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NEURO-FUZZY CONTROLLER ALGORITHM FOR OBTAINING MAXIMUM POWER POINT TRACKING OF PHOTOVOLTAIC SYSTEM FOR DYNAMIC ENVIRONMENTAL CONDITIONS

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ABSTRACT

In this paper, an efficient Neuro-Fuzzy controller for attaining maximum power point tracking of PV systems is proposed. The efficiency of the proposed Neuro-Fuzzy controller is enhanced by an evolutionary algorithm. Here, an enhanced hill climbing algorithm is used for optimizing the PV array current and the respective output power. The converter output depends on the values of current, voltage, and power of the system. In conventional hill climbing search algorithm, the current and power values are optimized based on the random search at different time instant. But, in the enhanced hill climbing search algorithm, the power and current values are optimized based on the change of values. So, the searching time of the algorithm is reduced compared to conventional search algorithm. Then, the output of the search algorithm is applied to the neuro-fuzzy controller. The proposed Neuro-Fuzzy controller is a hybrid controller, which is the combination of artificial neural network and fuzzy controller. Then, the outputs of both techniques are hybridized based on the mean operator and the hybrid output is generated. The output of the hybrid controller is the maximum output of the converter of PV system. The proposed controller is implemented in MATLAB working platform and the output performance is evaluated

KEYWORDS : PV system, DC-DC converter, Hybrid Controller, Hill climbing algorithm, Maximum Power Point Tracking (MPPT), Neuro-Fuzzy controller (NFC).

INTRODUCTION

In today’s growing industrialization and domestics, there is a very high demand for power. Thus, to preserve a green environment, it is indispensable to produce power from the various renewable energy sources in the environment friendly manner. Nowadays, due to the progress in photovoltaic solar technology, there is a substantial increase in the installation of photovoltaic (PV) solar panels in public infrastructures, residential houses, and PV solar power plants. Normally, PV systems generate DC electricity when the sunshine falls on the PV array, requiring less maintenance, and emitting no noise, among others [Solanki S (2009)]. There are two main types of photovoltaic power systems available, which are classified based on their functions and configurations, they are: i) stand-alone systems and ii) grid-connected systems. In recent years, there have been an ever-increasing number of grid-connected systems that are in parallel with the electric utility grid and provide solar power to the utility by means of the grid [Prodanovic M, Timothy C and Green (2003), Xiao W, Ozog N and Dunford (2007)]. Due to the non-linear characteristics of PV array,

MPPT

PV systems are usually equipped with the facility of Maximum Power Point Tracking (MPPT) feature. In nearly all the photovoltaic power systems, a particular control algorithm called MPPT is employed to make use of the available solar energy [Goudar M D, Patil B P, Kumar V (2010), Devishree J, et. al. (2006)]. The solar system utilizes the solar module as a source of electrical power supply. Each solar module has a best operating point known as MPP, which adjusts with its own characteristic as well as cell temperature and sunlight [Chang Y and Chang C (2010)]. MPPT is a control method, extensively utilized to take out maximum power available from the solar cells in a photovoltaic system [Ngan C, Tan C (2011)]. Moreover, the maximum power operating point varies when the insolation level and temperature changes. The perturb and observe (P&O) maximum power point tracking algorithm is the most frequently utilized technique owing to its simple implementation. The theory of the incremental conductance technique is to find out the variation direction of the terminal voltage for PV modules through gauging and comparing the incremental conductance and instant conductance of PV modules [Yu T, Lin Y (2010),]. Although, the parasitic capacitance algorithm is an analogous to incremental conductance, there is an effect of the solar cells' parasitic junction capacitance CP that models charge storage in the p–n junctions of the solar cells [Hohm D P and Ropp M E (2003)]. MPPT using Fuzzy Logic Control (FLC) provides numerous advantages of superior performance, robust and uncomplicated design. Further more, this technique does not necessitate the particulars of the exact model of system [Takun P, Kaitwanidvilai S and Jettanasen C (2011)]. Neural network has the capability to offer an enhanced technique of deriving non-linear models, which is complementary to traditional techniques [Premrudeepreechacharn S and Patanapirom N (2003)]. The hybrid neuro-fuzzy system is an extension of fuzzy and neural network, which is used for obtaining maximum power output of converter. In this paper, the outputs of the network and fuzzy system are hybridized by using the mean operator. From the output of the hybridization, the interference system can be generated. The neuro-fuzzy based interference system is used for balancing both the controllers. The description of the proposed controller based PV system and the problem statement are given in Section 3. Before that, a brief review of recent research works is presented in Section 2. The results and discussion are presented in Section 4, and Section 5 concludes the paper.

PROPOSED METHODOLOGY

To overcome the drawbacks, in this paper, an efficient Neuro-Fuzzy controller (NFC) for attaining MPPT of PV systems is proposed. The proposed NFC is the combination of FLC and ANN. The training dataset of ANN is generated based on the fuzzy rules, so the network complexity is reduced. The efficiency of the proposed controller is enhanced by an evolutionary algorithm (EA). The EA optimize the power converter duty cycle and observes the array output of the PV systems. Then, the output of the EA is applied to the NFC and the MPPT of the PV systems is determined. The EA is a subset of evolutionary computation, which is used for converging quickly to an operating point.

The PV grid system is playing an important role in electrical power application. The function of the grid system is it transfers the solar energy directly to the grid. The parts of the PV systems are PV generator, an inverter, and AC loads. The PV generator is an array, which is used to convert the solar electricity to DC electricity. The inverter is used for converting DC electricity into AC electricity. The block diagram of the grid connected PV system model is illustrated in Figure 1. In the block diagram, the DC electricity is produced when the sun illuminates PV modules. Then, it is converted to the AC power by the inverter and this AC power is used for the AC requirements. This AC power first supplies the system's AC requirements, and then outputs some or all of the remaining energy produced to the grid. At night, the power is supplied by the utility grid. The batteries used in the standalone PV applications are replaced by electricity from the utility grid in grid-connected systems, resulting in cost and maintenance reduction. If necessary, batteries can be used as they are in standalone systems. In the PV system model, the output voltage of the PV cell depends on the power tracking points of the array. The optimum power tracking points improves the converter output (ΔC). The converter output depends on the change of PV array output power (ΔP) and the change of output current (ΔI). For obtaining maximum converter output, the EA is used to optimize the values of ΔP and ΔI.

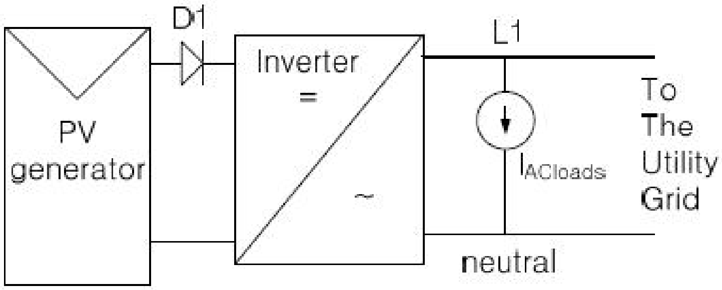

Figure 1: Block Diagram of the PV Grid System Model.

Enhanced Hill Climbing Algorithm

The hill climbing algorithm is one of the optimization algorithms, used for optimizing the input of the DC converter [Goudar M D, Patil B P, Kumar V (2011)]. From the optimized input, the maximum converter output is obtained.

The drawback of the conventional algorithm is it takes much time for obtaining the maximum operating point. In steady state condition, the PV power is oscillated, so the power loss can be occurred. To overcome these problems, in this paper, an enhanced hill climbing algorithm is proposed for optimizing the PV current and the corresponding power. So, the converter power efficiency is improved.

The knowledge of the direction of the irradiation change enables the MPPT to use different optimized tracking schemes for the different cases of increasing, decreasing, or steady irradiance. When the irradiance is changing rapidly this strategy leads to faster and better tracking, while in steady-state conditions it leads to lower oscillations around the MPP. The proposed hybrid algorithm combines the advantages of P & O, incremental, variable step and fractional voltage algorithms. The overall flow of the proposed algorithm is shown in Figure 2 The first step is the initialization program.

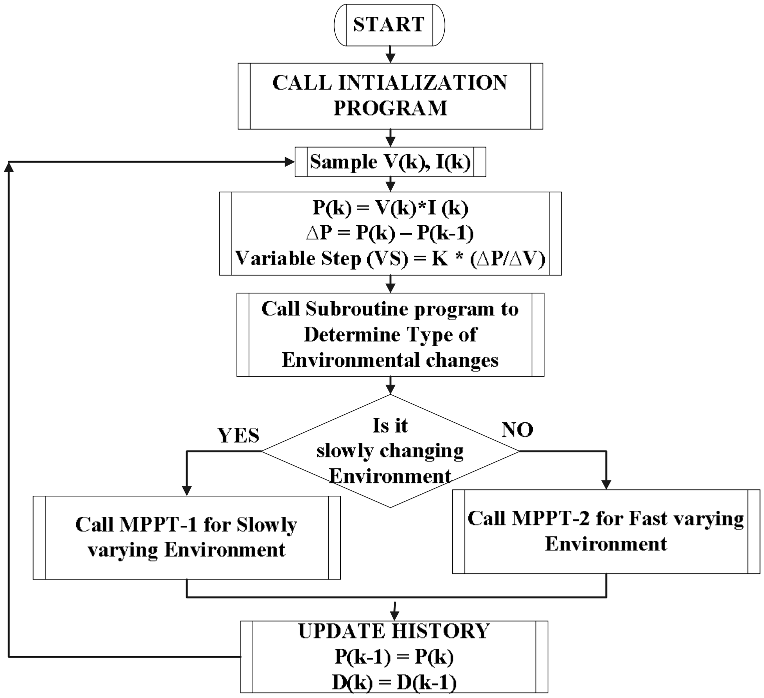

Figure 2: Flow Chart of Enhanced Hill Climbing Algorithm.

In conventional algorithm, the optimization is based on the PV current and the corresponding power value. But in this paper, the optimization is based on the change of PV current and the change of power. So, the power loss and the time for obtaining the optimal solution are reduced.

DETERMINE ΔC^F BY FUZZY CONTROLLER

The function of fuzzy controller is mainly based on fuzzy rules that are generated through fuzzy set theory. The fuzzy controller performs three processes: (i) fuzzification, (ii) decision making, and (iii) defuzzification.

Fuzzification is the process of changing the crisp value into fuzzy value. The fuzzification process has no fixed set of procedure and it is achieved by different types of fuzzifiers.

The shapes of fuzzy sets may be triangular, trapezoidale and more. In this paper, a triangular fuzzy set is employed. The fuzzified output is subjected to the decision making process, which contains set of rules. By using the fuzzy rules, the change of current, change of power, and the corresponding converter output are determined. Finally, the defuzzification process is performed and the output of the fuzzy controller ΔC^F is obtained. The structure of designed FLC is shown in Figure 3 and the steps involved in the design of FLC are given below,

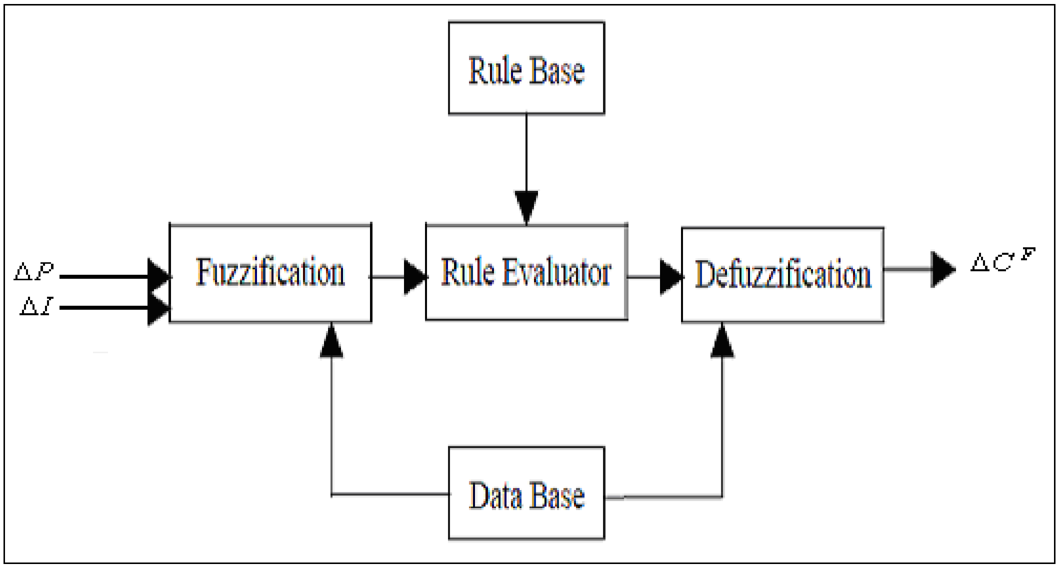

Figure 3: Fuzzy Controller Structure for PV System.

1. Choose the control variable of the power operation device.
2. Select the range of ΔP , ΔI and ΔC^F values of the system.
3. Perform the fuzzification process.
4. Design the decision making rules as per the selected range.
5. Perform the defuzzification process.
6. Evaluate the system output.

The inputs of FLC are ΔP & ΔI and the output is ΔC^F . The linguistic variables of the input and output of the fuzzy system are Negative Big, Negative Small, Positive Small, and Positive Big, which is referred as NB, NS, PS, and PB in the rule base. The developed fuzzy rules are tabulated in table 1. The ΔC^F is determined by means of these generated fuzzy rules.

Table 1: Fuzzy Rules for determining ΔC^F

ΔP / ΔI	NB	NS	PS	PB
NB	PB	PS	NS	NB

NS	PB	PS	NS	NB
PS	NB	NS	PS	PB
PB	NB	NS	PS	PB

DETERMINE ΔC^{NN} BY NEURAL NETWORK

Neural Network (NN) is an artificial intelligence technique, used for generating training dataset and testing the applied input data. A feed forward type NN is employed in the proposed method. Usually, NN is composed of three layers namely, input layer, hidden layer, and output layer.

The input layer consist of two inputs i.e., ΔP and ΔI . The output of the NN is network calculated voltage, which is represented as ΔC^{NN} . The process of NN is performed in the hidden layer. The structure of the network is illustrated in Figure 4. The hidden layer of the network is denoted as $H_{21}, H_{22}, \ldots\ldots\ldots\ldots H_{2N}$ and the weight of neuron is represented as w . The weight of neuron from input layer to hidden layer is w_1 and hidden layer to output layer is w_2 . Here, the Back Propagation (BP) neural network training and weight adjustment are utilized.

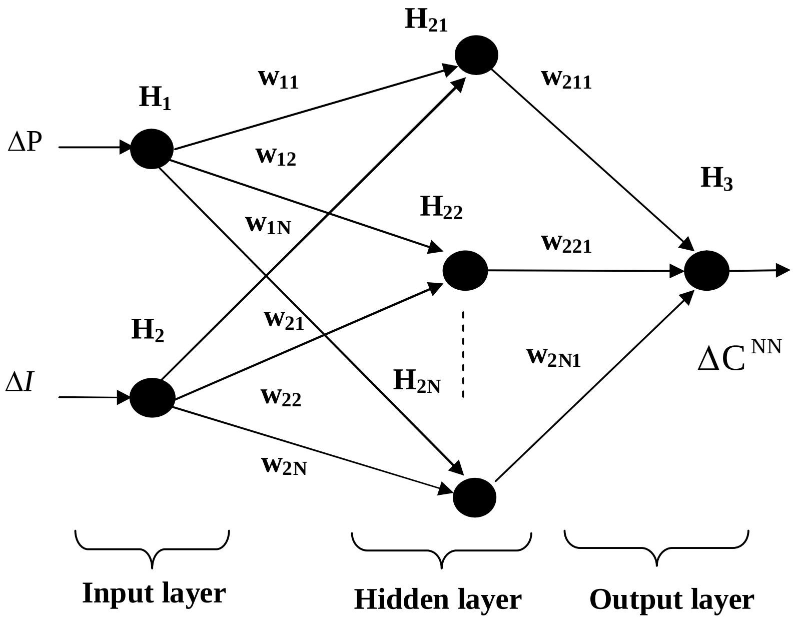

Figure 4: Network Structure of Proposed System.

DETERMINE ΔC BY N-F CONTROLLER

The proposed neuro-fuzzy (N-F) controller is the combination of fuzzy controller and neural network. In this paper, the hybridization is performed based on the mean operation. From the output of the N-F controller, the converter output ΔC is determined. The N-F controller based converter output is determined using the following equation.

$$\Delta C = \frac{1}{2}\left(\Delta C^{F} + \Delta C^{NN}\right)$$

$$\Delta C = \begin{bmatrix} \Delta C(1) \\ \Delta C(2) \\ : \\ : \\ \Delta C(t) \end{bmatrix} \quad \Delta C^{F} = \begin{bmatrix} \Delta C^{F}(1) \\ \Delta C^{F}(2) \\ : \\ : \\ \Delta C^{F}(t) \end{bmatrix} \text{ and } \Delta C^{NN} = \begin{bmatrix} \Delta C^{NN}(1) \\ \Delta C^{NN}(2) \\ : \\ : \\ \Delta C^{NN}(t) \end{bmatrix}$$

where, ΔC^{F} is the fuzzy controller output and ΔC^{NN} is the neural network output. Then using the equation, the maximum output of the converter is determined.

RESULTS AND DISCUSSIONS

The proposed hill climbing algorithm based hybrid controller is implemented in the working platform of MATLAB version 7.10. The description of the PV array is given in Table. 2 and the module current and module power voltage versus the voltage shown in Figure 5 (a) and Figure 5 (b).The efficiency of the proposed controller is tested with PV system. Then, the output performance of the proposed hill climbing based hybrid controller is compared with the fuzzy controller, neural network, and without using control technique. The simulation model of the proposed controller based PV system is illustrated in Figure 6. From the developed model, the output power characteristics of the proposed system are analyzed. The PV output of the system is analyzed at different time interval. The system output is analyzed based on the current, voltage, and the corresponding power value. Then, the change values are determined based on the current value and the previous value. The maximum converter output depends on the change of current and the change of power value.

Table 2: Description of the PV Array

Parameters		Range
PV Array	Short Circuit Current	5.45 A
	Open Circuit Voltage	22.2 V
	Maximum Power	85.14 W

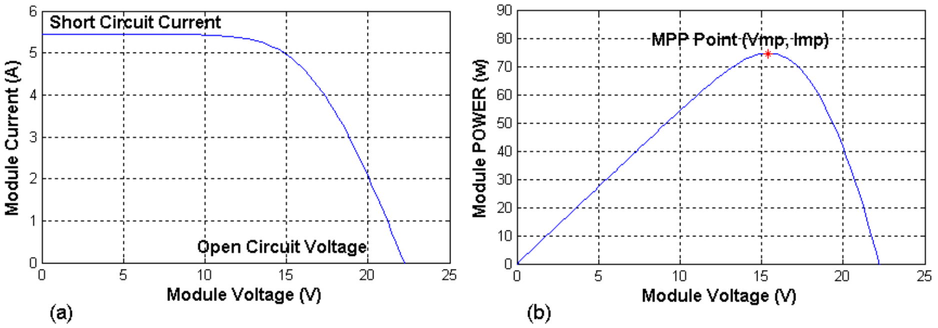

Figure 5: (a) Module Current versus Voltage (b) Module Power versus Voltage Characteristic curves

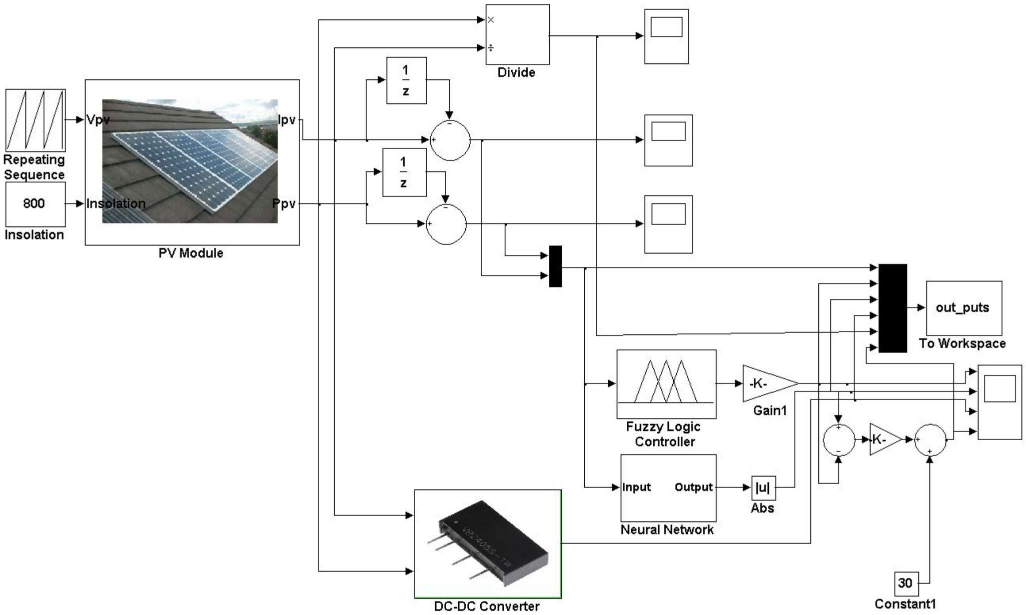

Figure 6: Simulation Model of Hybrid Controller Based PV System.

Where, the fuzzy rules are generated with respect to the change of current, the change of voltage, and the change of DC-DC converter output. The range of rules is defined based on the parameter values selected for implementation. The membership function diagram of the change of current, the change of power, and the 3-D structure of the fuzzy rules is described in Figure 7.

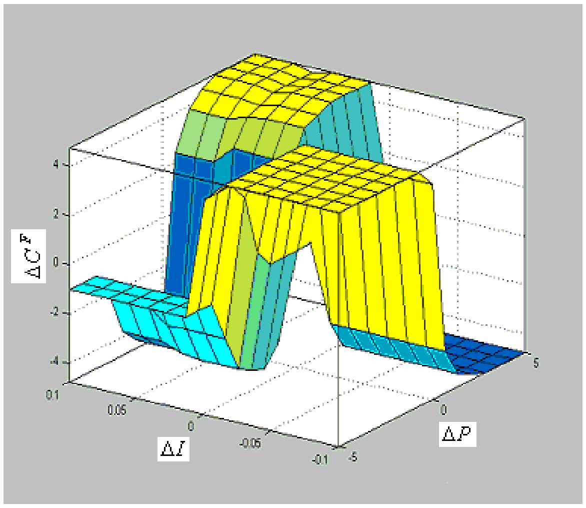

Figure 7 Structure of Input and Output Fuzzy Rules.

Furthermore, the output of the fuzzy controller, the input and output performance of the neural network are analyzed. The back propagation is used for training error of the network for achieving the target of the system. After that, the outputs of the fuzzy and neural network are hybridized using mean operator and the N-F hybrid controller is developed. Finally, the output of the fuzzy controller, neural network, and the neuro-fuzzy controller are compared. The comparison performance is shown in Figure 8.

From the comparison performance, the efficiency of the proposed hybrid controller in obtaining maximum power point is revealed. The proposed neural network and fuzzy controller based hybrid controller has accurately reached the maximum power tracking point of PV system. The convergence time of the hybrid controller is less compared to fuzzy and neural network based control techniques. Thus, the enhanced hill climbing algorithm based N-F controller is suitable for obtaining maximum power tracking point of photovoltaic system.

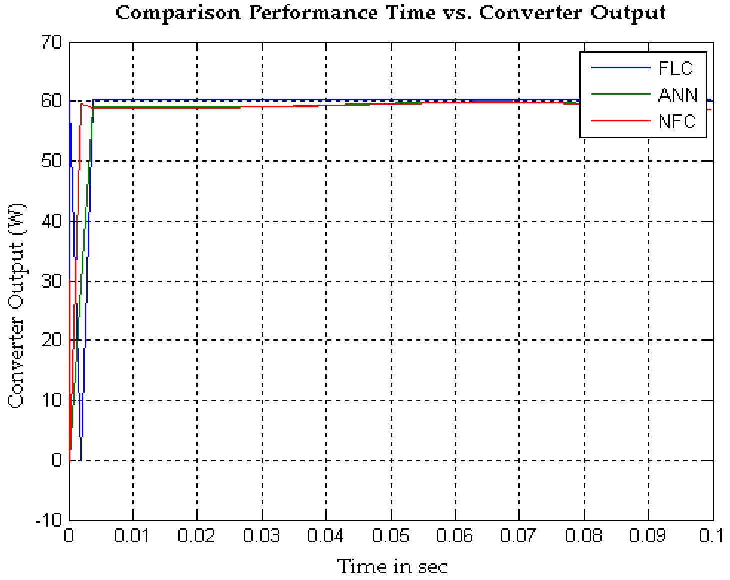

Figure 8: Comparison Performance of FLC, ANN and NFC

CONCLUSIONS

In this paper, the enhanced hill climbing algorithm based hybrid controller was proposed for obtaining MPPT of photovoltaic system. The proposed controller based PV system was implemented in MATLAB and the output performance was tested. Moreover, the output current and voltage of the PV system were analyzed. Using the output current and voltage of the PV system, the power value was determined. Then, the change of current, change of voltage, and the change of power values were determined by the enhanced hill climbing search algorithm. The output of the search algorithm was applied to the input of the fuzzy controller and neural network. The applied inputs were change of current and change of voltage. On the basis of input, the change of converter output was determined as well as the maximum power tracking performance was analyzed. Furthermore, the performance was compared with the fuzzy controller and neural network. From the analyzed performance, it was found that the proposed controller has achieved maximum converter output compared to other controller. As a result, the proposed controller has reached a remarkable level in obtaining maximum power of PV system.

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