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A Hybrid Neur-Fuzzy Optimization Method for PV Steady State Improvement in Maximum Power Point Tracking Controller

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ABSTRACT

This paper presents ahybrid Neural-Fuzzy optimization method for the purpose of assuringthe steady state case of the Maximum Power Point (MPP) for a Photovoatic (PV) system. Also, it works to decrease the oscillation occurring around MPP. The proposed method implemented via using an improved intelligent control method, neural fuzzy networks (Nueural-Fuzzy). The results showed that the PV system with Maximum Power Point Tracking (MPPT) always tracks the peak powerpoint of the PV module under various operating conditions. Afterwards, these results are validated by the comparison with the conventional and most used methods (P&O) and showed that the proposed MPPT method has better steady state and therefore less oscillation around the MPP than the P&O. It is also shown that, the increase in the output power due to usingthe MPPT is about 48.2% for a clear weather conditions and 34.8% for a shadow conditions.

1. INTRODUCTION

The PV solar cells are an evolving technology. The efficiencies of the solar cells in the late 2015 reached 34.7%(Ali M Humada, Hojabri, Hamada, Samsuri, & Ahmed, 2016a). Therefore, more focusing efforts installed via the world, its investments increased by 300% at the end of 2015 compared to 2012(Abdelsalam, Massoud, Ahmed, & Enjeti, 2011). On the other hand, high oil prices, pollution and political pressured to reduce carbon dioxide emissions are a few of the major reasons that drive governments to consider renewable energy sources. The increasing demand of electric energy drives nations to consider renewable and sustainable energies.

Several inverter topologies are being introduced to minimize losses and cost as well as provide a better performance(Ali Mahmood Humada et al.). With the demand for more reliable solar maximum power point tracking (MPPT), further work should be considered regarding the control aspects of the inverter to overcome the drawback of the traditional hill-climbing techniques. The PV solar cell model a challenging application field since the changes in the solar irradiance and the temperature are not known. This nonlinear and highly complex system of a grid-connected PV cells can be stimulated to control engineers.

Various adaptive control methods, both considering the possible variations (intelligent control) (De Brito, Galotto Jr, Sampaio, de Azevedo e Melo, & Canesin, 2013; Dorofte, Borup, & Blaabjerg, 2005; Elgendy, Zahawi, & Atkinson, 2012)and without considering the possible variations (hill climbing) have been studied (Ishaque & Salam, 2013; Ji et al., 2011; Jiang, Maskell, & Patra, 2013). PV cell inputs are highly indeterminate; it is not possible to model the system mathematically. Therefore, there is a need for implementing control method can consider the following issues,the inability of modelling the mathematical system accurately, operate under a wide operating range, adaptation to unforeseen system changing parameters and conditions, insensitivity to nonlinearity,simplicity of implementation and design, and finally decrease the oscillation around the maximum power point.

Intelligent control systems such as artificial neural networks (ANNs), fuzzy logic (FL) as well as meta-heuristic optimization methods meet the characteristics listed above. The intelligent control has presented some promising results. Commonly, researchers would use only one intelligent control technique, ANNs, FL, or evolutionary computing. The combination of ANN and FL has proven to be effective in several applications. The ANN compensates for the lack of learning capability and the limited adaptability of the FL. The FL, on the other hand, is a great way to model linguistic information(Zadeh, 1996). Combining the two methodologies provide a hybrid structure that is capable of dealing with systems involving different types of knowledge. Therefore, the proposed methodimplemented to solve the problems of the hill climbing methods such as, accuracy of tracking and decreasing the oscillation around the maximum power point, to provide finally an acceptable result compared with the most used tracking methods (P&O).

2. EFFECT OF THE PARTIALLY SHADING CONDITION ON PV SYSTEM

PV cells have an extreme sensitivity to partial shading. In cases where a cell or a small module's part in a series string becomes shaded, instead of making a contribution to the power output, the shaded cells get to absorb the power coming from the other cells that are in the string. The power that is absorbed thusly is then converted into heat; this contributes to hot spots that can bring damage to the cells. A majority of the commercial modules employs bypass diodes across a series of cells towards overcoming this effect (Ali M Humada, Hojabri, Hamada, Samsuri, & Ahmed, 2016b). The shaded cells are thus bypassed. Consequently, the only thing that is lost is the power of the shaded cell series. The graphs below illustrate the PV modules' characteristics under half- and full-shading conditions. Using a small PV system shown in Figure 1, the PV module's I–V and P–V curves with and without bypass are shown in Figures 2 and 3, respectively. Figure 2 presents the I–V curves for each PV module as well as for the combined PV string with and without bypass diodes.

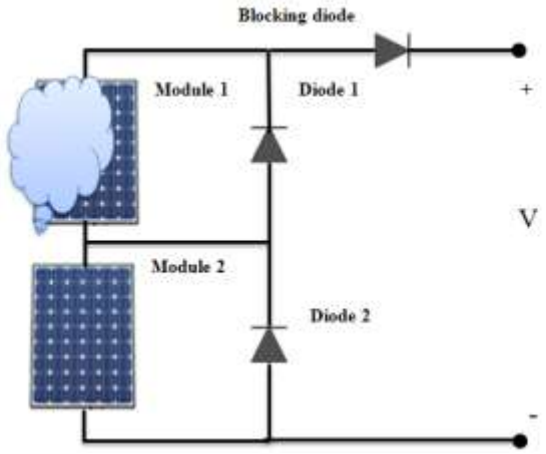

Figure 1: Two PV modules connected in series, when one module shaded and another operate with normal condition.

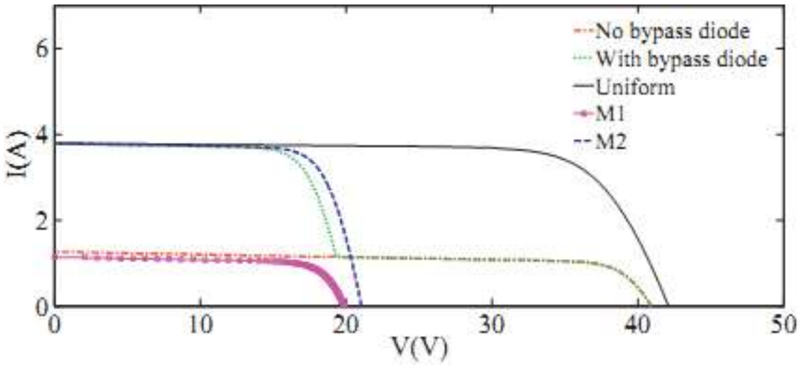

Figure 2: The I–V characteristic curve of a PV string, two module (Module 1 and Module 2) connected in series. In partial shadowing condition, the radiance on every PV module as follows: Module1=400 W/m^2 and Module 2 = 1000 W/m^2. In the normal condition: M1 = M2= 1000 W/m^2.

A different irradiance value (250 W/m^2, 750 W/m^2) is received by each PV module. The P–V curves are given in Figure 3, which likewise shows that, in the P–V curve for the module string, there is only one MPP that does not have bypass diodes (Ali M Humada, Hojabri, Sulaiman, Hamada, & Ahmed, 2016). Therefore, without bypass diodes, number of MPPs remain the same, similar to the case when there is a uniform irradiance (at 250 W/m^2) on these two modules.

A few researchers (Bidram, Davoudi, & Balog, 2012; El-Dein, Kazerani, & Salama, 2013; Storey, Wilson, & Bagnall, 2014) made suggestions using a bypass diode for every solar cell towards reducing the consequence of the partial shading within a PV module (i.e. power loss), but this would bring additional complexity and cost to the module.

3. MPPT UNDER PARTIALLY SHADED CONDITIONS

As demonstrated above, towards protecting the PV panel from hot spots caused by the module which acts as a load and consuming power, the addition of bypass diodes to commercial PV modules is undertaken. For the PV panel protection, two bypass diodes (i.e. Diode 1 and Diode 2) are added to the PV system; this is done through their parallel connection with the PV modules (Figure 1). Additionally, towards preventing the reverse current from the loader unbalance the current flow from other parallel PV strings, the blocking diode is typically connected in the series' PV string. Because of their series connection for the PV string that has bypass diodes, the current that passes through these two modules of different irradiance is equal. As such, this assembly's I–V curve (in green dotted line) can be derived through the addition of the voltages across them, while, at the same time, the current value constant is kept constant (Figure 2). From these two modules' I–V curve, there is evidence showing the formation of the two knee points, which then generates two local maxima (Global 1 and Global 2) in the P–V curve generated therein (Figure 3).

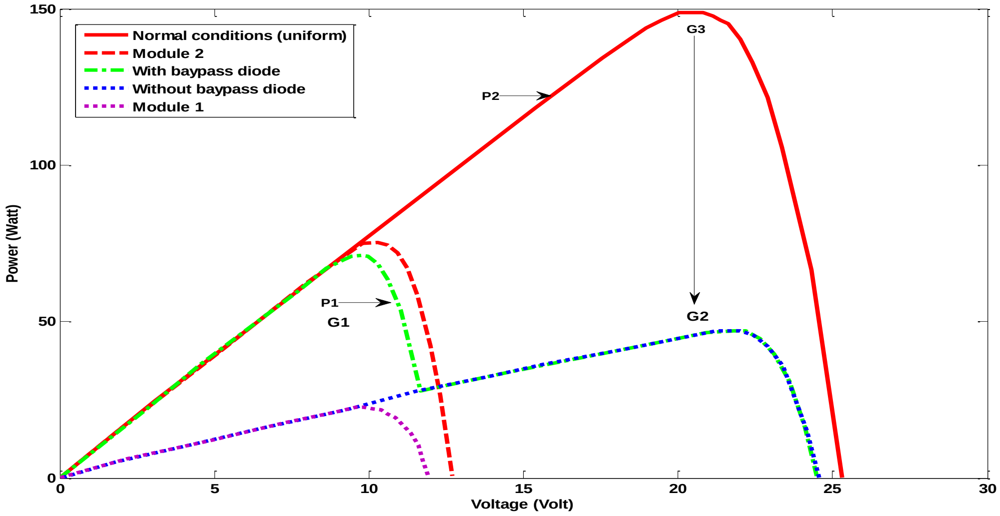

Figure 3: The P–V characteristic curve of a string with the same connection and weather conditions in Figure 1. However, P_1 and P_2 represent the PV modules in normal condition and partial shading condition, respectively.

4. PROPOSED NEURAL-FUZZY SYSTEM MODEL

The hybrid NF system acts as one entity that utilizes the parallelism of the ANN and the functionality of FL. The architecture of the hybrid NF system is represented in Figure 4.

The system implemented is four-layer ANFIS architecture with the hidden layers performing the tasks of the fuzzy inference system. The NF system has 2 inputs and 1 output. The first layer fuzzifies the two crisp inputs, the second layer has the fuzzy rules and applies the antecedent IF part, the third layer is the consequent THEN part of the logic and the fourth layer defuzzifies the fuzzy output from layer 3. A mathematical model is not needed to represent the system. The major drawback on the other hand is once the parameters of the system are set, it acts like a blackbox. The NF controller can either be trained offline or online. The offline training requires prior knowledge of the input and the output while the online training is adaptive.

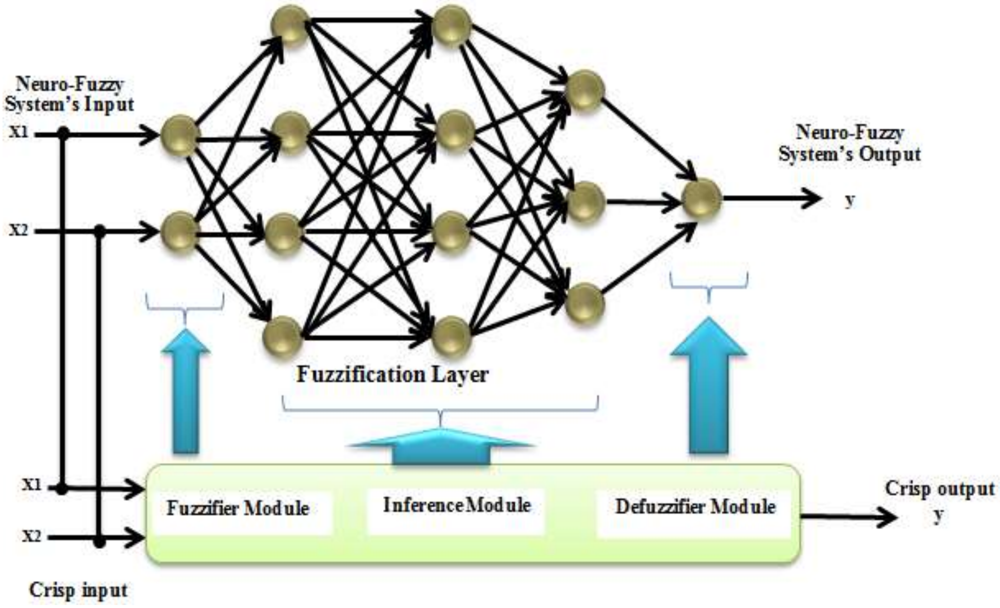

Figure 4. Hybrid Neuro-fuzzy logic structure [24]

The system implements a feed-forward architecture where the flow of information moves in one direction (input to output). The back propagation learning algorithm is used to train the weights of the hidden layers. The algorithm solves an optimization problem based on the radiant descent law, which involves the minimization of the cumulative error.

$$\mathrm{E(k)} = \frac{1}{2}\sum_{i=1}^{q}[t(k)-o(k)]^2 \qquad (1)$$

K is the number of training patterns, which is in this case is not predefined since the training will be done online. Vector w denotes the network weight vector with components corresponding to the interconnection weights. The cost function that needs to be minimized is Eqn. (2).

$$\mathrm{minE(k)} = \min\frac{1}{2}\sum_{i=1}^{q}[t(k)-o(k)]^2 \qquad (2)$$

Δw in eqn. (3) will be the delta rule for updating rules allowing for minimization of (2).

$$\Delta \mathrm{w} = -\eta\frac{\beta e(k)}{\beta \mathrm{w}} \qquad \frac{\beta e(k)}{\beta \mathrm{w}} \qquad (3)$$

is the gradient of the error *E(k)* with respect to w. η is the learning rate which is fixed throughout the simulation. The learning rate is initialed with a small value to avoid convergence problems. Usually a momentum is added to provide fast convergence and fewer oscillations. The momentum does not account for in the EMTP simulations. Therefore the weigh updates will be according to 4. The first step in the training is initializing the weights and the threshold.

The threshold of all hidden layers is initialized to 0.5 and the weights are initialized to 0.25. The weights are initialized to a small random number, hence why the 0.25 is chosen. Since the training is done online, the input pattern obtained from the voltage and power profile of the PV model. The output of the NF system is compared to the power output of the PV model and the error is calculated for each sampling period. The error is then propagated backward to each layer using eqn. (3), and the weights are updated. The maximum tolerable error is set to be 1% tentatively.

5.RESULTS AND DISCUSIONS

The collected data of proposed PV system, registered from January to December 2016, the global and diffuse solar radiation were recorded. During the midday (12–2PM), the solar radiation values were recorded as high. In the early (7AM–9AM) and late (5–7PM) daytime, a small solar radiation value was recorded. In this tropical area, Bangi has a reasonable clear sky for most days (at noon time), as depicted in Figure 5.

Figure 5. Daily irradiance level in Bangi area for January 2016.

The power produced from the solar PV power plant was measured after MPPT controller to assure reliability of the proposed method. Two shadow conditions were selected to test the credibility of the hybrid ANN-Fuzzy controller. The output curves for the two shadow conditions presented in Figure 6.

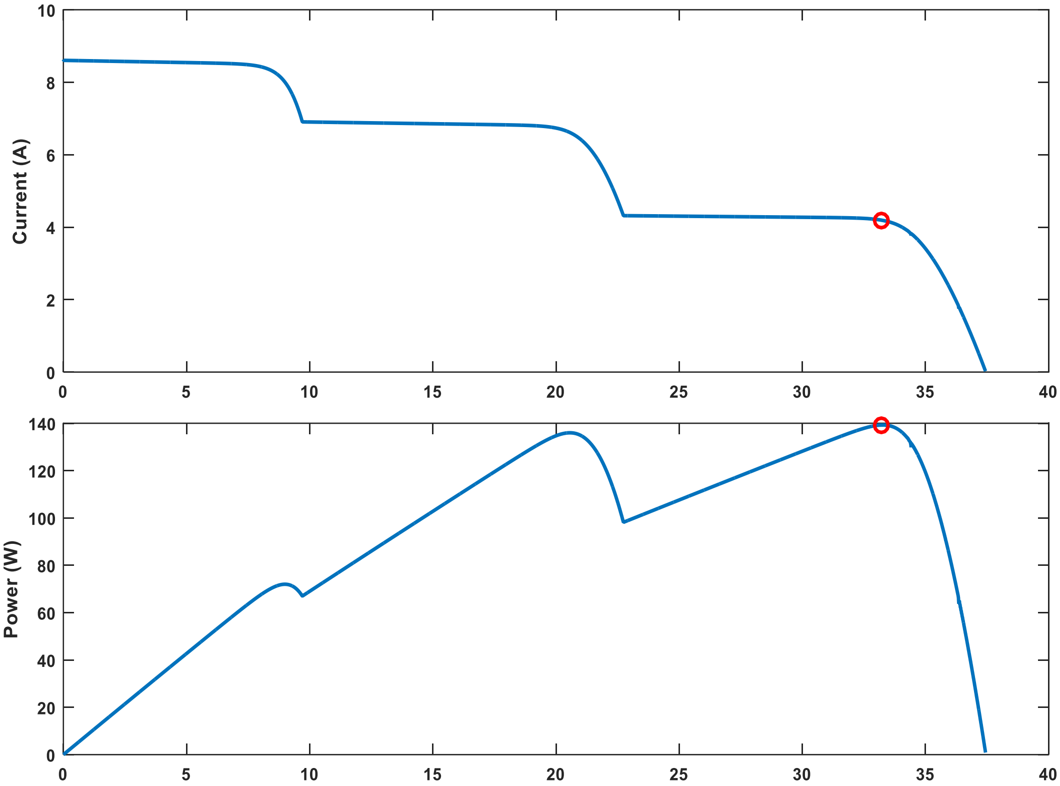

Figure 6. P–V characteristics of the PV array operating under shadow conditions.

The ability of tracking the MPP point throughthe above presented shadow condition was tested by using the proposed method. The results of the tracking presented in Figures 7 and 8.

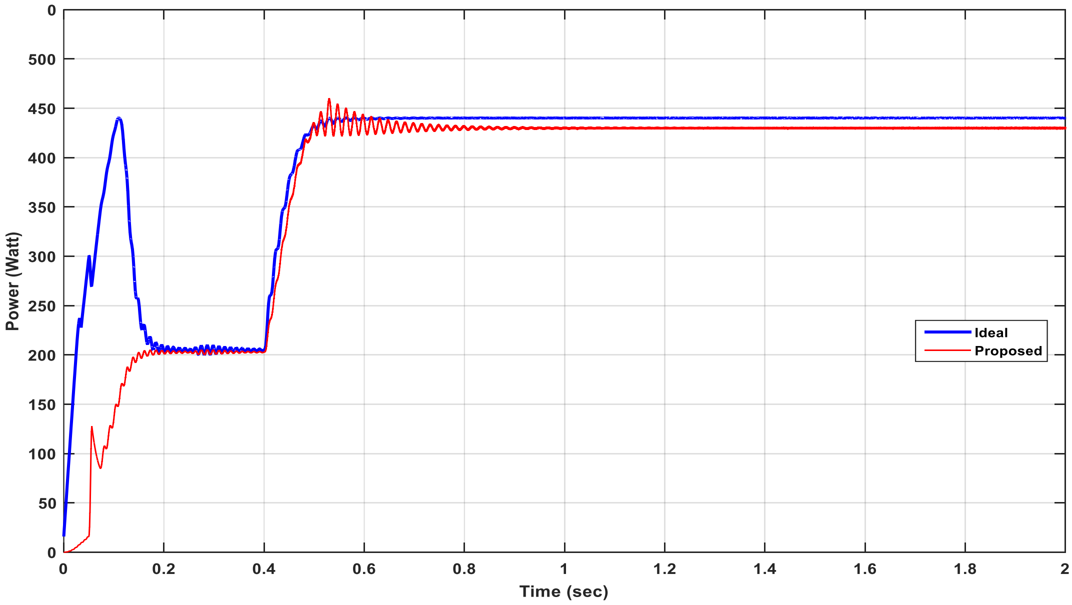

Figure 7. Result of MPP tracking by using the proposed method to compare with ideal MPP.

Figure 7 presents the tracking process by using the proposed method, while Figure 8presents the results by using the comparative method, MPPT based on P&O algorithm. By comparison, we can see that the proposed method, Figure 8 tracked the maximum power point before the time 1 second, however, in the comparative method, P&O method, it was only able to track the MPP at 1.25 second. In addition, the over shot value of the proposed method was less than the comparative method by around 50%. Therefore the proposed method could be supposed as a novel method when compared with an efficient method like P&O method.

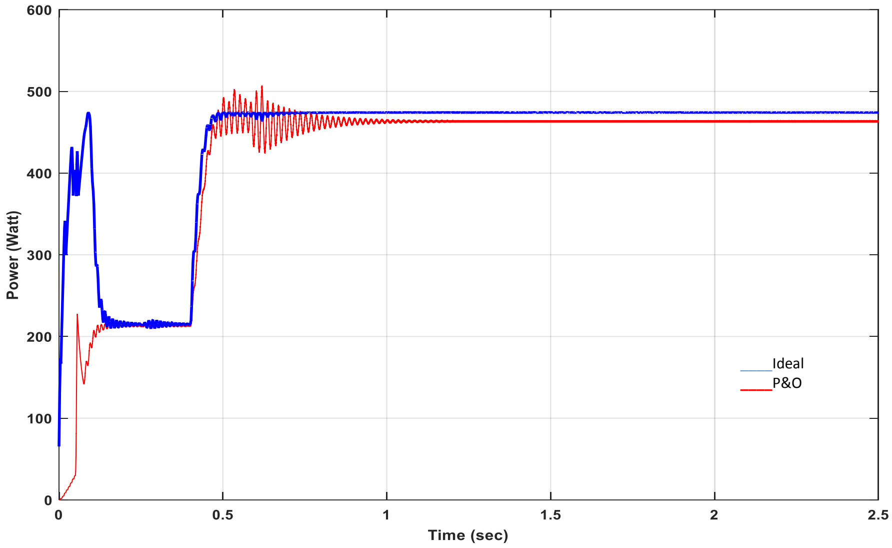

Figure 8: Result of MPP tracking by using the P&O algorithm to compare with ideal MPP.

CONCLUSION

A hybrid ANN-Fuzzy optimization method implemented in this study to track the maximum power point of a PV system within shadow conditions. In this method, applied a hybrid algorithmto assure the ability to recover the effects of shadow conditions in PV cells, which isthe main issue in the PV installation.The proposed method has assuredits abilityof attaining the steady state case and fast tracking time, compared with the conventional P&O method. Also,the results showed that the proposed method could track the MPP at any condition and day time with fast time response and low oscillation compare with the P&O method.

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