Computation of maximum power point tracking of PV module using modified Newton Raphson technique

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Article Info

Article history:

Received Jun 9, 2022
Revised Sep 9, 2022
Accepted Sep 22, 2022

Keywords:

Buck converter
Modified Newton Raphson method
MPPT
Solar power
State flow

ABSTRACT

The maximum power point tracking (MPPT) has been a popular terminology among those researchers who deal with one of the most available renewable energy resources called solar power. Many researchers have evolved and proposed a lot of techniques for tracking maximum power. But each technique has its pros and cons. Some techniques suffer from complexity as far as implementation is concerned, whereas other techniques lack accuracy. In current research work, it has been investigated the MPPT using Newton Raphson (NR) method, which has not yet received a good attention by researchers. After observing its limitation, this method is modified (i.e., abbreviated as modified Newton Raphson method (MNRM)) to make it suitable for extracting the maximum power from PV module. The feasibility and precision of this method depends upon accurate measurement of temperature and irradiation. By using MNRM, the presumption of initial value is close to the voltage corresponding to maximum power, so it leads faster converging to solution through a few rounds of iterations. In order to validate it, a MATLAB/Simulink model is developed and simulated. The proposed method is incorporated in PV module-fed buck converter so as to explore superior performance.

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1. INTRODUCTION

A photovoltaics PV cell is smallest unit of solar power generating unit and its basic characteristic (I~V) is mostly non-linear in nature. The connection of PV cells in series and parallel is known as PV module and the grouping PV modules in series and parallel is known as PV array. The modeling of PV cell is presented by Salmi *et al.* [1]. Since DC-DC converter is major component in solar power unit, so the comprehensive review of various DC-DC converters is detailed and analyzed [2]. The maximum power point tracking MPPT is common phenomenon among researchers in the field of solar technologies and the various techniques of MPPT are focused and compared [3]. In this literature, the comparison includes the positive aspects of each technique and its limitation. Also, it has been discussed about their performances and complexities about their implementation. Anand and Fernandes [4] have elaborated on implementation and power management of solar photovoltaic system. In literature [5]–[7], the researchers have presented the design, simulation and implementation of grid-tied solar power controller integrated with micro-inverter for power supply. The design and simulation for grid connected solar PV system connected with battery backup is presented [8]. For improvement of power quality [9], it is implemented the solar PV system associated with battery storage system based micro-grid operation. The researchers [10], [11] have successfully implemented solar PV-based multi-level inverter for power conditioning in distribution system and induction motor drives for water pumping system respectively. It is also presented analog, multiplier MPPT controller and optimal controller for solar PV based dc power supply for improvement of performances [12], [13]. The comparative study of maximum power point tracking under variable size perturbations is presented [14] and findings are placed. The concept of fuzzy logic controller [15] is applied in case of photovoltaic system for micro-grid system. A novel algorithm of particle swarm optimization (PSO) is extended solar PV system for better performance [16]. Nasir *et al.* [17] have critically investigated for rural electrification in developing nations, The application of single phase to three phase inverter and smart inverter are extended solar PV system [18], [19]. Here it has been focused the method of connectivity of solar inverters. Ogudo and Umenne [20] has presented design for buck-boost converter interfaced with solar PV based power supply. The output voltage of this converter is non-inverting type. A novel adaptive maximum power controller [21] is proposed for photovoltaic system and the parameters of controllers are automatically tuned to meet the performance requirement of PV system. On the other hand, it is proposed a model predictive controller [22]. This is exclusively for bidirectional DC/DC and AC/DC converters. This indicates that both variable output DC/AC and regenerative power feedback/power reversal are possible. Above all, the whole literature review comprises various controllers and modified Newton Raphson method MPPT methods [23]–[30]. In current research work, the MPPT technique is developed using MNRM that leads to faster convergence to the solution, which is later treated as tracking value. This MNRM is incorporated in PV module-fed buck converter and the whole system is simulated with MATLAB/ Simulink.

2. ANALYSIS OF PV MODULE

The solar PV array is formed by connecting the PV modules in series and parallel combinations to acquire the required current and voltage rating. The sum of the individual power rating of the module is equal to the rating of the PV array [31].The basic goal of full power point tracking is to interpret the voltage and current from the solar panel, measure the power, and then display the power to its limit. Multi-stage DC-DC converter manages MPPT, and PWM controls grid current from Inverter. The inverter circuit provides all the activities in a single phase that involve MPPT and grid current power [32]–[37].

The mathematical model of PV system is described by (1) the photo current.

$$I_{ph} = [\, I_{sc} + K_i(T - 298)]\, G/1000 \tag{1}$$

The saturation current is (2).

$$I_o = I_{rs}(T/T_n)^3 \exp\left[\frac{q\, E_{go}(1/T_n - 1/T)}{n\, K}\right] \tag{2}$$

The reverse saturation current (3).

$$I_{rs} = \frac{I_{sc}}{e^{\left(\frac{q\, V_{oc}}{n\, N_s\, K\, T}\right)} - 1} \tag{3}$$

The output current $I = I_{ph} - I_d - I_{sh}$

$$\text{or } I = I_{ph} - N_p I_o\, [\exp\{\frac{q(V + I\, R_s)}{n\, K\, N_s T}\} - 1] - \frac{(V + IR_s)}{R_{sh}} \tag{4}$$

The power is $P = VI$

$$P = VI = V[I_{ph} - I_o\, \{\exp\, (\frac{q(V + I\, R_s)}{n\, K\, N_s T}) - 1\} - \frac{(V + IR_s)}{R_{sh}}] \tag{5}$$

Where
I_{ph}= photo-current (A)
I_{sc}= Short-circuit current (A)
k_i = Short circuit coefficient of the cell(at nominal temperature
25 degrees centigrade and at G= 1000 W/m^2) = 0.0032

T : Operating temperature (degree kelvin)
G: : Solar Irradiation (W/m^2)
V_{oc} : Open-circuit voltage (V)
K : Boltzmann's constant (J/K) = 1.38 e-23
N_s : Number of cells in connected in series
R_s : Series resistance (Ω)
T_n : Nominal temperature (degree kelvin) = 298
q : Electron charge (C) = 1.6e-19 coulomb
n : Ideality factor of the diode =1.3
E_{go} : Band gap energy of the semiconductor (eV) =1.1
N_p : Number of PV modules connected in parallel
R_{sh} : Shunt resistance (Ω)

The parameters of a specific module are given as follows and considered in forthcoming simulation work. I_{sc} =8.21A, k_i = 0.0032, V_{oc} =32.09, N_s=54. N_p=1, R_s= 0.221 Ω, R_{sh} = 415.405 Ω, G <=1000 W/m^2.

In Figure 1, the characteristic of power, current and load conductance (Y) of PV unit with respect to its terminal voltage (V_{pv}) without MPPT are shown. The load conductance ($Y=I_{pv}/V_{pv}$) goes on decreasing from maximum towards zero with respect to gradual increase in terminal voltage of the circuit from zero to open-circuit condition(V_{oc}).The load resistance is reciprocal of load conductance. So higher load conductance leads to lower load resistance and vice-versa. With reference to peak power, there corresponds to current (I_{mp}), voltage (V_{mp}) and conductance (Y_{mp}). So Y_{mp} is the load conductance that corresponds to maximum power. Between peak power to open-circuit voltage, the power falls drastically, as the conductance tends towards zero. Similarly, from short-circuit position (i.e., v=0) to peak power, there is gradual change in increase of power. The I~V characteristic is complex in nature and upon close attention of graph of current and power with respect to voltage, it is noticed that the current fall is significantly small between v=0 to V_{mp} and it is approximated as current source. Beyond V_{mp}, there is drastically fall in current, but the voltage difference between v=V_{mp} and V_{oc} is small, so characteristic beyond v= V_{mp} is approximately treated as constant voltage characteristic.

The MPPT concept has been popular among researchers since more than a decade to explore the possibility of maximizing power at different load. The researchers have evolved various techniques for tracking the point of maximum power and the review paper [3] pertaining to this concept is illustrated. All these techniques lead to determination of tracking maximum power point so as to maximize power for particular load or to utilize the power as per researcher's choice. In current research work, the tracking of maximum power point is accomplished using MNRM and hence to accomplish desired task, a control strategy is developed which is explained in next section.

The buck converter is known as a prominent member among family of DC-DC converter having action similar to DC-DC chopper. This is also utilized now-a-days as a tool in extracting power from solar power unit. With controlled switching of the buck converter, output power can be controlled for desired value. It is assumed that input and output voltage remain constant over the cycle.

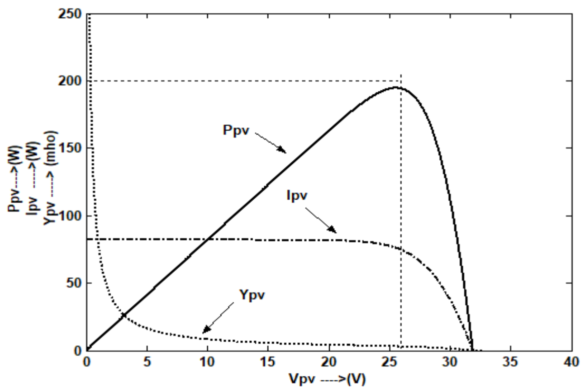

Figure 1. Curves of current, power and conductance with respect to voltage of PV unit at irradiation (G=1000 W/m^2) and temperature (T=30 °C), scale: Ypv-(1:10) , Ipv (1:10), Ppv (1:1)

3. CONTROL STRATEGY

3.1. Determination of V_{mp} by modified Newton Raphson method

In the determination of V_{mp} (i.e., voltage corresponding to maximum power) is necessary to know the boundary between constant current and voltage region. Though various techniques have been evolved by researchers earlier, but in this case, the MNRM technique is utilized to solve this problem.

$$X_{k+1} = X_k - \frac{f(X_k)}{f'(X_k)} \tag{6}$$

Where X_k and X_{k+1} is the k_{th} and $(k+1)_{th}$ iteration value of the f(X) = 0; It is needed the substitution of initial value of the solution X_0 in above equation. The iteration is continued till the difference $|X_{k+1} - X_k|$ is very small, which is order less than 1e-3. For the solution of non-linear equation f(X), there arise two major constraints. One is the substitution of proper initial value, without which there may occur divergence of the solution of f(X) instead of convergence. The second constraint is that many a times, during iteration of above equation, it may so happen that the derivative of $f(X_k)$ in denominator of above equation may be zero. So, this may lead to non-arrival /failure to the solution.

Now these two problems can be attended using following ways. For a fixed PV module, the open-circuit voltage, V_{oc} is highest and fixed with its highest irradiation and lowest temp. The main objective considering lowest temp is that the V_{oc} would increase with decrease in temperature. Secondly, the voltage V_{mp} which corresponds to maximum power lies very close to open-circuit voltage V_{oc} than to it short-circuit position (V=0). Also, the variation in temperature has a least significant impact than variation in irradiation. So based upon above facts, the V_{oc} corresponding to highest irradiation and normal temperature can be determined from mathematical model of PV module or its experimental setup. The accuracy of determining V_{oc} is dependent upon the accurate measurement of parameters for PV module. So, this V_{oc} can be used as initial value in solving NR Method and as this value is very close to V_{mp} and as a result, there will be faster convergence of solution for its non-linear equation. This is the way to attend the 1st problem. The solution for 2nd problem is that in order to overcome the problem for the derivative of $f(X_k)$ getting zero in the denominator of (6), it is added with a tolerance (ε), for which the equation in is modified as (7).

$$X_{k+1} = X_k - \frac{f(X_k)}{f'(X_k) + \varepsilon} \tag{7}$$

Where 'ε' a small value that varies between 1e-4 to 1e-6.

The initial value of variable for solution is the V_{oc} (i.e., the maximum possible open-circuit voltage V_{oc}) and it is treated as X_0. The inclusion of attending problems with above two ways in NRM is referred as MNRM and it would act as full proof for solution. It has been frequently observed that if the substitution of initial value X_0 is close to real solution, then it occurs faster converging to solution.

3.2. Development of mathematical model non-linear equation form for solution of V_{mp}

The determination of V_{mp} that corresponds to maximum power is determined by computing dP/dV=0 using (5).

$$dP/dV = d(IV)/dV = I + V(dI/dV) = 0 \tag{8}$$

Substituting value of 'I' from (4) into (8) and it is simplified as (9).

$$(1 + c\,V)\exp(c\,V) = k \tag{9}$$

where $k = \frac{I_{ph} + I_o - I_{sh}}{N_p I_o} \approx \frac{I_{ph}}{N_p I_o}$
and $c = \frac{q\,(1 + R_s/R_L)}{nKN_s\,T} \approx \frac{q}{nKN_s\,T}$

Since I_{ph} is function of T and G and these two variables are determined by proper sensor, then constants'k'and 'c'are determined and this leads to solution of non-linear equation. In (9) is simplified as (10).

$$f(V) = (1 + cV)\exp(cV) - k = 0 \tag{10}$$

In (10) is the non-linear equation that undergoes MNRM for solution of getting V_{mp} that corresponds to maximum power.

3.3. Flow-chart for implementation of control strategy

The flow-chart for above control strategy is shown in Figure 2. Initially, the measurement of temperature and irradiation is to be measured and these two parameters are necessary to determine the Vmp, voltage corresponding to peak power, from MNRM. This voltage is assumed as reference voltage of buck converter. The buck converter is to be operated under close-loop control during constant voltage region (i.e., between v= V_{mp} and V_{oc}) of I~V characteristic of PV unit. The load voltage and the current through filter inductance are considered as two feedbacks of close-loop control scheme. The error from comparison of reference voltage with actual one is processed through PI controller and then limiter to generate reference current. This reference current is then compared with those of filter inductance and then processed through hysteresis current controller to generate gate pulses of switching device.

For implementation of control strategy, the flow-chart shown in Figure 2 is transformed to MATLAB/Simulink/State flow. The complex logical thought process associated with MNRM is put into State flow block of Simulink. The Simulink model for whole control strategy is shown in Figure 3.

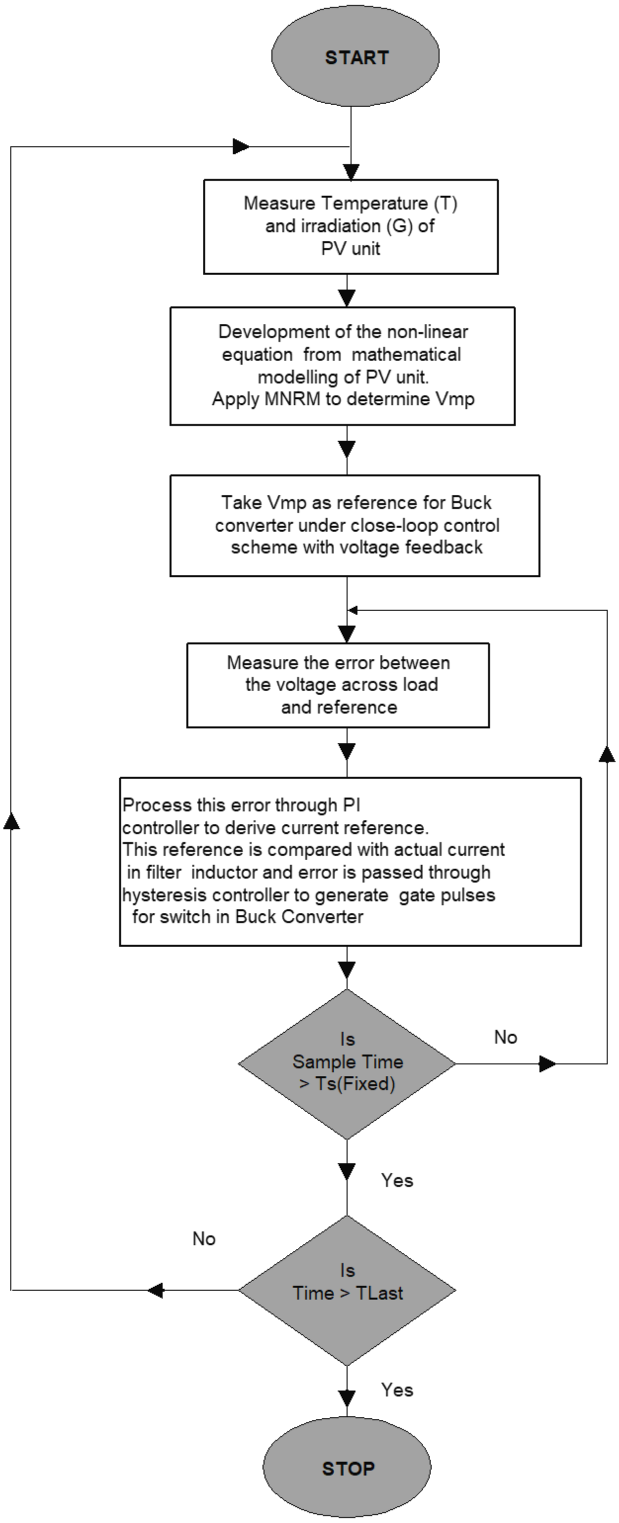

Figure 2. Flow-chart of control strategy

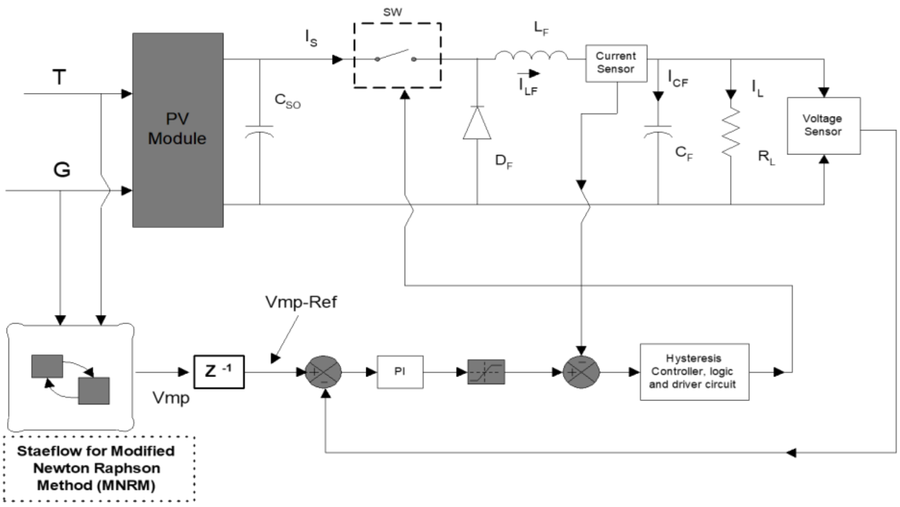

Figure 3. Close-loop control circuit of PV-fed Buck converter usingmodified Newton Raphson method

4. RESULTS AND DISCUSSION

The simulation results from conventional PV module without any close-loop is presented in Table 1. It shows that the variation of current, power and load conductance with respect to variation in voltage. The results of simulation from close-loop control of PV-module fed buck converter is given in Table 2. It shows the load voltage and power with respect to variation in load conductance.

The results of power from Tables 1 and 2 are plotted in Figure 4. It shows the power profile with respect to load conductance under open-loop and close-loop. Similarly, from the results of Table 2, it was plotted a graph for load voltage and power with variation in load conductance in Figure 5. From the observation, it shows that the load voltage remains constant during power from its zero to its maximum value and the load conductance (x-axis) corresponding to maximum power is Y_{mp}. But after the peak power, the close-loop controller fails to oblige. The observation is critically investigated and findings are noted as follows.

Table 1. Power and load voltage of PV module with respect to variation in load conductance (without MPPTand buck-converter) (i.e. at T=30 °C, G=1000 W/m^2, Vref=26.87 V)

Sl. No	Load conductance (Y)mho	Power without MPPT and buck converter(W)	Load voltage (V)
1	0.010	9.58	30.97
2	0.020	19.00	30.83
3	0.040	37.30	30.54
4	0.05	46.2	30.4
5	0.066	60.6	30.15
6	0.100	87.85	29.64
7	0.200	155.0	27.84
8	0.294	187.3	25.24
9	0.33	185	23.59
10	0.5	133.7	16.35
11	1	67.24	8.2

Table 2. Power and load voltage of PV modulewith respect to variation in load conductance (with MPPT and buck-converter) (i.e. at T=30 °C, G=1000 W/m^2, Vref=26.87 V)

Sl. No	Load conductance (Y) mho	Power with proposed method (W)	Load voltage (V)
1	0.010	7.18	26.8
2	0.020	14.05	26.74
3	0.040	28.09	26.53
4	0.05	35.11	26.46
5	0.066	45	26.1
6	0.100	71.87	25.97
7	0.200	121	24.6
8	0.294	171	24.17
9	0.33	174.0	22.85
10	0.5	132.84	16.3
11	1	66.91	8.18

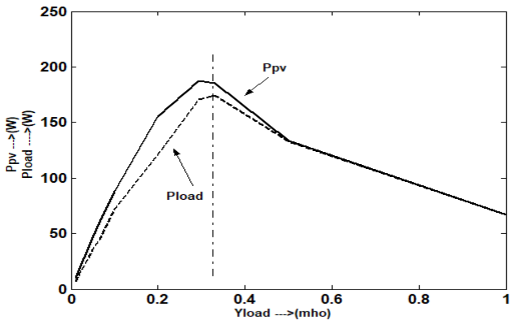

Figure 4. Output power of PV module (Ppv) under open loop and (Pload) under close-loop (i.e. output voltage of PV module-fed buck converter) with respect to variation in load conductance

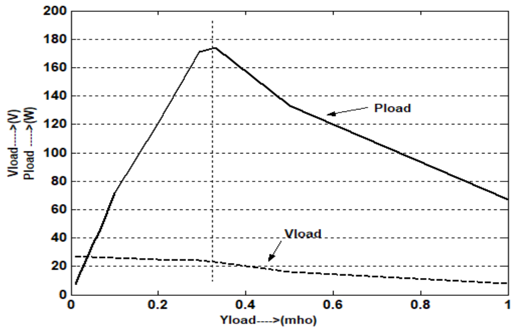

Figure 5. Voltage and power profile with respect to variation in load conductance of PV module-fed buck converter under close-loop operation

The close-loop control of buck converter with input having PV unit is stable under during $V=V_{mp}$ to V_{oc} of I~V characteristic of PV module, which can be characterized as constant voltage (CV) characteristic/region and it is equivalent to Y=0 to Y_{mp} of Figure 5. But in case of constant current characteristics (i.e., from V=0 to V_{mp} of I~V module), the constant current causes filter inductor to saturate early and thus fails to boost the voltage across load. This region is same as falling power with variation in load conductance in Figure 5. So, the former one, which is the constant voltage region of PV module, is considered to interface buck converter with PV unit for stability. Also, the load conductance to be considered in this region must lies in the range (i.e., between Y=0 and $Y=Y_{mp}$) so as to facilitate the satisfactory operation of close-loop control. The design of filter inductance and capacitance is based upon switching frequency and load condition. As the switching frequency is small and variable due to its operation under hysteresis current controller, so upper range of switching frequency is considered to design filter parameters. The design values of filter inductance and capacitance across load are considered as 10 µH and 500 µF respectively. The waveforms of current through filter inductance, filter capacitor, load resistance and voltage across load are shown in Figure 6 for two cycles under steady-state condition during close-loop operation with load resistance of 10 Ohm. The current through the filter inductance (I_{Lf}) is the summation of currents through filter capacitor (I_{Cf}) and load resistance (I_o).

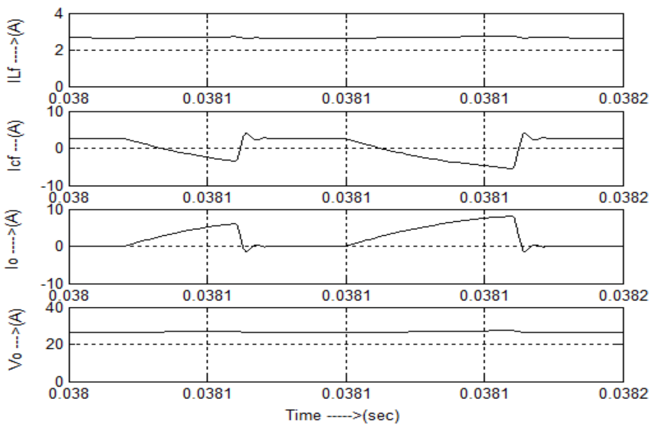

Figure 6. Waveforms of currents through filter inductance, filter capacitor, load resistance and voltage across load under steady-state condition during close-loop operation

5. CONCLUSION

A new concept of tracking maximum power using MNRM is successfully implemented. Here the issue of assumption of initial condition is sorted out using open circuit voltage of PV module, which is very close to the voltage (V_{mp}) corresponding to maximum power. As the assumption of initial value in MNRM is close to the voltage corresponding to maximum power, hence it leads faster converging to solution through a few iterations. But the specialty of this technique is to monitor continuously the measurement of temperature and irradiation of PV unit and the performance of this technique is dependent upon accuracy of sensors tracking above two parameters (i.e., temperature and irradiation). Also, the other feature of this proposed method is that the close-loop operation is implemented for the load conductance varying from zero to Y_{mp} or during constant voltage region of PV module that corresponds to maximum power. Beyond this range, the controller fails to take any action, which is the limitation of the proposed scheme. This scheme is applicable mostly for standalone dc load, where the matter of stabilizing accurate output voltage is not a matter of great concern.

ACKNOWLEDGEMENTS

Author thanks to Biju Patnaik University and Technology, Odisha for providing necessary research facility for carrying out this research work.

REFERENCES

[1] T. Salmi, M. Bouzguenda, A. Gastli and A. Masmoudi, "MATLAB/simulink based modelling of photovoltaic cell," *International Journal of Renewable Energy Research*, vol. 2, no. 2, pp. 213-218, 2012

[2] M. Forouzesh, Y. P. Siwakoti, S. A. Gorji, F. Blaabjerg and B. Lehman, "Step-Up DC–DC converters: a comprehensive review of voltage-boosting techniques, topologies, and applications," *IEEE Transactions on Power Electronics*, vol. 32, no. 12, pp. 9143-9178, 2017, doi: 10.1109/TPEL.2017.2652318.

[3] B. Subudhi and R. Pradhan, "A comparative study on maximum power point tracking techniques for photovoltaic power systems," *IEEE Transactions on Sustainable Energy*, vol. 4, no. 1, pp. 89-98, Jan. 2013, doi: 10.1109/TSTE.2012.2202294.

[4] S. Anand and B. G. Fernandes, "Power management control for solar photovoltaic based DC system," *IECON 2014 - 40th Annual Conference of the IEEE Industrial Electronics Society*, 2014, pp. 4365-4370, doi: 10.1109/IECON.2014.7049159.

[5] M. Billah, S. K. Das, M. T. Islam, M. A. Haque and B. B. Pathik, "Design, simulation and implementation of a grid tied solar power controller integrated with instant power supply technology," *IEEE Innovative Smart Grid Technologies - Asia (ISGT ASIA)*, 2015, pp. 1-6, doi: 10.1109/ISGT-Asia.2015.7387151.

[6] K. Dubey and M. T. Shah, "Design and simulation of Solar PV system," *International Conference on Automatic Control and Dynamic Optimization Techniques (ICACDOT)*, 2016, pp. 568-573, doi: 10.1109/ICACDOT.2016.7877649.

[7] J. Priolkar and A. Anvekar, "Design, simulation and implementation of solar PV based micro inverter," *Biennial International Conference on Power and Energy Systems: Towards Sustainable Energy (PESTSE)*, 2016, pp. 1-5, doi: 10.1109/PESTSE.2016.7516435.

[8] A. Jain, M. D. Vijay, G. Bhuvaneswari and B. Singh, "Design and simulation of a solar powered DC home with grid and battery back-up," *IEEE 7th Power India International Conference (PIICON)*, 2016, pp. 1-6, doi: 10.1109/POWERI.2016.8077197.

[9] W. J. Praiselin and J. B. Edward, "Improvement of power quality with integration of solar PV and battery storage system based micro grid operation," *Innovations in Power and Advanced Computing Technologies (i-PACT)*, 2017, pp. 1-5, doi: 10.1109/IPACT.2017.8245082.

[10] P. Vtas and Y. Pal, "Solar PV array buck-boost converter fed single phase induction motor drives for water pumping," *International Conference on Information, Communication, Instrumentation and Control (ICICIC)*, 2017, pp. 1-5, doi: 10.1109/ICOMICON.2017.8279090.

[11] M. Ghosh Majumder, P. Ranjan Kasari, B. Das and A. Chakraborti, "Solar Photovoltaic array based multilevel inverter for power conditioning in four-wire distribution system," *Third International Conference on Advances in Electrical, Electronics, Information, Communication and Bio-Informatics (AEEICB)*, 2017, pp. 193-197, doi: 10.1109/AEEICB.2017.7972410.

[12] S. S. Nag, S. Mandal and S. Mishra, "Solar PV based DC power supply for rural homes with analog, multiplier-less MPPT controller," *IECON 2017 - 43rd Annual Conference of the IEEE Industrial Electronics Society*, 2017, pp. 2689-2694, doi: 10.1109/IECON.2017.8216452.

[13] W. Xiao, M. G. J. Lind, W. G. Dunford and A. Capel, "Real-time identification of optimal operating points in photovoltaic power systems," *IEEE Transactions on Industrial Electronics*, vol. 53, no. 4, pp. 1017-1026, 2006, doi: 10.1109/TIE.2006.878355

[14] N.S. D'Souza, L.A.C. Lopes, X.J. Liu, "Comparative study of variable size pertubation and observation maximum power point trackers in PV systems," *Electric Power system Reserch*, vol. 80, no. 3, pp. 296-305, 2010, doi:10.1016/j.epsr.2009.09.012.

[15] B. N. Alajmi, K. H. Ahmed, S. J. Finney and B. W. Williams, "Fuzzy-logic-control approach of a modified hill-climbing method for maximum power point in microgrid standalone photovoltaic system," *IEEE Transactions on Power Electronics*, vol. 26, no. 4, pp. 1022-1030, 2011, doi: 10.1109/TPEL.2010.2090903.

[16] R. B. A. Koad, A. F. Zobaa and A. El-Shahat, "A novel MPPT algorithm based on particle swarm optimization for photovoltaic systems," *IEEE Transactions on Sustainable Energy*, vol. 8, no. 2, pp. 468-476, 2017, doi: 10.1109/TSTE.2016.2606421.

[17] M. Nasir, H. A. Khan, A. Hussain, L. Mateen and N. A. Zaffar, "Solar PV-based scalable DC microgrid for rural electrification in developing regions," *IEEE Transactions on Sustainable Energy*, vol. 9, no. 1, pp. 390-399, 2018, doi: 10.1109/TSTE.2017.2736160.

[18] L. U. Monteiro, C. M. Freitasand, and M.D. Bellar, "Improvements on conductance MPPT method applied to a PV string with a single-phase to three-phase converter for rural grid applications," *Advances in Electrical and Computer Engineering*, vol. 19, no. 1, pp. 63-70, 2019, doi: 10.4316/AECE.2019.01009.

[19] R. K. Varma and E. M. Siavashi, "Enhancement of solar farm connectivity with smart PV inverter PV-STATCOM," *IEEE Transactions on Sustainable Energy*, vol. 10, no. 3, pp. 1161-1171, 2019, doi: 10.1109/TSTE.2018.2862405.

[20] K. A. Ogudo and P. Umenne, "Design of a PV based power supply with a non-inverting buck-boost converter," *IEEE PES/IAS Power Africa*, 2019, pp. 545-549, doi: 10.1109/PowerAfrica.2019.8928656.

[21] B. Subudhi and R. Pradhan, "A new adaptive maximum power point controller for a photovoltaic system," *IEEE Transactions on Sustainable Energy*, vol. 10, no. 4, pp. 1625-1632, 2019, doi: 10.1109/TSTE.2018.2865753.

[22] Y. Shan, J. Hu, K. W. Chan, Q. Fu and J. M. Guerrero, "Model predictive control of bidirectional DC–DC converters and AC/DC interlinking converters—a new control method for pv-wind-battery microgrids," *IEEE Transactions on Sustainable Energy*, vol. 10, no. 4, pp. 1823-1833, 2019, doi: 10.1109/TSTE.2018.2873390.

[23] A. Safari and S. Mekhilef, “Simulation and hardware implementation of incremental conductance MPPT with direct control method using cuk converter,” *IEEE Transactions on Industrial Electronics*, vol. 58, no. 4, pp. 1154-1161, 2011, doi: 10.1109/TIE.2010.2048834.

[24] T. Radjai, L. Rahmani, S. Mekhilef, and J. P. Gaubert, “Implementation of a modified incremental conductance MPPT algorithm with direct control based on a fuzzy duty cycle change estimator using dSPACE,” *Solar Energy*, vol. 10, pp. 325-337, 2014, doi: 10.1016/j.solener.2014.09.014.

[25] M. Seyedmahmoudian *et al*., “Simulation and hardware implementation of new maximum power point tracking technique for partially shaded PV system using hybrid DEPSO method,” *IEEE Transactions on Sustainable Energy*, vol. 6, no. 3, pp. 850-862, 2015, doi: 10.1109/TSTE.2015.2413359.

[26] T. Radjai, J. P. Gaubert, L. Rahmani, and S. Mekhilef, “Experimental verification of P&O MPPT algorithm with direct control based on fuzzy logic control using Cuk converter,” *International Transaction on Electrical Energy systems*, vol. 25, no. 12, pp. 3492-3508, doi: 10.1002/etep.2047.

[27] T. K. Soon and S. Mekhilef, “A fast-converging MPPT technique for photovoltaic system under fast-varying solar irradiation and load resistance,” *IEEE Transactions on Industrial Informatics*, vol. 11, no. 1, pp. 176-186, 2015, doi: 10.1109/TII.2014.2378231.

[28] M. Seyedmahmoudian, *et al*, “State of the art artificial intelligence-based MPPT techniques for mitigating partial shading effects on PV systems–A review,” *Renewable and Sustainable Energy reviews*, vol. 64, pp. 435-455, 2016,doi: 10.1016/j.rser.2016.06.053.

[29] K. S. Tey, S. Mekhilef, M. Seyedmahmoudian, B. Horan, A. T. Oo and A. Stojcevski, “Improved differential evolution-based MPPT algorithm using SEPIC for PV systems under partial shading conditions and load variation,” *IEEE Transactions on Industrial Informatics*, vol. 14, no. 10, pp. 4322-4333, 2018, doi: 10.1109/TII.2018.2793210.

[30] M. Seyedmahmoudian, T. K. Soon, B. Horan, A. Ghandhari, S. Mekhilef and A. Stojcevski, “New ARMO-based MPPT technique to minimize tracking time and fluctuation at output of PV systems under rapidly changing shading conditions,” *IEEE Transactions on Industrial Informatics*, pp. 1-16, doi: 10.1109/TII.2019.2895066.

[31] P. Manoharan *et al*., “Improved perturb and observation maximum power point tracking technique for solar photovoltaic power generation systems,” *IEEE Systems Journal*, vol. 15, no. 2, pp. 3024-3035, 2021, doi: 10.1109/JSYST.2020.3003255.

[32] R. Tiwary and D. Murodia, “An improved strategy for high-efficiency multistage PV module using MPPT technique,” *5th International Conference on Trends in Electronics and Informatics (ICOEI)*, 2021, pp. 5-9, doi: 10.1109/ICOEI51242.2021.9452905.

[33] M. E. Ahmad, A. H. Numan and D. Y. Mahmood, “Enhancing performance of grid-connected photovoltaic systems based on three-phase five-level cascaded inverter,” *International Journal of Power Electronics and Drive Systems*,vol. 12, no. 4, pp. 2295-2304, 2021, doi: 10.11591/ijpeds.v12.i4.pp2295-2304.

[34] H. Attia and S. Ulusoy, “A new perturb and observe MPPT algorithm based on two steps variable voltage control,” *International Journal of Power Electronics and Drive Systems*, vol. 12, no. 4, pp. 2201-2208, 2021, doi: 10.11591/ijpeds.v12.i4.pp2201-2208.

[35] T. N.Manjunath,S. Mallikarjunaswamy, M.Komala, N. Sharmila, and K.S. Manu, “An efficient hybrid reconfigurable wind gas turbine power management system using MPPT algorithm,” *International Journal of Power Electronics and Drive Systems*, vol. 12, no. 4, pp. 2015-2510, 2021, doi: 10.11591/ijpeds.v12.i4.pp2501-2510.

[36] B. A. Numan, A. M. Shakir and A. L. Mahmood,“Photovoltaic array maximum power point tracking via modified perturbation and observation algorithm,” *International Journal of Power Electronics and Drive System*, vol. 11, no. 4, pp. 2007-2018, pp. 2007-2018, doi: 10.11591/ijpeds.v11.i4.pp2007-2018.

[37] Y. Amara, R. Bradai, R. Boukenoui, and A. Mellit, “Grid connected photovoltaic system efficiency and quality improvement using fuzzy-incond MPPT,” *International Journal of Power Electronics and Drive System*, vol. 11, no. 3, pp. 1536-1546, 2020, doi: 10.11591/ijpeds.v11.i3.pp1536-1546.

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