among them described in this study can be used as a reference to address the gaps for further research in this field. A comparative review in tabular form is also presented at the end of the discussion of each category to evaluate the performance of these methods, which will help in selecting the appropriate technique for any specific application.*

Keywords: *MPPT; PV System; MPPT Controller; P&O.*

I. Introduction

The steady increase in the level of greenhouse gas emissions and fuel costs are the main motive behind the attempt to use different sources of renewable energy [1, 2]. Among various sustainable sources of energy, the solar energy is a suitable one because it is clean, free from emission and easy to change directly to electricity utilizing a photovoltaic (PV) system [2–4]. The generation of PV power has demonstrated a noteworthy potential in satisfying the demand for energy. Up to the year 2016, the worldwide operation of the sun-oriented power generation capacity has ascended to 302 GWp, which is enough to supply 1.8 per cent of the world energy demand. The solar power generation capacity has increased by nearly 100 GWp in 2017, which is about 31 per cent more from 2017 [5, 6]. However, the extensive use of a PV system is not so common because of its high starting cost. Again, there is no assurance that the energy delivered from PV exhibits steady output since it relies completely on the sun-oriented irradiance and the surrounding temperature of the PV modules, cell region, and load. For efficient operation of the PV cell under prevailing climatic conditions, an appropriate mechanism is necessary for achieving maximum power from it, which is considered as a maximum power point tracking (MPPT) in the literature. The MPPT increases the efficiency and lifetime of the PV module [7, 8].Researchers around the world create various methodologies to take out as much power as could reasonably be expected from sustainable power sources and particularly, from the PV panels. Until now, a large number of MPPT algorithms are accessible in the literature for both off-grid and grid associated PV systems [9]. The selection of a specific MPPT system from the various existing MPPT methods is a confounding errand since every method has certain focal points and disadvantages [10]. For example, the hill climbing (HC) [11] and perturb and observe (P&O) [1, 2] methods are broadly utilized as MPPT algorithms because of their simple execution and fewer sensor necessities. The incremental conductance (INC) algorithm [12], which looks at incremental and momentary conductance of PV systems, can track the maximum power point (MPP) of a PV system and exchange high PV power to the load. The research work presented in [13] clarifies the misconception between the widely used P&O and INC algorithms and shows that they are almost highly identical under steady-state and transient conditions. It is shown that they both have similar mathematical expression except that the INC ignores the higher- order term in the discrete differentiation of the power. The sliding control (SC) method, however, complex in equipment usage yet, is more precise than ordinary methods [14]. The classical algorithms, such as P&O, INC, HC, fuzzy logic and neural network, cannot find the global MPP (GMPP) under partial shading condition (PSC) [15]. A comparison among various global MPPT (GMPPT) methods based on meta-heuristic algorithms is given in [16]. It is concluded that particle swarm optimisation (PSO) and Cuckoo search (CuS) algorithms based trackers ensure the convergence to the GMPP and the tracking performance of the CuS algorithm is better than the PSO. For effectively tracking the MPPT of a PV system, a model-free spline-guided Jaya algorithm is proposed in [17], which is able to perform efficiently under PSC and also provides faster convergence speed. An MPPT technique based on temperature described in [18] needs a fewer number of sensors than customary strategies. This technique is straightforward in execution and is economical too. The bisection search theorem- based MPPT, detailed in [19], is generally utilized when the PV array shows at least two neighborhood MPPs under changing climatic conditions, where the utilization of different methods is a troublesome undertaking.

II. MPPT controller

The system that operates the PV in such a way to extract maximum power is termed as the MPPT controller. If the controller works deliberately at MPP, independent of the climatic condition, the efficiency of the PV system is enhanced. This should be possible by legitimately coordinating PV source with the load for any climate condition to accomplish maximum power production. There are two processes by which maximum power can be extricated from the PV array and they are: mechanical and electrical tracking. In mechanical tracking, the PV panel direction changes according to the changes of months and seasons throughout the year, while in electrical tracking, the I − V curve is used for locating MPP [20] MPPT is an integral component of modern power systems, which ensures the penetration of maximum power to the load/batteries/motors and the power grid, for off-grid and on-grid applications, respectively. Since the conversion rate of sun energy to electrical energy of PV arrays is still low and the solar irradiance is not always uniform, the MPPT controller finds its widespread application in PV plants. A brief discussion on the necessity of the MPPT controller is presented.

Need for an MPPT controller

Any environmental changes impose imperatives on power production from a sustainable power source. Especially, the impact is more serious in solar and wind energy systems. Additionally, wind and solar systems confront challenges on (i) changing climatic conditions and (ii) grid incorporation. Henceforth, solar PV and wind energy conversion systems embrace MPPT procedures to give supportable power output [21]. For this reason, it is necessary to ensure that there exists an MPP in I − V and P − V curve for variable irradiation and temperature. This MPP continuously moves its position when any environmental change happens. Therefore, MPPT controllers are designed to continue the tracking of MPP and they form an indispensable piece of the PV system. The presence of a controller adequately modifies the resistance seen by the panel and consequently, urges the panel to work nearer to MPP [22]. Efficient MPPT controllers are essential to modify the operating point of the load associated with changing the duty cycle of the converter. Essential information about which method is better for a particular application. These selection parameters are used only for making comparison among the methods of each categorized MPPT method, not to classify the methods into categories.

III. MPPT controller under PSC

Some well-recognized MPPT methods under uniform irradiance and PSC are surveyed for the comparison among the PSC supported MPPT methods. The methods are compared in terms of six selection parameters, such as PV array dependency, convergence speed, periodic tuning, complexity, analogue/digital in nature, and sensitivity. It is seen that most of the methods under PSC are digital in nature and highly complex. Moreover, in terms of convergence speed, periodic tuning and PV array dependency, the PSO, genetic algorithm (GA), differential evolution (DE), biological swarm chasing (BSC), PV output senseless (POS), SC, firefly algorithm (FA) and ant colony optimization (ACO) performs better under PSC than the other classical methods. However, as the characteristics of the PV array under PSC comprises many local MPPs and one global, the classical MPPT algorithms cannot accurately track the GMPP. Therefore, the GMPPT algorithm is needed [23]. In the literature, the GMPPT algorithm is classified into two classes [24] a) firmware-based and (b) hardware architecture-based algorithms. The firmware-based GMPPT methods use the hybrid approach by combining two MPPT algorithms. Firstly, the approximate GMPP is located using search algorithms and then, it is accurately tracked using classical MPPT algorithms. The hardware architecture-based algorithms are related to the power converter topology and design of the PV system. Soft computing techniques such as PSO, grey wolf optimization (GWO), and CuS optimization can tackle the GMPP of a PV system under the same PSC [16]. However, these techniques suffer from high oscillations around the GMPP and they cannot dynamically track the new GMPP when it changes its position. To solve these problems, a hybrid GWO–fuzzy logic control (FLC) algorithm is proposed in [25], which is able to track dynamic GMPP. The global perturbed-based extreme seeking (GPESC) scheme is proposed in [25] and the ability of this scheme to track the GMPP is analyzed for both static and dynamic PV patterns which shows a high value of tracking accuracy (99.99%).

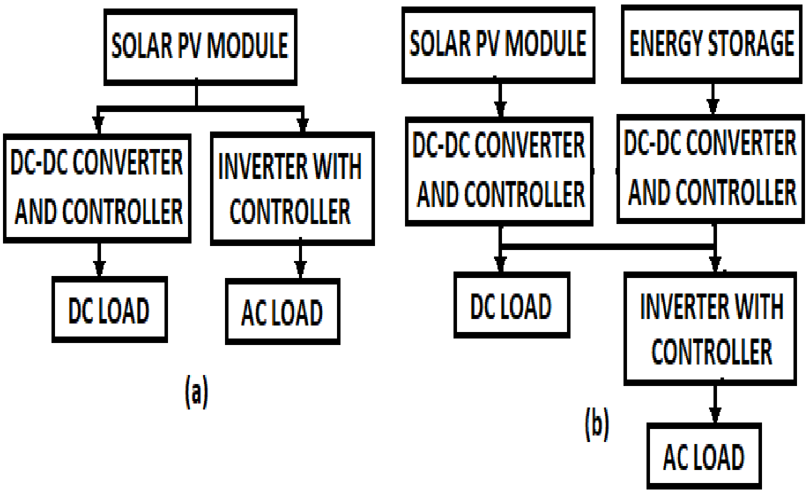

Figure 1: Block diagram of stand-alone PV system (a) direct connected system without storage, (b) with energy storage and through dc-dc converter

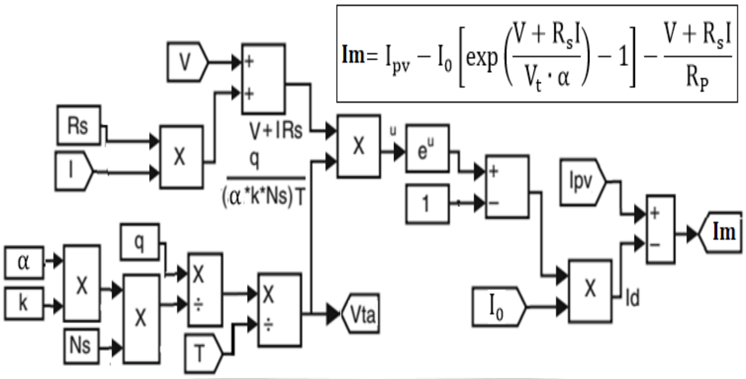

Figure 2: Simulink model for calculating I_m

IV. Review of various MPPT algorithms

Owing to its versatile use, researchers attempted a lot to soak up the maximum amount of power from the panel. Until now, a lot of MPPT methods have been developed. Each technique has its own types of operation processes, advantages, disadvantages, and applications. To classify the available methods there is no proper assessment since one might be useful for a particular application and not for other, again one can be extremely efficient but another is not. In this review work, the discussed 50 methods that are classified into eight groups based on their tracking nature.

Conventional methods

The P&O, INC, and HC methods and their modifications are classified as conventional methods as these methods have existed for decades. The details of these conventional methods are listed in the following sections.

Table 1 Conventional methods based MPPT and their comparison

V = voltage, *I* = current, EX = expensive, INEX = inexpensive.

Properties	P&O	Modified P&O	INC	Modified INC	HC	Modified HC
PV array dependency	no	no	no	no	no	no
true MPPT	yes	yes	yes	yes	no	no
analogue or digital	both	digital	digital	digital	both	both
periodic tuning	no	no	no	no	no	no
convergence speed	normal or low	fast	normal or low	medium	normal	fast
complexity	low	complex	low or medium	high	low	low
sensed parameter	*V, I*	*V, I*	*V, I*	*V, I*	*V, I*	*V, I*
cost	EX	EX	EX	EX	INEX	INEX
prior training	no	no	no	no	no	no
stability	not stable	not stable	not stable	not stable	not stable	not stable
efficiency	96.98% [9]	96.07% [9]	97% [9]	96.95% [9]	54.10% [54]	65.68% [54]

V. Conclusion

Improvements in the efficiency of the solar PV system by extracting maximum power is presently one of the key challenges in research sectors of renewable energy. In that sense, the concept of the MPPT controller is found to be a valuable concept as it maximises the output power delivered by the solar PV module. A lot of articles have been already published for presenting the detailed analysis of several MPPT methods. In this review work, the discussed 50 methods are classified into eight categories based on the nature of the algorithm. The MPPT methods are detailed in this study along with their pros and cons, which signify that the selection of the MPPT technique should be based on the specific application and requirement of the utility. A tabular comparison is also presented at the end of each category, which may be a striking apparatus to the utility of choosing the most productive and perfect kind of MPPT to satisfy the prerequisites of both operators and consumers. This data may find an alluring source to help the engineers in setting with the predominant mechanical scenario.

References

[1] Reisi, A.R., Moradi, M.H., Jamasb, S.: 'Classification and comparison of maximum power point tracking techniques for photovoltaic system: a review', Renew. Sustain. Energy Rev., 2013, 19, pp. 433–443

[2] Knez, M., Jereb, B.: 'Solar power plants – alternative sustainable approach to greener environment: a case of Slovenia', Sustain. Cities Soc., 2013, 6, pp. 27–32

[3] Roy, N.K., Das, A.: 'Prospects of renewable energy sources', in Islam, M.R., Roy, N.K., Rahman, S. (Eds.): 'Renewable energy and the environment' (Springer, Singapore, 2018, 1st edn.), pp. 1–39

[4] Hill, J.S.: 'Global solar market demand expected to reach 100 Gigawatts in 2017, says solarpower Europe', 2017. Available at https://cleantechnica.com/ 2017/10/27/global-solar-market-demand-expected-reach-100-gw-2017- solarpower-europe/, accessed 05 November 2017

[5] International Energy Agency: 'Snapshot of global photovoltaic markets 2017', 2017. Available at http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/IEA-PVPS-A Snapshot of Global P V-1992-2016-1.pdf, accessed 05 November 2017

[6] P. Mahapatra and C. Gupta, *Study of Optimization in Economical Parameters for Hybrid Renewable Energy System*, Res. J. Eng. Technol. … 39 (2020).

[7] Bahgat, A.B.G., Helwa, N.H., Ahmad, G.E., et al.: 'Maximum power point tracking controller for PV systems using neural networks', Renew. Energy, 2005, 30, (8), pp. 1257–1268

[8] Bendib, B., Belmili, H., Krim, F.: 'A survey of the most used MPPT methods: conventional and advanced algorithms applied for photovoltaic systems', Renew. Sustain. Energy Rev., 2015, 45, pp. 637–648

[9] C. Gupta and V. K. Aharwal, *Optimizing the Performance of Triple Input DC-DC Converter in an Integrated System*, J. Integr. Sci. Technol. **10**, 215 (2022).

[10] Teulings, W.J.A., Marpinard, J.C., Capel, A., et al.: 'A new maximum power point tracking system'. Proc. 24th Annual IEEE PESC, Seattle, WA, USA, 1993, pp. 833–838

[11] Wasynezuk, O.: 'Dynamic behavior of a class of photovoltaic power systems power apparatus and systems', IEEE Trans. Power Appar. Syst., 1983, PAS-102, (9), pp. 3031–3037

[12] Sera, D., Mathe, L., Kerekes, T., et al.: 'On the perturb-and-observe and incremental conductance MPPT methods for PV systems', IEEE J. Photovoltaics, 2013, 3, (3), pp. 1070–1078

[13] A. Dwivedi and Y. Pahariya, *Design and Analysis of Hybrid Multilevel Inverter for Asymmetrical Input Voltages*, J. Electr. Eng. Technol. (2021).

[14] Bizon, N.: 'Global extremum seeking control of the power generated by a photovoltaic array under partially shaded conditions', Energy Convers. Manage., 2016, 109, pp. 71–85

[15] Rezk, H., Fathy, A., Abdelaziz, A.Y.: 'A comparison of different global MPPT techniques based on meta-heuristic algorithms for photovoltaic system subjected to partial shading conditions', Renew. Sustain. Energy Rev., 2017, 74, (6), pp. 377–386

[16] Khan S, Gupta C. An optimization techniques used for economic load dispatch. Int J Adv Technol Eng Res (IJATER). 2014;4(4).

[17] Coelho, R.F., Concer, F.M., Martins, D.C.: 'A MPPT approach based on temperature measurements applied in PV systems'. Proc. IEEE Int. Conf. on Sustainable Energy Technologies (ICSET), Kandy, 2010, pp. 1–6

[18] Wang, P., Zhu, H., Shen, W., et al.: 'A novel approach of maximizing energy harvesting in photovoltaic systems based on bisection search theorem'. Proc. 25th Annual IEEE Applied Power Electronics Conf. and Exposition, Palm Springs, CA, 2010, pp. 2143–2148

[19] A. Hridaya and C. Gupta, *Hybrid Optimization Technique Used for Economic Operation of Microgrid System*, Academia.Edu **5**, 5 (2015).

[20] Karami, N., Moubayed, N., Outbib, R.: 'General review and classification of different MPPT techniques', Renew. Sustain. Energy Rev., 2017, 68, pp. 1–18

[21] Takun, P., Kaitwanidvilai, S., Jettanasen, C.: 'Maximum power point tracking using fuzzy logic control for photovoltaic systems'. Proc. International Multiconference of Engineers and Computer Scientists (IMECS), Hong Kong, 2011, vol. 2, pp. 1–5

[22] V. Meena and C. Gupta, *A Review of Design , Development , Control and Applications of DC − DC Converters*, 28 (2018).

[23] Villalva, M.G., Gazoli, J.R., Filho, E.R.: 'Comprehensive approach to modeling and simulation of photovoltaic arrays', IEEE Trans. Power Electron., 2009, 24, (5), pp. 1198–1208

[24] Ishaque, K., Salam, Z., Syafaruddin, : 'A comprehensive MATLAB Simulink PV system simulator with partial shading capability based on two-diode model', Sol. Energy, 2011, 85, (9), pp. 2217–2227

[25] Hua, C., Lin, J.: 'An on-line MPPT algorithm for rapidly changing illuminations of solar arrays', Renew. Energy, 2003, 28, (7), pp. 1129–1142