Automatic adaptation of a Solar Plant Intelligent Control System

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Abstract. The article continues the authors’ scientific research in the field of solar plant intelligent control system. This paper presents a developed on-line and off-line automatic adaptation methods which allow solar plant intelligent control system to adapt to rapid dynamic of insolation in real time and to seasonal insolation fluctuations during night time. The experimental results show that the proposed solar plant intelligent self-adaptive control system produced robust and rapid maximum power point tracking, as compared to a classical solar plant MPPT system based on Perturb & Observe or particle swarm optimization under seasonal fluctuations or rapid dynamic of insolation.

1. Introduction
Solar plants are the most affordable during pandemic COVID-19 and waste-free sources of energy among energy sources [1]. Solar plants are highly scalable and productive in a large number of world locations, equally in household and industrial needs. The solar plant intelligent control systems (SPICS) include deeply intertwined photovoltaic and intelligent software components, provide effective control that according irradiation mode and represent cyber-physical systems. The development of SPICS provides sustainable evolution and progress of smart grid and smart town.

The article continues the authors’ scientific research in the field of SPICS. In [2] we developed, simulated and validated the SPICS based on a modified fuzzy neural network (MFNN). In order to transform proposed in [2] SPICS into cyber-physical system we add to it self-adaptation subsystem based on developed automatic adaptation methods. The proposed self-adaptive SPICS easily can be embedded into a smart grid or smart town. The developed on-line automatic adaptation method allows SPICS to adapt in real time under rapid dynamic of insolation. The developed off-line automatic adaptation method allows SPICS to adapt during night time to seasonal fluctuations in insolation. All the experimental results we obtained from the 1KW off-grid solar plant at the site of Abakan (Long. 91.4° E, Lat. 53.7° N, altitude of 246 m) from February 2020 through March 2020 under seasonal fluctuations or rapid dynamic of insolation based on the modified and developed author's software [4-6]. The experimental results show that the proposed self-adaptive SPICS produced robust and rapid maximum power point tracking (MPPT), as compared to a classical solar plant MPPT System based on Perturb & Observe (P&O) or particle swarm optimization (PSO) under seasonal fluctuations or rapid dynamic of insolation.
2. Automatic adaptation method of a Solar Plant Intelligent Control System

Figure 1 represents the developed automatic adaptation method which includes off-line and on-line automatic adaptation of a SPICS on the basis of MFNN. We tuned the MFNN based on the data

\[ Z^i = (x^i, P^i, dI/dV^i), s^i = (dI/dV^i), u^i = D^i ] (1)\]

where \( I \) and \( V \) represent the current and voltage respectively, \( D^i \) is the duty cycle of boost converter, \( dl \) and \( dV \) represent (respectively) the current error and voltage error before and after the increment, \( P \) – the PV system’s power, \( i \in [1, 10^6] \) – data of previous days which seasonal insolation fluctuations closes to forecasting insolation of tomorrow, \( x^i \) – input signal of modified fuzzy neural net, \( u^i = D^i \) – control signal and output signal of the MFNN.

In this research the MFNN includes the recurrent neural networks \( F_j(\mu_j(s^i), x^i, \mu_j(s^i), x^i), j = 1, 2 \) (number of hidden layers and delays are 2). We defined the proposed self-adaptive SPICS based on the following If-then rules:

\[ \Pi_j: IF x^i \ is \ A_j \ THEN \ u^i = F_j(\mu_j(s^i), x^i), \] (2)

where \( A_j \) – the fuzzy sets \( A_1 \) is uniform insolation, \( A_2 \) is non-uniform insolation) with membership function \( \mu_j(s), j = 1, 2 \).

![Flowchart of automatic adaptation method](image)

**Figure 1.** The developed automatic adaptation method.

In [3] we developed, simulated and validated a modified multi-dimensional PSO. We perform automated off-line adaptation method based on the modified multi-dimensional PSO to tune up a MFNN. The proposed off-line adaptation method scales by the number of tuned neurons, by the complexity of optimization: from local to global of correction and tuning up a modified fuzzy neural network by combining optimization and evolution steps. First, we initialize the \( g \) – Global Best position of swarm and \( p_{X,j} \) – the personal best position of particle \( X \) which correspondent seasonal insolation fluctuations and stored based on the developed author's software [4] at the end of the tuning cycle of MFNN. Then, we perform the modified multi-dimensional PSO to tune up a MFNN based on data (1) of previous days which seasonal insolation fluctuations closes to forecasting insolation of tomorrow and obtain trained MFNN.

This efficient initialization helps to avoid the possibility of superfluous searching in an area which doesn’t include the best MFNN configuration best. This allows to reduce time wasted to find in the wrong area the best MFNN configuration which according to seasonal insolation fluctuations. Therefore, initial values of the \( g \) and \( p_{X,j} \) set close to the best MFNN configuration which according to
seasonal insolation fluctuations. Thus, the developed automatic off-line adaptation method provides the following benefits:

- a faster convergence than for pure modified multi-dimensional PSO;
- a greater probability of finding the best MFNN configuration which according to seasonal insolation fluctuations.

The developed off-line automatic adaptation method allows SPICS to adapt during night time to seasonal fluctuations in insolation and provides trained MFNN which effectively generate the control signal – best solution $X$.

Figure 2 briefly shows the developed on-line automatic adaptation method. We compose and solve relatively to $w$ the following matrix equation

$$B \cdot (w^{i}_{1}, ..., w^{i}_{h})^{T} + (s^{i}_{1}, ..., s^{i}_{r})^{T} = Y,$$

where $w^{i}_{q}$ – vector of $q^{i}$ hidden layer’s weights of the recurrent neural networks $F_{z}(\mu_{z}(s^{i}), x^{i})$, $s^{i}_{q}$ – vector of $q^{i}$ hidden layer’s biases of the recurrent neural networks $F_{z}(\mu_{z}(s^{i}), x^{i})$, $B_{i} = (\tan s \in \sum_{j=1}^{n_{1}+p_{1}} (x_{j} \cdot w^{1}_{j1}) + s^{1}_{1}, ..., \tan s \in \sum_{j=1}^{n_{h}+p_{h}} (x_{j} \cdot w^{h}_{j}) + s^{h}_{1})^{T}.$

### Figure 2. The developed on-line automatic adaptation method.

The benefits of the developed automatic on-line adaptation method include low computational costs and simple procedure of a GMPP fast finding.

### 3. Result

To illustrate the benefits of the proposed self-adaptive SPICS, we revisited the numerical examples from the previous section II based on the modified and developed author’s software [4-6]. In this research we consider a low cost 1KW off-grid solar plant. This solar household plant includes: four Solar Panels Sundragon i250-60P, 250W; Off-grid Inverter, 1kW; PV Cable; Roof or Ground Mounting Structure, 1kW; Charge Controller, 24V/60A; two Gel Storage Battery, 12V/200AH. Table I shows the parameters of a Solar Panel Sundragon i250-60P. All the experimental results we obtained from the 1KW off-grid solar plant at the site of Abakan (91.4° of longitude East, 53.7° of latitude North and 246 m of altitude) under seasonal fluctuations or rapid dynamic of insolation based on the modified and developed author’s software [4-6].

In this experimental research we selected data from February 2020 through March 2020 according three partial shading cases:

- first case represented a smooth partial shading of the solar plant in the morning;
second case represented a cloud (or snow, an obstacle) covering, which causes slow or rapid
dynamic of insolation;
third case represented a smooth partial shading of the solar plant in the evening.
In such partial shading cases the power of a solar plant MPPT system based on P&O declines on
10% -70% [7-8].
The swarm size of pure PSO is 10. The base value of evaporation rate of pure PSO is 0.9.
Table 1 summarizes the experimental results of the proposed self-adaptive SPICS and a classical
MPPT system based on P&O or PSO under rapid dynamic of insolation accordingly with three partial
shading cases. We evaluated an average effectiveness of the proposed self-adaptive SPICS as follows

\[
100\% \ast \frac{\sum_{t\in T}(P_{MFNN}^t - P^t)/P_{max}^t}{\sum_{t\in T}1},
\]

where \(P_{MFNN}\) is energy provided by proposed self-adaptive SPICS, \(P\) is energy provided by standard
solar plant MPPT system based on PSO or P&O, \(P_{max}\) is maximum power of the solar plant, time \(t \in \{February 2020, March 2020\}\) accordingly with partial shading case.

| Number of a partial shading case | P&O (W) | PSO (W) | Proposed self-adaptive SPICS (W) | Maximum power of the solar plant (W) |
|---------------------------------|--------|--------|---------------------------------|-----------------------------------|
| 1                               | 324    | 292    | 479                             | 483                               |
| 2                               | 611    | 531    | 871                             | 879                               |
| 3                               | 434    | 376    | 617                             | 623                               |

According to table 1, the proposed self-adaptive SPICS is more robust and produces on average
29.54% and 38.87 % more energy than does the case of the standard solar plant MPPT system, which
is based on a P&O algorithm and PSO, respectively. It is clear that the solar plant power provided by the
proposed self-adaptive SPICS is above 99 % under all partial shading cases.

This paper proposes an automatic adaptation method of a SPICS. The developed on-line automatic
adaptation method allows SPICS to adapt in real time under rapid dynamic of insolation. The developed
off-line automatic adaptation method based on the modified PSO allows the SPICS to adapt during night
time to seasonal insolation fluctuations. This is a huge improvement upon the conventional PSO which
provides the new operating point too far from the MPP and requires many iterations to reach GMPP.
The experimental results show that the proposed self-adaptive SPICS produced robustness, rapid
GMPP and response rate, as compared to a classical solar plant MPPT System based on P&O algorithm
or PSO under seasonal fluctuations or rapid dynamic of insolation. The implementation of the proposed
self-adaptive SPICS provide automation and increase efficiency of solar plants. The proposed self-
adaptive SPICS easily can be embedded into a smart grid or smart town. It can be also elaborated as a
starting point or an additional software module to promote and create efficient renewable energy or
smart grid projects faster.

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