Intelligent control of PV system on the basis of the fuzzy recurrent neuronet

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Abstract. This paper presents the fuzzy recurrent neuronet for PV system’s control. Based on the PV system’s state, the fuzzy recurrent neural net tracks the maximum power point under random perturbations. The validity and advantages of the proposed intelligent control of PV system are demonstrated by numerical simulations. The simulation results show that the proposed intelligent control of PV system achieves real-time control speed and competitive performance, as compared to a classical control scheme on the basis of the perturbation & observation algorithm.

Introduction

Solar energy is being recognized as one of the main renewable energy sources due to its essentially non-polluting inexhaustible nature. We consider a non-linear maximum power point tracking (MPPT) problem [1] from photovoltaic applications. There are many existed MPPT algorithms such as voltage feedback, perturbation and observation, linear approximation, incremental conductance, hill climbing, actual measurement, fuzzy control and so on [1]. The goal of MPPT algorithms is to achieve the condition \( \frac{dP}{dV} = 0 \) to find the maximum power point of PV system. MPPT algorithms required parameters are only the voltage and current of PV system. However the PV array is non-linear system and works under uncertainty of the environment due to sudden variations in the solar irradiation levels. Therefore unstable dynamics must be confronted when designing control systems to track maximum power point quickly – in order to provide stability, disturbance attenuation. Moreover, the non-linear photovoltaic (PV) system should be robust to different environmental conditions, in order to reliably generate maximum power. Therefore, automatic design methods utilizing intelligent techniques such as neural network and fuzzy logic are a promising alternative [2-6]. This forms the motivation for development of the effective control of PV system on the basis of the fuzzy recurrent neuronet presented in this paper. For real-life photovoltaic applications, the PV system behavior can change; system parameters can exhibit random variations; the solar irradiation can fluctuate. Hence neural-network based solutions have been proposed to overcome these difficulties. But the network needs to become more adaptive. Adaptive behavior can be enabled by modifying the network to have fuzzy and neural units which respond to the changing behavior of the photovoltaic system, thus making the network into a fuzzy recurrent neuronet. Therefore, photovoltaic systems are best modeled as hybrid systems since their behaviors result from the interaction between continuous and discrete dynamics. Several methods have been developed to overcome the aforementioned difficulties. The most important approaches are those that combine the basic MPPT algorithm, with the intelligent models, which are neural network and fuzzy logic. This paper presents the intelligent control of PV system on the basis of the fuzzy recurrent neuronet.

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1. **Control model based on perturbation & observation algorithm**

One of the most common MPPT algorithm is perturbation & observation algorithm due to its simplicity, applicability and less required parameters. The main disadvantages of the perturbation & observation algorithm are: (1) the power tracked by the perturbation & observation algorithm can take considerable time to settle down from oscillating near the maximum power point; (2) if solar irradiation levels change suddenly then misjudgment phenomenon for the perturbation & observation algorithm takes place. Figure 1 shows such situation.

![Figure 1. The misjudgment phenomenon for the perturbation & observation algorithm](image)

The first point is point A, and ΔV voltage perturbation will move the operating point from A to B and will lead to decreasing power when the solar irradiation is constant. If the solar irradiation level increases in one sampling period, then the power curve will be moved from P1 to P2, and the operating point will be moved from A to C instead of A to B. Consequently, the power will be increased continuously and the voltage perturbation still moves toward ΔV direction. It can be seen that a continuous perturbation in one direction will lead to an operating point far away from the maximum power point. If the solar irradiation level increases without intermission, the distance between operating point and maximum power point will be farther. As a result, the power loss of photovoltaic system will increase, and the effectiveness of the photovoltaic system will reduce. In order to overcome the aforementioned difficulties the fuzzy recurrent neural net is proposed to track maximum power point of PV system.

2. **Intelligent control of PV system on the basis of the fuzzy recurrent neuronet**

In this paper, the function approximation capabilities of fuzzy recurrent neural net are used to approximate a nonlinear control law of maximum power point tracking. This paper considers the development of an effective control method that remains easy to implement. The proposed fuzzy recurrent neural net is capable of handling uncertainties in both the PV system parameters and the environment. As formed, the fuzzy recurrent neural net creates the effective control signal, and identifies the system’s state under sudden variations in the solar irradiation levels (Fig. 2). On the basis of the analysis of perturbation & observation algorithm for the adaptive maximum power point tracking it is necessary to trace voltage increment and solar irradiation changing. To make the intelligent control of PV system on the basis of the fuzzy recurrent neuronet become adaptive, it needs to have some idea on how the actual PV system’s behavior is differing from its expected behavior, so that the fuzzy recurrent neural net can recalibrate its behavior intelligently during run time, and try to eliminate the constant maximum power point tracking error. Hence the input signal of the fuzzy recurrent neural net will be non-zero, and it will give useful feedback for telling how to adapt to the dynamically changing PV system’s parameters. This control approach does provide a more intelligent method of implementing the control signal. The fuzzy recurrent neural net is trained based on the data.
where $i$ – time, $I_r$ is the solar irradiance, $\Delta I_r = I_r^i - I_r^{i-1}$, $V$ represents the voltage, $\Delta V$ – the voltage increment, $P$ – PV system’s power; $x=(\Delta I_r^i, V^i, P^i, \Delta V^{i-2}, \Delta V^{i-1}, \Delta V^i)$ – input signal of fuzzy recurrent neural net. The control signal and output signal of the fuzzy recurrent neural net is $u=\Delta V$. Data (1) have a training set of $9*10^5$ examples, and a test set of $10^5$ examples. First, sets $A^j_i(j \in \{1, ..., n^i_s\}, j=1..10)$ formed using GNG’s (Growing Neural Gas [7]) clustering of the data (1); fuzzy sets $A^j_i(j \in \{1, ..., n^i_s\})$ with membership function $\mu^j_i(x)$ formed using Fuzzy c-means of the data (1) (the sets $A^j_i$ was input for Fuzzy c-means); in order to effective obtain the dynamics of the system the fuzzy sets $A_j(j \in \{1, 2, 3\})$ with membership function $\mu_j(x)$ determined according condition (2):

$$
\eta = \frac{1}{n^s} \sum_{u=1}^{n^s} \left( \min_{i=1}^{n^i_s} [\mu^i_j(x), \mu^i_j(x)] \right).
$$

I unit: The fuzzy recurrent neural net for PV system’s control fulfills as Simulink model

The sets $A^j_i(j \in \{1, ..., n^i_s\}, j=1..10)$ formed using GNG’s clustering of the data (1); fuzzy sets $A^j_i(j \in \{1, ..., n^i_s\}, j=1..10)$ with membership function $\mu^j_i(x)$ formed using Fuzzy c-means of the data (1) (the sets $A^j_i$ was input for Fuzzy c-means); in order to effective obtain the dynamics of the system the fuzzy sets $A_j(j \in \{1, 2, 3\})$ with membership function $\mu_j(x)$ determined according condition (2).

Using Matlab’s Neural Network Toolbox we train two-layered recurrent neural networks $f_j: u=f_j(x)$. These recurrent neural networks create the effective control signals $f_j(x)$:

Formed as Simulink’s block if-then rules are defined as:

$$
H_j: \text{IF } x \text{ IS } A_j \text{ THEN } u=f_j(x)
$$

II unit: Simulation of the intelligent control of PV system $\forall i \in \{0..T\}$

Aggregation antecedents of the rules (3) maps input $x$ into their membership functions and matches data with conditions of rules. These mappings are then activates the $k$ rule, which indicates the $k$ PV system’s state $k = 1..3$.

According the $k$ system's state the recurrent neural net $f_k$ creates the effective control signal $u=f_k(x)$ under random perturbations.

Fig. 2. The intelligent control of the PV system basis on the fuzzy recurrent neural net

Second, for each $j$ an identifier is constructed by a two-layer feed forward neural network. Third, an fuzzy recurrent neural net for the photovoltaic system’s control is carefully designed to correctly tackle the control task under uncertainty of the photovoltaic system and of the environment.

3. Matlab Simulink model of the photovoltaic system

The model of PV system contains:

- Two PV generators providing each a maximum of 0.1 MW at 1 kW/m$^2$ sun irradiance;
- 5-kHz boost converter;
- 20-kvar capacitor bank.

The model of photovoltaic system has two Kyocera-DD205GX-LP modules. This model uses a MPPT subsystem with a duty cycle that generates the required voltage to extract maximum power. To illustrate the benefits of the newly proposed intelligent control of the photovoltaic system’s control, the numerical examples from the previous section 2 is revisited.
4. Simulation and results
All the simulations for this study are implemented in MATLAB, Simulink. The true benefits of the proposed
the intelligent control of PV system on the basis of the fuzzy recurrent neuronet are best demonstrated
through a simulation study. Figure 2 and figure 3 show the solar irradiance during simulation time for the first
PV generator – PV1 and for the second PV generator – PV2 respectively.

![Figure 2. Plot of solar irradiance for PV1](image1)

![Figure 3. Plot of solar irradiance for PV2](image2)

In this comparison study, the performance of the energy saving technology of the PV system’s control is
compared against the standard model on the basis of the perturbation & observation algorithm, under the
same conditions. Figures 4 to 6 illustrate the simulation’s results. Figure 5 shows the misjudgment
phenomenon for the perturbation & observation algorithm (black curve from time=2 s to 2.3 s). The
intelligent control of PV system on the basis of the fuzzy recurrent neuronet is more robust and provided
more power (Fig. 4-6) in comparison with the control model based on the perturbation & observation
algorithm.
Figure 4. Plot of PV1’s power provided by control model based on perturbation & observation algorithm and the intelligent control of PV1 on the basis of the fuzzy recurrent neuronet respectively

Figure 5. Plot of PV2’s power provided by control model based on perturbation & observation algorithm and the intelligent control of PV2 array on the basis of the fuzzy recurrent neuronet respectively

Figure 6. Plot of PV system’s power provided by control model based on perturbation & observation algorithm and the intelligent control of PV system on the basis of the fuzzy recurrent neuronet respectively
The tolerance of a fuzzy recurrent neural net to noise is explained by two factors: the ability of the model to have similar responses for patterns contaminated with different intensities of noise and the resilience to noise of the low similarity of the responses for patterns of different PV system’s state defined by sudden variations in the solar irradiation levels.

The use of the fuzzy recurrent neural net provides a more suitable approach to the MPPT problem, with the pointing accuracy. Extensive simulation studies on Simulink model have been carried out on different initial conditions, different disturbance profiles and variation in PV system and the solar irradiation levels parameters. It shows consistent performance has been achieved for the proposed intelligent control of PV system on the basis of the fuzzy recurrent neuronet with good stability and robustness as compared with the standard model based on perturbation & observation algorithm.

5. Conclusions

Extensive simulation studies show that the intelligent control of PV system on the basis of the fuzzy recurrent neuronet is robust to PV system uncertainties. Unlike popular perturbation & observation MPPT algorithm, a fuzzy recurrent neural net is used to approximate the control law, and not the system nonlinearities, which makes it suitable to handle a wide range of nonlinearities. Compared to standard MPPT algorithm – perturbation & observation, the intelligent control of PV system on the basis of the fuzzy recurrent neuronet produces good response time, low overshoot, and, in general, good performance. Simulation comparison results for a PV’s control system demonstrate the effectiveness of the intelligent control of PV system on the basis of the fuzzy recurrent neuronet as compared with the standard model based on perturbation & observation algorithm.

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