

A Compound Algorithm for Maximum Power Point Tracking Used in Laser Power Beaming

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Abstract. With the high voltage intelligent substation developing in a pretty high speed, more and more artificial intelligent techniques have been incorporated into the power devices to meet the automation needs. For the sake of the line maintenance staff's safety, the high voltage isolating switch draws great attention among the most important power devices because of its capability of connecting and disconnecting the high voltage circuit. However, due to the very high level voltage of the high voltage isolating switch's working environment, the power supply system of the surveillance devices could suffer from great electromagnetic interference. Laser power beaming exhibits its merits in such situation because it can provide steady power from a distance despite the day or the night. Then the energy conversion efficiency arises as a new concern. To make as much use of the laser power as possible, our work mainly focuses on extracting maximum power from the photovoltaic (PV) panel. In this paper, we proposed a neural network based algorithm which relates both the intrinsic and the extrinsic features of the PV panel to the proportion of the voltage at the maximum power point (MPP) to the open circuit voltage of the PV panel. Simulations and experiments were carried out to verify the validness of our algorithm.

1. Introduction

The high voltage isolating switch plays an important role in the maintenance of high voltage line, because it controls the connecting and breaking states of the circuit. The maintenance staff have to make sure that the high voltage circuit is completely OFF before conducting the subsequent inspection and repairing. Thus how to effectively monitor the switch's working manner becomes an essential part in the normal operation of the high voltage intelligent substation. An easy way coming into people's mind is remote video surveillance. Considering the high level voltage working environment of the isolating switch, the wired power supply of the surveillance system can be enormously interfered. The laser power supply serves as a great alternative, because it can charge the system from a long distance and provide much higher energy conversion efficiency than solar [1]. To preserve the energy transmission efficiency, our work mainly focuses on the maximum power point tracking (MPPT) module, which keeps track of the maximum power extracted from the PV arrays under atmospheric condition variations. A typical MPPT module's structure is illustrated in Fig. 1. The power is mainly managed by adjusting the DC-DC converter's duty cycle.



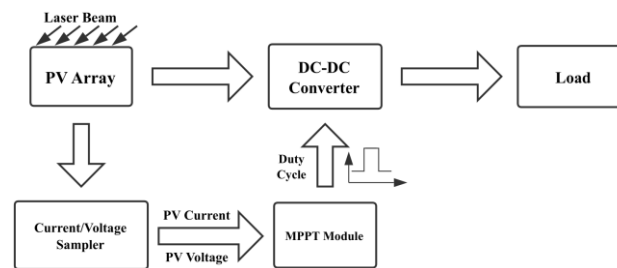


Fig.1 MPPT module block diagram

2. Literature Survey

Criteria for tracking the maximum power from PV arrays include fractional open circuit voltage and short circuit current, current sweep, perturb and observe (P&O), incremental conductance (INC) and so forth. The researches mainly take place around these methods [2,3,4,6]. In [2,3], the maximum power point (MPP) is tracked based on the knowledge that the current or voltage at MPP can be represented as a proportion of the short circuit current or open circuit voltage [7]. However, this scheme alone needs the PV system to undergo periodical disconnection during power supplying, which drags down the overall energy conversion efficiency of the whole system. The current sweep utilizes a repeated sweep waveform triggered at fixed time to update the I-V curve of the MPPT module periodically [4,6] but it lacks of practice because of implementation complexity and slow convergence speed [5]. The P&O algorithm and the INC algorithm are known as “hill-climbing” principle based algorithms. The P&O algorithm employs a perturbation in the working voltage and observes the sign of the increment in power. The standard INC algorithm works by adjusting the circuit by fixed increment in voltage until the optimal condition is satisfied. Both “hill-climbing” principle based algorithms encounters a problem that they often jiggle around at the beginning, which causes extra power loss.

To solve the problems above, we presented a compound algorithm containing two phases. During a working cycle, once the excessive ambient temperature or laser irradiation is detected, the first phase immediately adjusts the working point of the circuit to the estimated MPP. Then the second phase keeps tuning the working point towards the real MPP under small atmospheric changes. More details are explained in the next section.

3. Proposed Method

Our method is divided into two phases. The first phase is called location phase, which uses a neural network (NN) to predict the proportion of the MPP voltage to the open circuit voltage of the PV array, so as to make the circuit quickly reach the estimated MPP under current working environment. The second phase is called tracking phase. After deriving the estimation of the MPP, further tuning are undertaken using varied step size INC method proposed in [6] to make the system operate efficiently under small ambient changes. The algorithm starts all over again after excessive ambient changes.

3.1. Location phase

According to [8,9,10], the PV array's I-V relationship is related to factors such as the photocurrent and reverse saturation current of a single PV unit, the numbers of PV units connected in parallel and serial and etc. Furthermore, the PV array's photocurrent also varies linearly with the optical irradiation and can be affected by the ambient temperature as well [11,12]. Inspired from the information above and the fractional open circuit voltage algorithm, we locate the approximate MPP once at the beginning of a working cycle using the powerful ANNs.

The input of our NN model contains two parts: intrinsic features and extrinsic features.

1) Intrinsic features: This refers to the original specifications of the PV array once it is produced or the impact these specifications have on the working states. These specifications characterize the fundamental electrical property, e.g. the trajectory of the P-V curve. We finally chose N_p , N_s , V_{oc} and I_{sc} as the intrinsic features, where V_{oc} and I_{sc} respectively represent the open circuit voltage and short circuit current.

2) Extrinsic features: This refers to the ambient temperature and the laser irradiation.

One important thing to notice is that the input of the NN model are normalized to have common scale before being fed into the model. The output of our NN model is a fractional number indicating the ratio of the MPP voltage to the open circuit voltage of the circuit, which tends to be between 0.71 and 0.78 [7]. The objective function J of the NN model we used is the mean squared error, which takes on the form as

$$J = (t - y)^2 \quad (1)$$

where t represents the true ratio and y represents the predicted value of the NN model. Putting it together, our regression model is a three-layer NN model shown in Fig.2, of which the hidden layer contains 20 hidden units. The activation function we used is the rectified linear unit (ReLU), which truncates the negative part of the input of the unit and proves to converge fast and consume little computation source.

To train the NN model, we used back propagation algorithm. The learning rate varies between 0.05 and 0.0005 randomly and the update rule follows the state-of-the-art Adam optimizer [13].

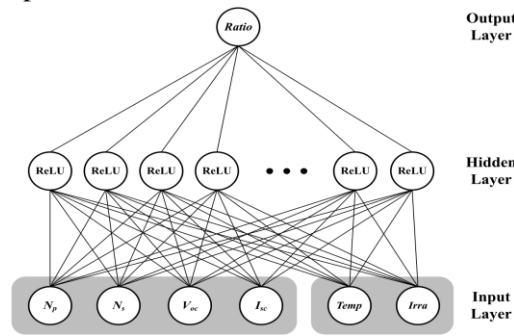


Fig.2 Neural network model in location phase

3.2. Tracking phase.

After obtaining the predicted MPP, we assume that the atmospheric conditions barely change for a while from this time node. The INC algorithm works based on the knowledge that the slope at the MPP of the P-V curve equals 0, as illustrated in Fig.3. Since

$$dP / dV = d(IV) / dV = (VdI + IdV) / dV = V(dI / dV) + I. \quad (2)$$

when the circuit reaches the MPP, we now have

$$dP / dV = V(dI / dV) + I = 0 \quad (3)$$

then

$$dI / dV = -I / V \quad (4)$$

The varied step INC method [7] works on top of the basics above as well. The working flow chart of the varied step INC method is illustrated in Fig.3. DC is the abbreviation for duty cycle.

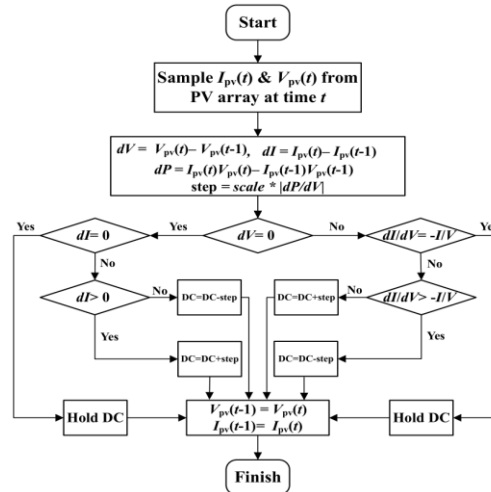


Fig.3 Varied step INC method flowchart

4. Experimental Results

4.1. Characteristics of the PV array.

The PV array's electrical characteristics can easily be obtained through simulation using MATLAB/Simulink software, the P-V and I-V curves are shown in Fig.4-Fig.5.

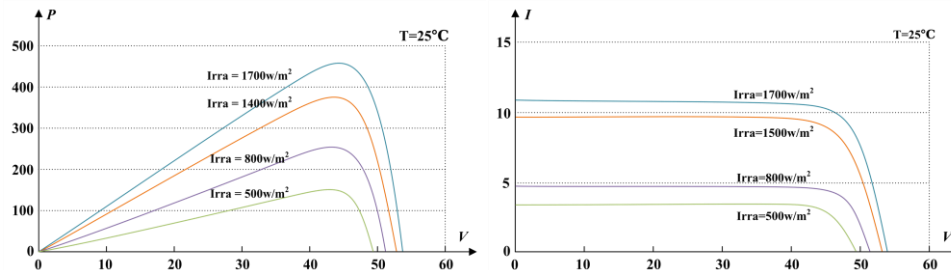


Fig.4 P-V and I-V curves under 25 °C with varied irradiation

As illustrated in Fig.4, under the same temperature, the MPP barely changes its position even though the open circuit voltage keeps reducing with the irradiation going down. However, small changes need to be tracked dynamically. The photocurrent has a positive correlation with the laser irradiation.

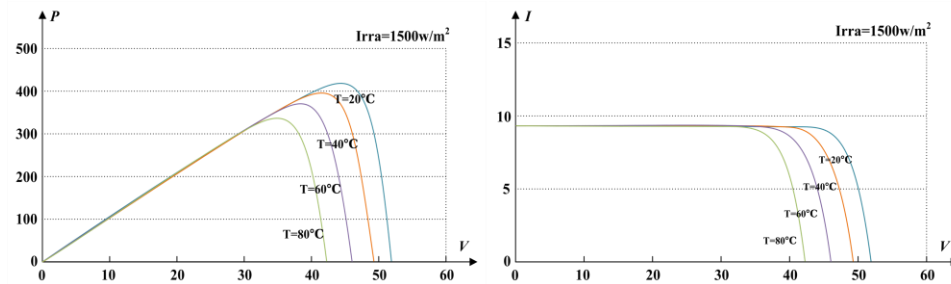


Fig.5 P-V and I-V curves under 1500W/m² irradiation with varied temperature

From Fig.5, we can tell that the MPP voltage decreases as the temperature goes up. The photocurrent doesn't change much with the irradiation staying unchanged.

4.2. Performance of the compound algorithm.

To exhibit the merits of our algorithm, we compared our algorithm with the conventional INC algorithm. In Fig.8 we can tell that both algorithms reach the MPP finally, however, at the beginning of rapid irradiation or temperature changes, our compound algorithm grows directly towards the MPP position in much less time compared to the conventional INC algorithm, which no wonder saves the power during this time interval.

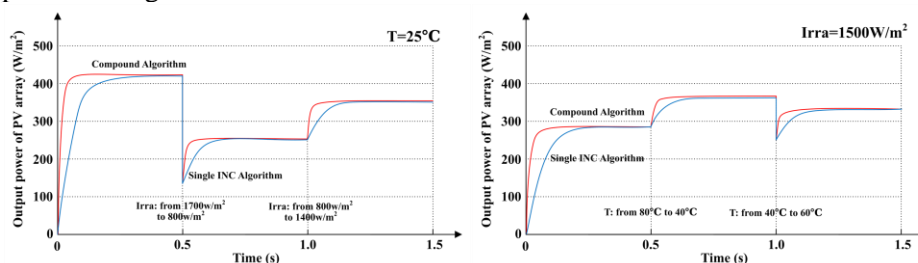


Fig.6 PV array's output power MPP tracking results

5. Conclusion

To solve the maximum power extraction problem of the laser power supply system used for remote video surveillance in high voltage intelligent substation, we proposed a compound algorithm for the MPPT technique. The algorithm is divided into two phases: location phase and tracking phase. The location phase is responsible for global optima searching and the tracking phase is utilized for local

optima tuning. The experiment results reveals that the algorithm has a promising prospect in laser power supply system, or other radiation based wireless power supply system. Furthermore, since the manually chosen features can hardly be complete, more feature extraction methods need to be developed to make better use of the powerful ANNs.

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