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

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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 optimization of MPPT algorithms.
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 Umene [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 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.

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

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

The saturation current is (2).

\[
I_o = I_{sc} G/1000 \exp \left\{ \frac{q [E_{oc} - (1/T) - n K]}{n K} \right\} \tag{2}
\]

The reverse saturation current (3).

\[
I_{rs} = \frac{I_{oc}}{e^{q [E_{oc} - (1/T) - n K] / n K} - 1} \tag{3}
\]

The output current \( I = I_{ph} - I_d - I_{sh} \)

\[
or I = I_{ph} - I_p I_o \left[ \exp \left( \frac{q [V + I R_s]}{n K n_s T} \right) - 1 \right] - \frac{V + I R_s}{R_{sh}} \tag{4}
\]

The power is \( P = VI \)

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

Where

\( I_{ph} \) = photo-current (A)

\( I_o \) = Short-circuit current (A)

\( k_i \) = Short circuit coefficient of the cell(at nominal temperature 25 degrees centigrade and at G= 1000 W/m²) = 0.0032
\[ T : \text{Operating temperature (degree kelvin)} \]
\[ T_n : \text{Nominal temperature (degree kelvin)} = 298 \]
\[ G : \text{Solar Irradiation (W/m}^2\text{)} \]
\[ q : \text{Electron charge (C)} = 1.6e^{-19} \text{ coulomb} \]
\[ V_{oc} : \text{Open-circuit voltage (V)} \]
\[ n : \text{Ideality factor of the diode} = 1.3 \]
\[ K : \text{Boltzmann’s constant (J/K)} = 1.38e^{-23} \]
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The parameters of a specific module are given as follows and considered in forthcoming simulation work.

- \( I_{sc} = 8.21 \text{A} \)
- \( k_i = 0.0032 \)
- \( V_{oc} = 32.09 \text{V} \)
- \( N_s = 54 \)
- \( N_p = 1 \)
- \( R_s = 0.221 \Omega \)
- \( R_{sh} = 415.405 \Omega \)
- \( G \leq 1000 \text{ W/m}^2 \)

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 \( (G=1000 \text{ W/m}^2) \) and temperature \( (T=30 \degree \text{C}) \), scale: \( Y_{pv}-(1:10) \), \( I_{pv} (1:10) \), \( P_{pv} (1:1) \)

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.

\[
X_{k+1} = X_k - \frac{f(X_k)}{f'(X_k)}
\]

---

Where \( X_0 \) 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 (\( \varepsilon \)), for which the equation in is modified as (7).

\[
X_{k+1} = X_k \frac{f(X_k)}{p(X_k)} + \varepsilon
\]  

Where '\( \varepsilon \)' 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).

\[
dP/dV = d(IV)/dV = 1 + V(dl/dV) = 0
\]  

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

\[
(1 + cV) \exp (cV) = k
\]

where \( k = \frac{i_{ph} - i_{sh}}{N_{ph}} \approx \frac{i_{ph}}{N_{ph}} \)

and \( c = \frac{q(1+R_s/R_L)}{kN_{ph}T} \approx \frac{q}{kN_{ph}T} \)

Since \( i_{sh} \) 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).

\[
f(V) = (1 + cV) \exp(cV) - k = 0
\]  

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 \( V_{mp} \), 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
Computation of maximum power point tracking of PV module using modified ... (Siddhartha Behera)
The close-loop control of buck converter with input having PV unit is stable under \( V = V_{mp} \) 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 \( Y=Y_{mp} \) 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 (\( I_{o} \)).

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.

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REFERENCES


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