Critical Evaluation of Offline MPPT Techniques of Solar PV for Stand-Alone Applications

Mohammad Asim, Mohd Tariq, M.A. Mallick, Imtiaz Ashraf, Supriya Kumari and Akash Kumar Bhoi

Abstract This paper critically presents the analysis of the performance of offline maximum power point tracking techniques such as voltage- and current-based MPP technique, look-up table method, and curve fitting-based MPP technique. Based on the analysis presented in the paper, authors have selected offline voltage-based MPPT technique for using in their modeling and simulation study for stand-alone applications. An offline voltage-based MPPT technique which is capable of tracking MPP has been selected because of numerous advantages it offers such as simple and low cost of implementation. The modeling has been done in MATLAB®/ SIMULINK simulation environment, and MPPT technique is developed and implemented by taking a variable resistance as a load. To remove the limitation of the momentarily interruption in power delivery to the load due to measurement of the open circuit voltage (V_{oc}), a pilot PV panel of same rating to that of main PV panel is used in the paper to calculate V_{oc}. It resulted in an increase in efficiency as more energy can be delivered to the load as the main panel is never disconnected to calculate V_{oc}. The simulation results are presented and discussed in the paper, and the results shows that the MPP is tracked under changing atmospheric conditions such as variation in temperature and insolation. The study presented in the paper will help the researchers/engineers/professionals in the industry to implement the

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MPP technology at large scale thus making India a self-reliant country on tapping solar energy resources.

Keywords MPPT · Offline technique · Constant voltage · Photovoltaic Look-up table · Curve fitting

1 Introduction

The world relies on coal, oil, and gas for most of the current energy needs. The energy demand is continuously on the rise [1, 2]. The conventional energy sources are depleting, which may cause devastating consequence on the global quality of life.

The security of global energy is an issue as most of the gas and oil reservoirs are with few nations. The security concerns have led leaders all over the world to look for alternative energy sources. Moreover, an issue such as global temperature rise due to greenhouse gas emissions, which is primarily caused by burning of fossil fuels, has aggravated the issue to for renewable energy resources. The increase use of renewable energy resources and improving overall conversion efficiency is one of the best possible conditions to energy crisis [3, 4].

Renewable energy is energy that is generated from natural process that are continuously republished which includes wind, sunlight, tides, water, geothermal heat, and various form of biomass. These energies have low environmental impact and are being seen as an answer to the global warming issue [5, 6]. Most renewable energy ultimately comes from sun. The solar power is a complete renewable energy source. It produces no noise pollution as compared to other, and very little maintenance is required, as there is no moving part. The solar-powered panels are easy to install.

The drawbacks of solar are being high initial cost, weather dependent, and occupy a lot of space. To maximize the efficiency of a solar PV array, the PV array is made to operate at MPP, irrespective of changing atmospheric conditions [7, 8]. Maximising the efficiency is required especially when the electrical drives are operated from PV [8]. Maximum power generation can be achieved by matching PV source with load for any given atmospheric condition. The MPP can be tracked in two ways i.e., mechanical tracking and electrical tracking. In mechanical tracking, the PV panel orientation is changed physically according to the movement of sun. The positions of PV panels are precalculated according to the length of the day and seasons. The electrical tracking is done by tracking P–V or I–V curve of PV panel, and the panel is made to operate around MPP with the help of power electronic devices [7].

This paper aims to assess the various offline MPPT techniques such as voltage- and current-based MPPT techniques, look-up table method, and curve fitting method. These methods are discussed in terms of tracking speed, applications, number of sensors required, complexity, and cost. The effect due to various weather conditions, variation in isolation, and variation in temperature is discussed. Finally, the MATLAB®/Simulink for voltage-based MPPT for resistive load is discussed.

2 Offline MPPT Techniques

MPPT techniques are broadly classified as offline method, online method, and hybrid method on the basis of technique used to track MPP. Offline control technique calculates MPP using technical data of PV panels such as open circuit voltage, short circuit current, and P–V and I–V curves. Offline methods have low cost compared with online method, but performance wise online methods are better.

Online method used real-time data such as voltage and current to track MPP. This method does not require the measurement of solar insolation and temperature. Online methods do not rely on model of solar cell and are also called model-free method.

Offline method uses reference signal such as open circuit voltage (V_{oc}), short circuit current (I_{sc}), solar insolation, and temperature which is used to generate the control signal to track MPP. The instantaneous value of voltage and current of PV panel is used to generate control signal to track MPP in case of offline method (Fig. 1).

Hybrid method is a combination of offline and online method. The MPP is tracked in two steps. The first step which is offline method places the operating point close to MPP and in second step which is online method fine-tunes the operating point to MPP.

2.1 Curve Fitting-Based MPPT

It is an offline method where in addition to technical data, panel characteristics other details such as output equation of PV panel in terms of the voltage corresponding to the MPP is calculated based on the mathematical model and equation used. The operating point is made to move to MPP. This method though simple has the disadvantage that prior knowledge of PV model and mathematical equation are required. It requires large number of calculation; hence, speed is less, and large memory is required.

2.2 Constant Voltage Method

The maximum power point voltage V_{mpp} and open circuit voltage V_{oc} have linear relationship for different values of solar insolation and temperature. Equation (1) is

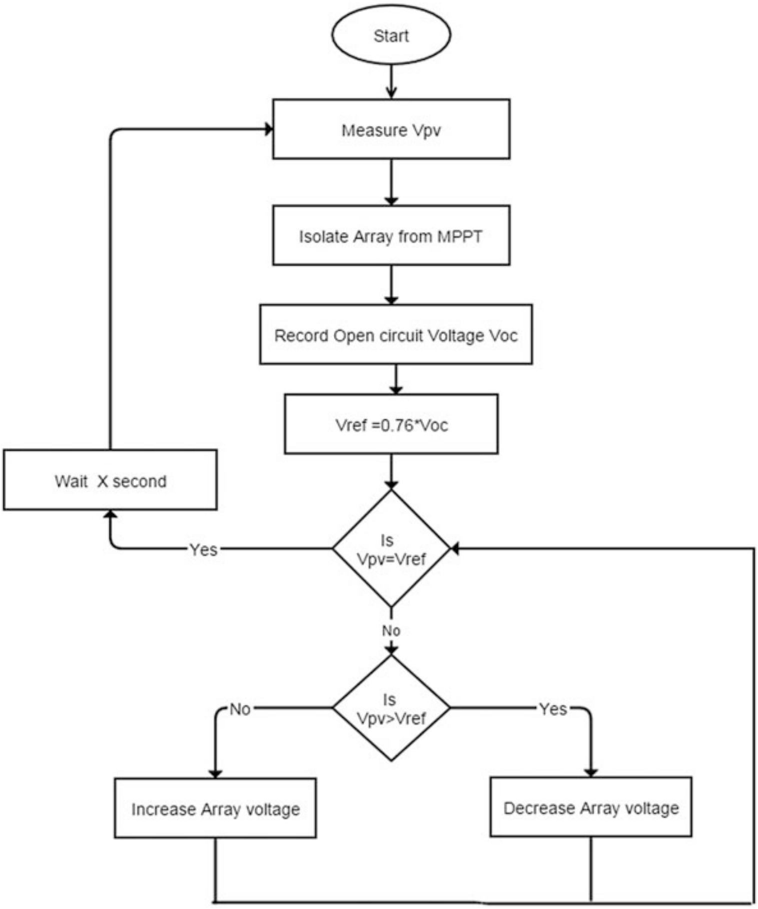

Fig. 1 Constant voltage algorithm

the basis of constant voltage method where K is called voltage factor whose value varies from 0.7 to 0.95.

$$V_{mpp} = K \cdot V_{oc} \tag{1}$$

There are basically two types of constant voltage technique available in the literature [9–11]. In one method, we isolate the solar panel to calculate V_{oc}, then by using Eq. (1), correct operating point is calculated for a particular value of K whose value is depend upon the material of solar cell. Then, the array voltage is adjusted till V_{mpp} is reached.

The drawback of this method is it is difficult to choose optimal value of K which varies in the range of (73–80)%. Its efficiency is relatively low.

The other constant voltage method is the use of pilot panel to calculate open circuit voltage. A pilot solar panel of same characteristic as that of main solar panel is used to calculate V_{oc}, which eliminates the loss of PV power during V_{oc} measurement as in previous method of constant voltage. The drawback of this method is that it is costlier as an extra pilot panel is being used.

$$I_{MPP} = K_I I_{sc} \quad (2)$$

The current-based MPPT method is based on Eq. (2) where K_I is called current factor whose value varies from 0.7 to 0.9 which depends upon characteristics of panel and cell material.

The voltage-based MPPT works on the principal that MPP generally lies from 0.7 to 0.95 of V_{oc} [12]. The pilot panel of same rating of main panel is used to calculate V_{oc}. This value is used as reference voltage. The error signal obtained is based through a PI block and then compared with a high-frequency triangular wave. The output obtained due to pulse width modulation (PWM) is fed to a DC–DC step-down converter. The duty cycle of the converter keeps charging till the PV panel voltage becomes equal to MPP voltage. The complete MATLAB model is shown in Fig. 2. The model in Fig. 3 shows that a pilot panel is being used to calculate V_{oc}.

The simulation was carried out up to 20 s for constant temperature 26 °C, $N_s = 4$, $N_p = 4$, and various insolation conditions of PV modules. The different outputs for different insolations from 100 to 30 mW/cm^2 for PV array are shown in Table 1.

Here, N_s is the number of series connected modules, and N_p is the number of parallel connected modules. The motor efficiency or load matching factor is tabulated in Table 1. The array efficiency is calculated as $(P_{max}/P_{Array}) \times 100$ where P_{max} is the output power of the array and P_{array} is output power of the PV array. The motor efficiency tabulated in Table 1 is given by $(P_{motor}/P_{Array}) \times 100$, where P_{motor} is the motor power that PV array can generate at the given ambient

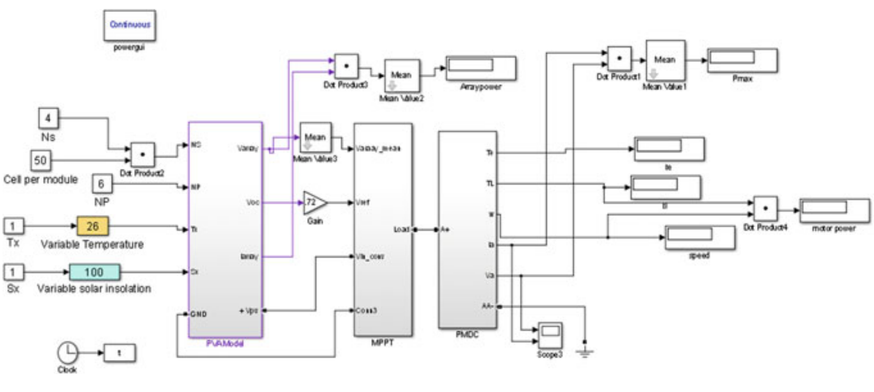

Fig. 2 Simulink model of constant voltage MPPT

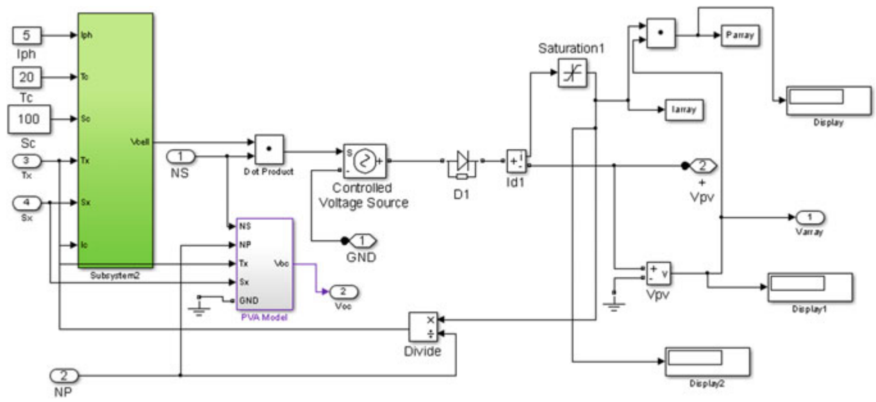

Fig. 3 Details of PVA block

Table 1 Variation of output parameters (WMPPT) at 26 °C

S_x (W/m^2)	P_a	$P_{\max}$ (WMPPT)	P_m (WMPPT)	Eff$_A$ (WMPPT)	Eff$_M$ (WMPPT)
100	1646	1579	1088	95.92	68.9
95	1562	1494.8	1028.44	95.7	68.83
90	1526	1459	1004	95.6	68.81
85	1361	1253.4	862.39	92.1	68.8
80	1275	1148.39	790.78	90.07	68.86
75	1240	1088.72	747.9	87.8	68.71
70	1065	935.07	641.7	87.8	68.63
65	998.1	863.9	592.2	86.6	68.54
60	963.8	834.3	571.7	86.6	68.52
55	821.7	676.4	461.9	82.1	68.28
50	797.3	655.3	447	82.2	68.21
45	648.5	615.8	419.9	82.33	68.18
40	565.7	424.6	281.9	75.07	66.39
35	483.7	329.4	211	68.1	64.05
30	403.9	176.2	98.67	43.62	55.98

conditions. The array efficiency indicates the extent of utilization of PV array and has been plotted in Fig. 4.

At low insolation, a very low array voltage is observed whereas the array current is observed to be very near (proximate/closed) to the array short circuit current. With the above observation, it is stated that the PV array is not operating at the MPP (maximum power point) condition which results in a very poor array efficiency. It is further observed that the highest array efficiency is at the solar insolation of 100 mW/cm^2. At low insolation, the efficiency of the motor is also observed to be lower. Hence, the poor utilization of the motor and array will take place at less

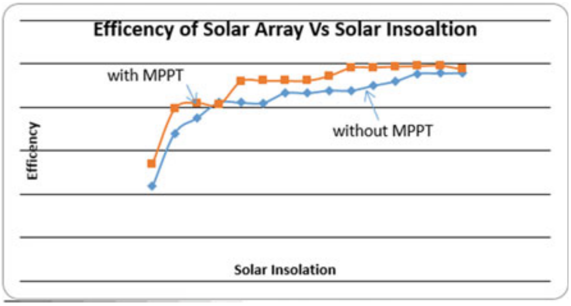

Fig. 4 Array efficiency versus solar efficiency at 26 ° C

Table 2 Variation of output parameters (WMPPT) at 26 °C

S_x (W/m^2)	P_a	$P_{\max}$ (MPPT)	P_m (MPPT)	Eff$_A$ (MPPT)	Eff$_M$ (MPPT)
100	1646	1608.47	1157.45	97.72	71.96
95	1562	1553	1106	99.42	71.21
90	1526	1513.02	1087.71	99.15	71.89
85	1361	1347	944.5	98.97	70.11
80	1275	1256.51	877.54	98.55	69.84
75	1240	1220.9	852.43	98.46	69.82
70	1065	1007.49	694.16	94.6	68.9
65	998.1	922.1	626.2	92.38	67.91
60	963.8	890.2	604.3	92.36	67.88
55	821.7	758.75	514.74	92.34	67.84
50	797.3	734.31	497.64	92.1	67.77
45	648.5	527.1	346.3	81.27	65.69
40	565.7	464.7	297.9	82.14	64.1
35	483.7	384	245.2	79.38	63.85
30	403.9	218.6	126.9	54.12	58.05

WMPPT Without maximum power point tracking
MPPT Maximum power point tracking

insolation. Poor utilization implies that the motor will be running at low speed at low insolation. The motor speed will increase on increasing the solar insolation. The motor will start to run at the rated speed for the insolation of 100 mW/cm^2 (Tables 2 and 3).

2.3 *Look-up Table Methods*

In this method, previous knowledge of PV panel material, panel characteristics, and technical data are stored. The output of PV panel is compared with the previously stored data in the look-up table to track the V_{PV} or I_{PV} to the V_{MPP} or I_{MPP} with the

Table 3 Summary of the major characteristics

MPPT technique	PV AD	Sensor	Complex	TA	Econ.	ETF	ECSR	TTS
Curve fitting	Yes	V	C	Low	NE	Low	Two	Slow
Look-up table	Yes	V, I	S	High	NE	Low	One	Faster
VMPPT	Yes	V	S	Low	NE	High	Two	Slow
CMPPT	Yes	I	S	Low	NE	High	Two	Slow

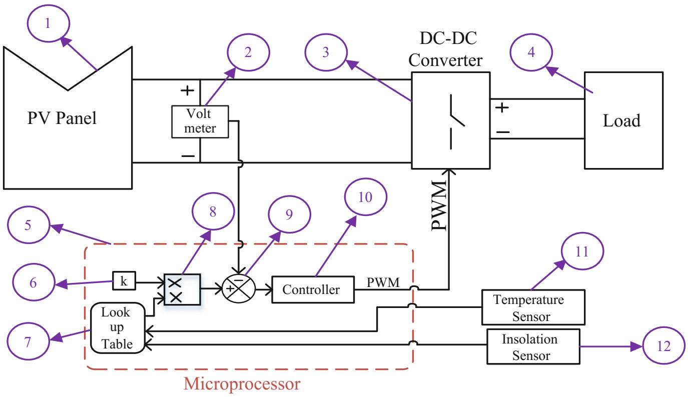

Fig. 5 Look-up table method

help of some converter [13, 14]. A large amount of data need to be stored. For varying atmospheric conditions, the system becomes complex, making the system slow. The block diagram for a look-up table for PV module is shown in Fig. 5.

At solar insolation of 100 mW/cm^2, the array power is 1646 W, whereas at 30 mW/cm^2, the array power is 403.9 W only. The efficiency is in the range 95–82% for solar insolation 100–45 W/m^2, and in the range of 75–43% for solar insolation 40–30 W/m^2 for a directly connected system. The efficiency is seen to increase after MPPT is implemented and is in the range 99–82% for solar insolation 100–45 W/m^2 and in the range of 81–54% for solar insolation 40–30 W/m^2 for a MPPT connected system.

3 Conclusion

The use of energy from PV panels is slowly becoming a reality, and its use is becoming a solution to environmental and energy problems very soon. Various offline techniques have been reviewed with their advantages and disadvantages. An open circuit voltage-based MPPT has been designed and simulated for PMDC load. The efficiency is seen to increase at various solar insolation and temperature. The advantage of this MPPT algorithm is that the loss of energy which takes place when V_{oc} is calculated by disconnecting the load has been avoided by implementing the pilot panel. The pilot panel calculates V_{oc} and sends it as reference signal. The error in calculating MPP between sampling periods is also removed. The setup though bit costly due to addition of pilot panel gives higher efficiency.

References

1. Tariq, M., Shamsi, K.: Application of RET to Develop educational infrastructure in Uttar Pradesh. International Journal of Recent Trend Inengineering, ACEEE. **4**, 187–190 (2010)
2. Tariq, M., Bhardwaj, S., Rashid, M.: Effective battery charging system by solar energy using C programming and microcontroller. Am. J. Electr. Power Energy Syst. **2**, 41–43 (2013)
3. Yongxiu, H., Xu, Y., Pang, Y., Tian, H., Wu, R.: A regulatory policy to promote renewable energy consumption in China: review and future evolutionary path. Renew. Energy **89**, 695–705 (2016)
4. Tariq, M., Yuvarajan, S.: Modeling and analysis of self excited induction generator with electronic load controller supplying static loads. Can. J. Electr. Electron. Eng. **4**(1), 9–13 (2013)
5. Khare, V., Nema, S., Baredar, P.: Solar-wind hybrid renewable energy system: a review. Renew. Sustain. Energy Rev. **58**, 23–33 (2016)
6. Tariq, M., Yuvarajan, S., Wakode, P.: Digital simulation of electronic load controller with reduced THD for self-excited induction generator. IUP J. Electr. Electron. Eng. **6**(4), 36 (2013)
7. Ramli, M.A.M., Twaha, S., Ishaque, K., Al-Turki, Y.A.: A review on maximum power point tracking for photovoltaic systems with and without shading conditions. Renew. Sustain. Energy Rev. **67**(January), 144–159 (2017)
8. Tariq, M., Iqbal, M.T.: Power quality improvement by using multi-pulse AC-DC converters for DC drives: Modeling, simulation and its digitalimplementation, Journal of Electrical Systems and Information Technology, **1**(3) ,255–265, (2014)
9. Elgendy, M.A., Zahawi, B., Atkinson, D.J.: Comparison of directly connected and constant voltage controlled photovoltaic pumping systems. IEEE Trans. Sustain. Energy **1**(3), 184–192 (2010)
10. Tariq, A., Asghar, M.S.J.: Development of an analog maximum power point tracker for photovoltaic panel. In: Proceedings of "the sixth international conference on power electronics and drive systems-PEDS 2005", Kuala Lumpur, Malaysia, Nov 28–Dec 01 (2005)
11. Ahmad, J.: A fractional open circuit voltage based maximum power tracker for photovoltaic arrays. In: International Conference on Software Technology and Engineering, pp. 247–250 (2012)
12. Asim, M., Tariq, M., Mallick, M.A., Ashraf, I.: An improved constant voltage based MPPT technique for PMDC motor. Int. J. Power Electron. Drive Syst. (IJPEDS) **7**(4), 1330–1336 (2016)
13. Tariq, A., Asim, M., Tariq, M.: Simulink based modeling, simulation and performance evaluation of an MPPT for maximum power generation on resistive load. In: 2nd international conference on environmental science and technology, IPCBEE vol. 6 (2011)
14. Asim, M., Tariq, A., Sarwar, A.: Simulation and analysis of a directly coupled solar PV based water pumping system. J. Electr. Eng. **2**(3), 72–81 (2009)

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