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EFFICIENCY ENHANCEMENT OF MODULAR MULTILEVEL CONVERTER BASED SOLAR MICROGRID SYSTEMS USING ANFIS MPPT CONTROLLER UNDER DIFFERENT WEATHER CONDITIONS

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In this paper, we present a study and simulation results about the behaviour and performance of the Adaptive Neuro-Fuzzy Inference System (ANFIS) based maximum power point tracking (MPPT) controller for enhancing the efficiency and robustness of the solar energy conversion microgrid system, which is implemented using multilevel power converter under various scenarios of weather conditions.

The simulation results demonstrate a robust behaviour of the maximum power point tracker and a relevant improvement of the whole system performance of accuracy and speed of reaching and stabilization at the maximum power point regardless of the variable climate condition.

Keywords: solar microgrid system, modular multilevel converter, adaptive neuro-fuzzy inference system, maximum power point tracking, energy efficiency, performance optimization.

1. Introduction

In recent years, solar photovoltaic (PV) based electrical power conversion systems are attracting particular interest by the researchers due to the fact that the solar energy source is free and abundant worldwide, it also provides perfectly clean electricity without any environmental effect. However, the production and generation of electrical energy from this renewable resource is known to be intermittent and of moderate efficiency when compared to the traditional fossil fuel and even to the production efficiency of the other renewable energies [1-4]. Therefore, the tendency of improving the efficiency of electrical power generation and conversion from solar PV systems under variable weather conditions represents a challenging and hot research subject [5, 6]. In this respect, the use of new technology for power conversion appears among the trends and issues towards improving both the operating performances of the solar based renewable energy conversion system and the quality of electrical power delivered to the end user. The Modular Multilevel Converter (MMC) is recently becoming an emerging and

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advanced power electronics mechanism due mainly to its high switching frequency and low switching stress and losses due to modular and multilevel structure, high voltage operation capabilities and high power quality with improved efficiency [7-12]. These advantageous features of this energy conversion technology have extensively been exploited in improving the efficiency and operational performance of high power wind energy conversion systems such as HVDC systems [13-15]. Unfortunately, the use of this device in the field of solar energy conversion systems, particularly those of low and medium power levels, is still requiring more research coverage [16, 17], for which we consider the use of this new technology can bring significant energy savings and improve the efficiency of the whole conversion system.

Besides the use of the MMC converter, the development and design of a well performing and advanced algorithm to track and force the system to operate at the maximum level of the power generated by the PV array under whatever weather conditions is a second alternative that can be targeted to increase the total capacity of the generation system and level up its energy efficiency. In this vein, many techniques and algorithms have been designed and implemented to enhance the power generated and produced by the Photovoltaic (PV) array system, where the aim is to track and ensure the operating point at the maximum power. Reported in the literature we can just list some of the classical methods of controlling the maximum power point generated by the PV array [18, 19], however the most familiar and used of these algorithms are the perturbation and observation algorithm [20, 21] and Incremental conductance [22, 23].

Recently, artificial intelligent methods are widely investigated and employed to design and implement the MPPT controller and achieve a significant improvement of the solar array-based energy generation system operating performance under variable climate conditions. Such of these methods are artificial neural network (ANN) [24], fuzzy logic (FL) [25], Evolutionary computing [26], simulated annealing [27], sliding mode and fuzzy logic [28] and Particle swarm optimization (PSO) [29].

The purpose in this work is to investigate, study and simulate under MATLAB/Simulink environment the behaviour and reaction of the ANFIS based MPPT controller under various and different climatic condition characterized particularly by the rate of the sunlight intensity variation during the day as well as its performance of improving the energy efficiency of the whole grid tied solar conversion system whatever these atmospheric situations. To attain this aim, the paper’s content is structured as follows. In section 2, we describe the components of the solar conversion system subjected to this study. In section 3, we explain the theory behind the MPPT controller whereas the ANFIS principle of operation is described in section 4. Section 5 will be devoted to the application of that algorithm as well as the discussion and interpretation of the obtained results to end up with general concluding points to be pointed out in section 6.

2. General description of the studied microgrid PV system

Grid connected PV energy conversion systems are more reliable and cost effective in providing the electricity generated from the sunlight to the end user mainly because it does not need a battery bank for power storage. This energy conversion system is however realized via the use of power inverter to convert DC power generated by the PV array into variable and stable AC power which is ready for use by the utility grid and any other connected load. Therefore, the inverter technology is a critical issue to implement an efficient PV generation and conversion system. Due to the aforementioned very interesting and attractive advantages of the modular multilevel power converter, we chose to implement our system around this type of power electronics converter technology to gain a priori improved output power quality as well as some other enhanced operating performance of the system. By using this type of inverter, the structure of the Microgrid PV system which is subjected to performance improvement is firstly composed of a PV generation source that uses the sunlight to produce an electric power characterized by with the voltage $\boldsymbol{V_{pv}}$ and the current $\boldsymbol{I_{pv}}$, which are intermittent and depend on the climate condition of temperature and irradiance. Since the generated output voltage of the PV unit is of low level, a DC-DC boost converter is being used to produce an enhanced DC voltage level compatible with that needed for the operation of the MMC inverter described above. The power transfer from the inverter to the utility grid as well as the AC connected load is controlled using an appropriate Voltage Source Converter (VSC) controller. Using this controller, a permanent stable and synchronized power in both frequency and voltage is being delivered to the grid and the load.

On the other hand, and in order to further improve the efficiency of the whole solar based Microgrid conversion system, an Adaptive Neuro-Fuzzy Inference System (ANFIS) based MPPT controller is being investigated and implemented. A general block diagram of this MMC based Microgrid PV system is represented in Fig.1.

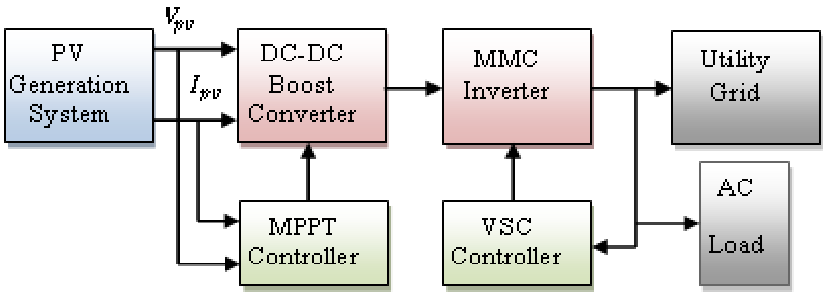

Fig.1. General block diagram of the MMC based Microgrid PV system

3. Maximum power point tracking of a PV array

The Maximum Power Point of a photovoltaic module describes the point on a current voltage (I-V) curve at which the solar PV device generates the largest output power, where the product of current intensity (I_{pv}) and voltage (V_{pv}) is maximum. But this Maximum Power Point changes due to changes in weather conditions such as temperature and amount of solar radiation (irradiance). Therefore, the output power from the PV array is dependent on inputs irradiation and temperature which vary throughout the day. However, there is always one point that gives the maximum power from the PV array depending on the variations at the time we consider. That is there will be a lot of energy being wasted because of weather condition intermittence, which leads the generation system to be of poor output efficiency, hence, more PV arrays are to be installed to cover for the wasted power [30]. In order to prevent this wastage, the use MPP Tracker as a control mechanism is generally required to track and force the solar modules to work at their Maximum Power Points under different weather conditions. Consequently, the operating point of the PV module is always corresponding to the highest value on the I-V curve for the system to generate the maximum power regardless of weather variation and changes.

Regarding the system structure of Fig.1, the MPPT controller is used to automatically produce the optimal operating switching duty cycle of the boost converter for generating the required output voltage corresponding to the maximum power level extracted from the PV array unit.

4. Adaptive Neuro-Fuzzy inference system (ANFIS)

ANFIS stands for Adaptive Neuro-Fuzzy Inference System. It is an artificial intelligence system that combines between Artificial Neural Networks (ANN) and Fuzzy Logic (FL) characteristics, where its principle of operation consists of using neural network training methods to adaptively and iteratively learning the numerical input data in order to tune and optimize the membership functions and the consequent function parameters of the fuzzy system structure. The objective is to transform a given system's input data into a desired output via a highly interconnected artificial neural network [31]. A typical structure of that system is depicted in Fig. 2.

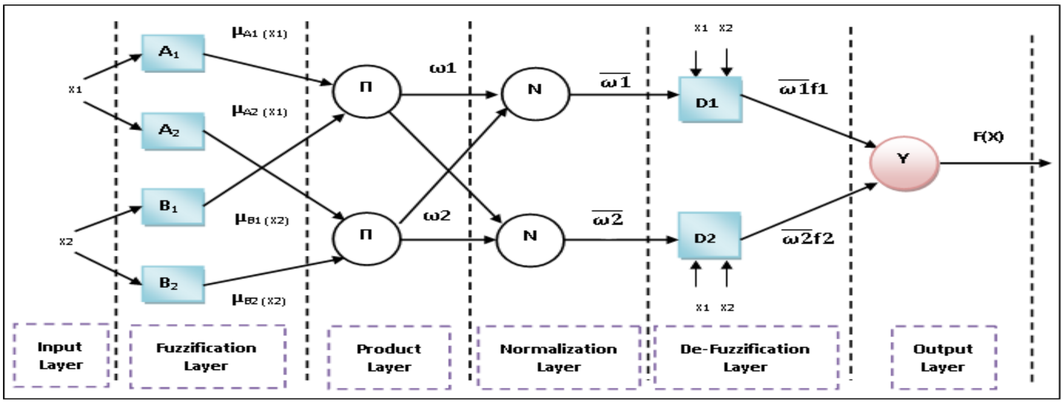

Fig. 2. Typical structure of ANFIS system

Where (A_1, A_2, B_1, B_2) and (D_1, D_2) are the parameter sets of the membership functions corresponding respectively to the fuzzification and de-fuzzification layers of the ANFIS controller. These parameters are optimally tuned using NN learning algorithms of least squares and backpropagation.

The ANFIS structure is composed of mainly five layers that ensure the intelligent input data processing required for adaptively updating the internal parameters characterizing both fuzzification and de-fuzzification layers' functions using neural network training algorithm. The data is then processed within two intermediate layers of constant parameters and are called respectively product layer (Π) and normalization layer (N) to generate in overall the desired output collected at the output layer.

5. System's performance improvement using ANFIS MPPT controller

In order to investigate the operational behaviour and performance characteristics of the ANFIS algorithm in tracking and maintaining the maximum power level generated by the solar array and delivered to the Microgrid system, different scenarios of weather conditions are considered. Special attention is given to the way the sunlight intensity varies and changes within the day while assuming the system operates at the nominal temperature of 25 °C. The objective is to understand how the MPPT algorithm reacts when operating under different weather conditions.

Accordingly, the following cases are considered for study.

Case 1: it is named as fine or stable weather condition, in which the sun irradiation varies slightly with slow rate during the day, particularly this is defined to be slowly varying within the range from 700 W/m^2 to 1000 W/m^2.
Case 2: this is named as the average weather conditions; here the sun irradiance variation is considered more frequent than that of case 1.
Case 3: this represents the harsh or extreme weather conditions, where the sunlight irradiance is characterized by fast variation and change during the hours of the day. We intentionally applied the most extreme atmospheric and weather conditions on the PV array to observe the reaction of the proposed MPPT controller as well as its tracking capability of the maximum output power level.

The imposed profiles of the sun intensity variation corresponding to each previous assumed weather scenarios are respectively depicted in Fig.3, Fig.4 and Fig.5.

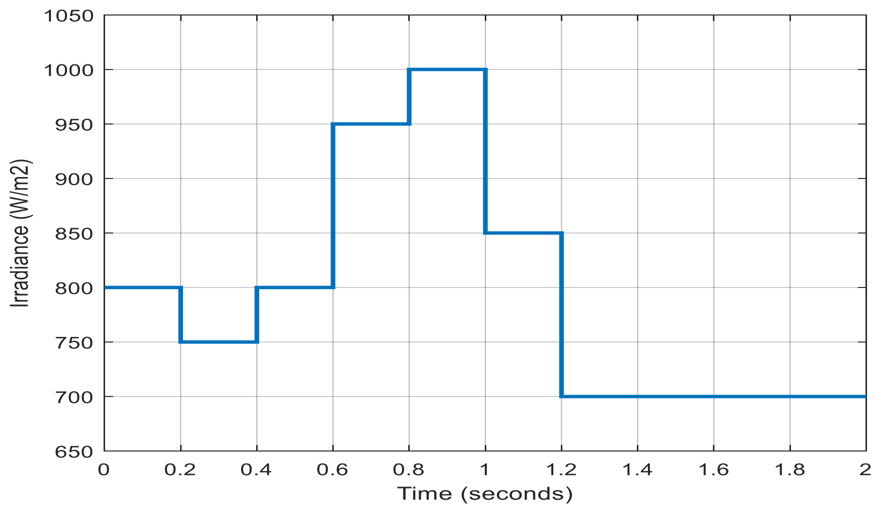

Fig.3.The imposed irradiance variation illustrating fine weather condition

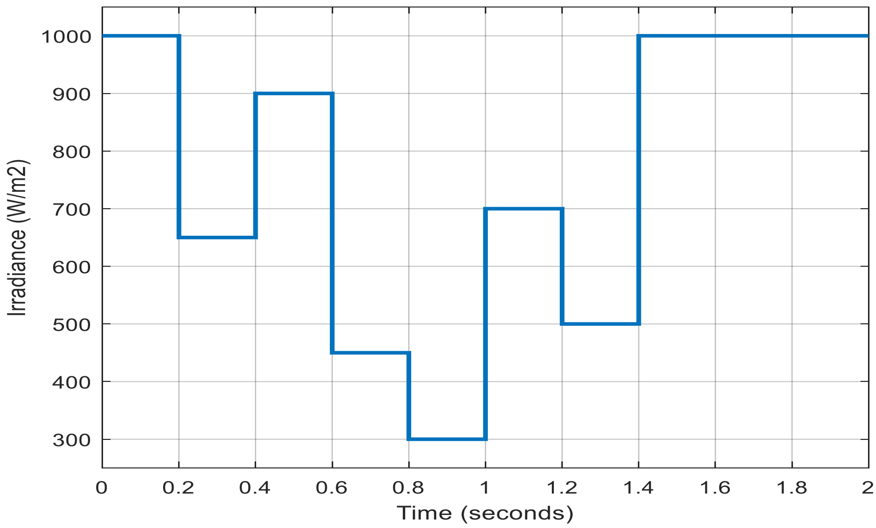

Fig.4.The imposed irradiance variation illustrating average weather condition

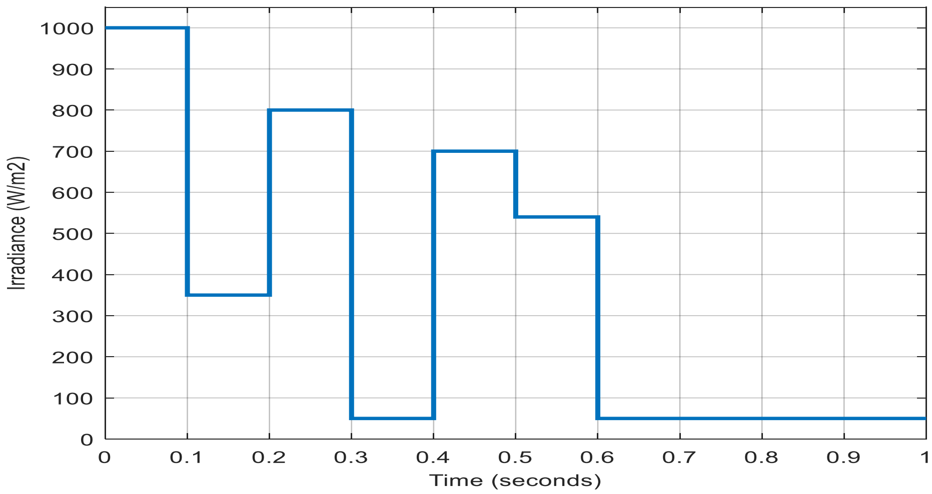

Fig.5 The imposed irradiance variation illustrating harsh weather condition

In order to show and demonstrate the superiority and effectiveness of the proposed ANFIS algorithm as an MPPT controller for improving the energy efficiency of the solar array and modular multilevel power converter based Microgrid system, it is compared with the Perturb and Observe (P&O) MPPT method which is the most familiar and the widely used algorithm. The obtained simulation results showing the behaviour and tracking capability of both algorithms as it corresponds to each one of the three aforementioned weather condition scenarios are presented respectively in Fig.6, Fig.7 and Fig.8.

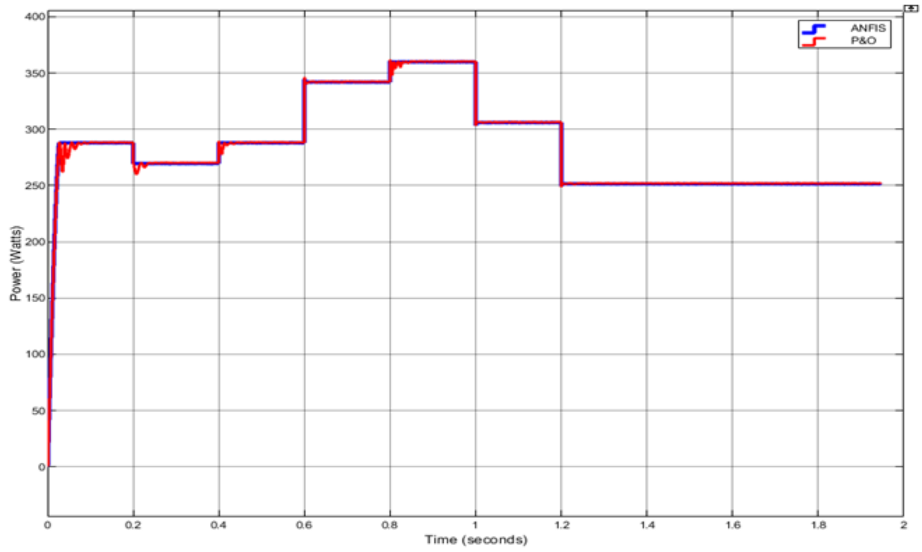

Fig.6. ANFIS controller power tracking behaviour under fine weather conditions [32]

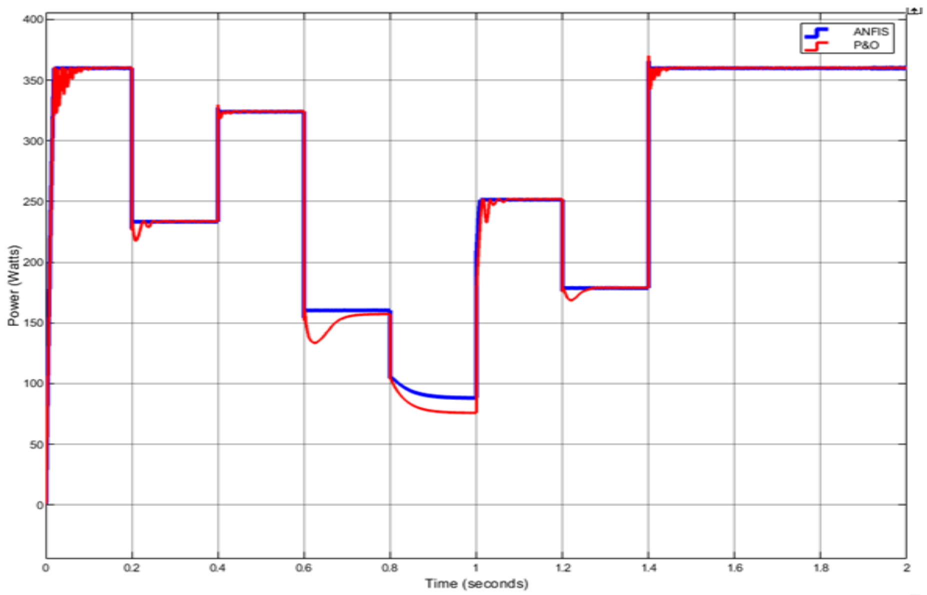

Fig.7. ANFIS controller power tracking behaviour under average weather conditions [32]

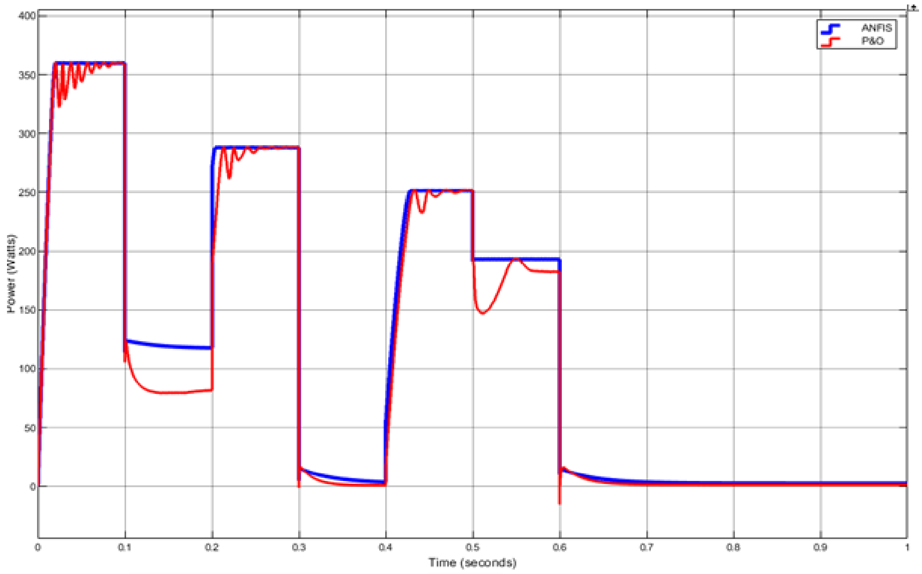

Fig.8. ANFIS controller power tracking behaviour under harsh weather conditions [32]

6. Results interpretation and discussion

Obviously, the P&O algorithm behaviour and performance of tracking and maintaining the maximum operating power point of the studied solar based conversion system can be judged to be accepted in case of uniform and slow variation of environmental weather (sun irradiance) although its oscillatory behaviour, which is its major drawback characterizing its performance at the MPP. Unfortunately, this performance is getting worse in average weather conditions with poor and less effective response where it completely fails to track the operating maximum power point under harsh weather changes. All these drawbacks and ill functioning presented by P&O algorithm are clearly avoided and compensated effectively and efficiently by the use of ANFIS based MPPT controller which was able to rapidly track the maximum power point of the generated power in all times and keeping stable operation at that power level. This behaviour reveals that an important efficiency enhancement of the whole generation and conversion system can be achieved when implementing the ANFIS MPPT controller.

7. Conclusion

In this paper, we attempted to give a thorough study on the dynamical behaviour and performance of the ANFIS MPPT controller as it is implemented with grid-tied solar energy conversion system using multilevel converter as a new and advanced power electronics technology device allowing of achieving a cost effective of the electrical power plants with an extra of energy conversion efficiency improvement.

It is proved by the simulation results obtained out of this study that ANFIS based MPPT controller is more effective and stable; it reacts rapidly with the variation of weather condition at the different studied atmospheric scenarios, which reveals a high capability of tracking and maintaining the maximum power operating point of the whole system. Overall, unlike P&O based MPPT controller which judged to be of accepted operating performance although its drawbacks, ANFIS is not affected by changes in climate condition and it exhibits a fast and stable dynamics of reaching and tracking the maximum operating power point of studied system. Hence, it can be recommended as an excellent MPPT controller whatever the weather variation of temperature and sunlight irradiance.

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