

Comparative Analysis of Intelligent Controller Based MPPT for Photovoltaic System with Super Lift Boost Converter

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Abstract: In recent years, the electrical energy demand increases gradually and the power generation does not meet the demand due to lack of fossil fuel and environmental issues. The only solution is to use renewable energy sources for generating electricity and meet the consumers demand. In this paper, photovoltaic power system analyses their performance under various weather conditions. The objective of this paper is comparing the different intelligent controllers such as Fuzzy, ANFIS and Hybrid Fuzzy & Firefly Algorithm (HFFA) for Maximum Power Point Tracking (MPPT) of 100 Watts PV system using a Super Lift Boost Converter (SLBC). The proposed intelligent controller is designed and simulated in MATLAB environment under various weather conditions. The simulation results have been analyzed and the performance of the proposed model evaluated with changing irradiation conditions. Finally, the performance of Hybrid Fuzzy and firefly based MPPT has been suggested as the optimum controller for the photovoltaic system.

Keywords: ANFIS; Fuzzy Logic; HFFA; MATLAB; MPPT; photovoltaic; super-lift boost converter

1 INTRODUCTION

The generation of electric power from a photovoltaic cell (PV) essentially relies upon the adjustment in atmospheric terms, such as the temperature, irradiance, and the associated loads, with the terminals to the PV system. To enhance the generation of PV, a suitable framework for MPPT is set up, which anticipates developing the most extreme power that is harvested by PV. The MPPT framework is consolidated with PV to drive it to work at its maximum Power point (MPP). This MPPT framework has three sections, the equipment part which is predominantly used in DC-DC converter for disengaging PV panel. The photovoltaic panel part, which changes over the sunlight, is based on the detailed information of current and voltage to perform power into electrical power. In the control section, the detailed information of current and voltage is to perform the converter with the changes of impedance in the PV panel [1, 2]. The next part of the framework, the PV panel with MPPT attains the synchronization of connected loads and extracts the maximum power. Hence, the solar power tracking efficiency becomes increased. To endorse the PV system that is operating at MPP a chopper (DC-DC converter) along with an MPPT controller is interleaved within the PV panel and load. The open circuit voltage method, short circuit current method, Ripple Correlation Control (RCC), Perturb and Observe (P & O), Incremental Conductance (INC) and sliding mode control methods are the existing MPPT techniques for the proposed work. Traditional hill climbing approach is simple and flexible to adapt. But it has a few difficulties like fluctuations of operating point nearby MPPT, entails long duration to estimate MPP, rapidly changing weather conditions and ineffective operation under Partial Shading Circumstances (PSC); it decreases the complete system efficiency. Open circuit voltage (V_{oc}) based MPPT is basic and easy to implement, yet it is essential to estimate the V_{oc} intermittently by commutating the converter instantly, results in a momentary loss of power [3-6]. The MPPT is working with the short circuit current approach and is easy to execute with only one sensor, but instantly occurring the short-circuit of PV module is a prerequisite to estimate the short circuit current (I_{sc}). The state space based MPPT and

linearization based MPPT methods are transforming the non-linear current and power equations into linear, then it tracks the MPP. In temperature based MPPT method, a minimum number of transducers are used to trace MPP. The majority of the MPPT methods are specified previously to attain the maximum power point during the rapidly fluctuating climatic circumstances and partial shading conditions. The MPPT with Soft Computing (SC) techniques are familiarized to identify the MPP under uncertain climatic conditions effectively [18]. The best features of soft computing methods are predicted to accomplish tractability, flexibility to climate, quick changes in irradiance, low cost, instability, tolerance for imprecision and power.

In soft computing methods, the Fuzzy Logic Control (FLC) is an ultimate technique compared to the conventional methods. In FLC, there is no need of any mathematical modeling of a system and therefore, the nonlinear systems are dealt with easily. The process of an FLC is realized in three different phases. They are fuzzification, rule-based table and defuzzification. The errors are assessed by using irradiance, PV voltage, PV current, temperature, and output power [20-22]. The actual PV voltage and the actual PV current are the inputs of FLC. Based on the fuzzy logic controller output, the converter gets the Pulse Width Modulation (PWM) signal in various circumstances like irradiance, temperature and etc.

The Artificial Intelligence (AI) based approach is the most appropriate one for enhancing the dynamic response of the MPPT. Nowadays, the unification of Artificial Neural Networks and Fuzzy Logic are known as ANFIS, which is used in most of the automated computational applications in industry. It associates with the merits of both fuzzy and artificial neural network [6, 7]. So, it can be effectively adopted for nonlinear I-V responses of the PV panels. It has the excellent features like quick response, flexibility and calculating stimulus solutions for the MPPT problems [11, 13].

This paper ventured a novel technique of Firefly Algorithm (FA) by envisaging the points of membership functions of FLC for MPPT in photovoltaic systems using Super Lift Boost Converter (SLBC). In firefly algorithm, the coefficients α , β and γ are fixed to get every recurrence

to attain rapid merging. The suggested firefly algorithm is used for generating the PWM pulses by adjusting the fuzzy logic controller to achieve the optimum result for PV using MPPT. The simulation result of the suggested Hybrid Fuzzy & Firefly Algorithm (HFFA) is compared with FLC and ANFIS control methods to validate the response of the projected technique [15-17]. In this paper, the intelligent controller based MPPT techniques are incorporated with super-lift boost converter for attaining the maximum power output from the PV panel. The super-lift boost converters are used to improve the voltage transfer gain to a great extent. This investigation presents a modified super-lift boost converter that actualizes the super-lift operation too and its voltage transfer gain improves step by step in geometric development.

This enhanced transfer gain due to the super lift boost converter has been compared with the different intelligent controllers' response such as Fuzzy, ANFIS and hybrid fuzzy & Firefly algorithm for MPPT of 100 Watts PV system.

The organization of this work is presented as follows; section 2 presents the super-lift boost converter and its operation with necessary equations. Section 3 depicts the different proposed MPPT controllers in detail. Section 4 illustrates the simulation model and its results for different operating conditions. Finally, the findings of this work have been presented as a conclusion with optimized operating conditions of PV with different MPPT controllers in section 5.

2 SUPER LIFT BOOST CONVERTER

Super-lift practice is more influential than CUK and SEPIC converters which makes it powerful; it can generate the arithmetic progression output voltage and it has a high efficiency and power density [10, 11]. A Voltage-lift DC-DC Chopper (converter) operates with high voltage transfer gain and large voltage amplification in the first quadrant. This converter is used by industrial and domestic applications but it is still under research.

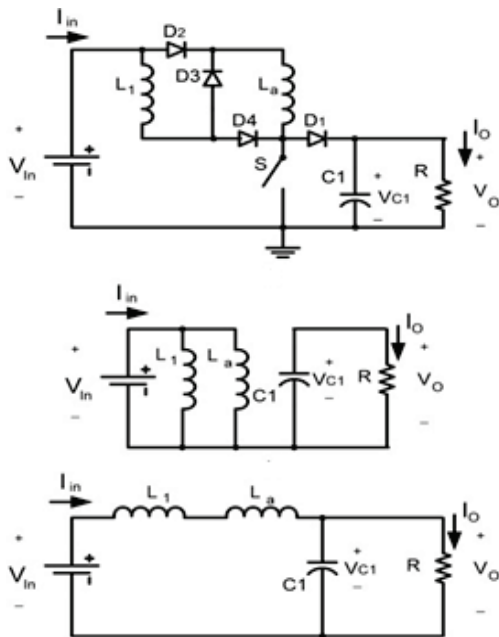


Figure 1 Super lift Boost Converter

The actual fundamental super lift boost converter circuit (called as an elementary circuit) and its equivalent circuits under two operating conditions (ON and OFF) are presented in Fig. 1. For obtaining the voltage-lift, one more set of L_a and $D_2 - D_4$ has been introduced for conventional boost converters (L_1, D_1, C_1 and R are the original components). The inductor L_a included in the proposed circuit has identical values of L and L_1 [9]. It is essential for the continuous current flow in the circuit as soon as the switch is under turn-off condition. It is expressed that $L_1 = L_a$ under switching-on period kT , so the current flow through L_1 (i_{L1}) is boosted with the input voltage (V_{in}). During this operating period, the D_2 and D_4 are in ON condition and D_1 and D_3 are in OFF condition (blocking mode). Therefore, the i_{L1} current starts to decrease with $-(V_0 - V_{in})$ during its off period $(1 - k)T$ through inductors ($L_1 + L_a$). Hence, $D_1 - D_3$ are conducted and $D_2 - D_4$ are blocked.

Therefore, inductor ripple current i_{L1} is:

$$\Delta i_{L1} = \frac{V_0 - V_{in}}{L_a - L_1}(1 - kT) \tag{1}$$

The voltage transfer gain can be expressed as:

$$G = \frac{V_0}{V_{in}} = \frac{1 + k}{1 - k} \tag{2}$$

Addition of inductor $q(L_b)$ with the basic super lift boost converter results in the repeated operation and it is as shown in Fig. 2.

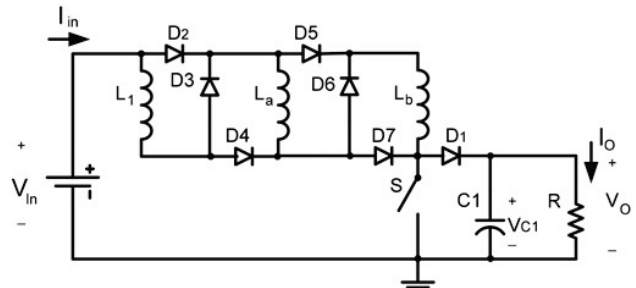


Figure 2 Super lift Boost Converter with $q(L_b)$ added inductor

Table 1 VTG's Comparison of different converters

Duty cycle	0,1	0,1	0,2	0,5	0,6	0,75	0,8	0,9
$G_{plf} = \frac{k}{1-k}$	0	0,11	0,25	1	1.5	3	4	9
$G_{pf} = \frac{k}{1-k}$	0	1,11	1,25	2	2.5	4	5	10
$G_{pslf} = \frac{2-k}{1-k}$	1	2,11	2,25	3	3.5	5	6	11
$G_{f1} = \frac{1+k}{1-k}$	2	1,22	1,5	3	4	7	9	19
$G_{f2} = \frac{1+2k}{1-k}$	1	1,33	1,75	4	5.5	10	13	28
$G_{f3} = \frac{1+3k}{1-k}$	1	1,44	2	5	7	13	17	37

The VTG of elementary circuit with q .

Added inductors is:

$$G_f = \frac{V_0}{V_{in}} = \frac{1+qk}{1-k} \tag{3}$$

When $q = 1$,

$$G_f = \frac{V_0}{V_{in}} = \frac{1+k}{1-k} \tag{4}$$

When $q = 2$,

$$G_f = \frac{V_0}{V_{in}} = \frac{1+2k}{1-k} \tag{5}$$

When $q = 3$,

$$G_f = \frac{V_0}{V_{in}} = \frac{1+3k}{1-k} \tag{6}$$

where: q - number of inductors in each stage; k - duty cycle; G_f - VTG of fundamental Circuit.

By using the fundamental VTG equation for different boost converter topologies like fundamental super-lift boost converters, positive output Luo and super lift Luo converter, boost converter with different duty cycles is computed and tabulated in Tab. 1. From this, it is clearly shown that the super-lift boost converters are more superior (when $k > 0,5$) than the existing converters.

3 MPPT CONTROLLERS

The renewable energy sources play an important role to meet the consumer power demand due to their abundant availability and a smaller amount of impact on the environment. The main hurdle in PV energy expansion is the investment cost of the PV power system implementation. The PV energy generation is continuously varying throughout the day due to the changing of weather condition. The efficiency of power generation is very low (the range of efficiency is only 9 - 17% in low irradiation regions). Therefore, MPPT technologies have an important role to operate the PV with the maximum power generation at various weather conditions [12-16]. The different MPPT techniques are established with respect to usage of equipment and cost. In this paper, different intelligent controller based MPPT techniques have been designed and investigated.

3.1 Fuzzy Logic Based MPPT Controller

In this method, the proposed fuzzy logic controller has been designed [3, 4] with two inputs, namely, actual PV current and PV voltage are shown in Fig. 3, Fig. 4, and Fig. 5. The trapezoidal method is used to convert these parameters to a fuzzy set. According to the time-varying voltage and current as an input to the fuzzy rule table, the rules are used to select the duty cycles to the converters which is shown in Fig. 6 and Fig. 7. Finally, the fuzzy set value is converted into a crisp set using the center of

gravity method, and then the signal is fed into a PWM generator to generate the pulses for DC-DC converter [22].

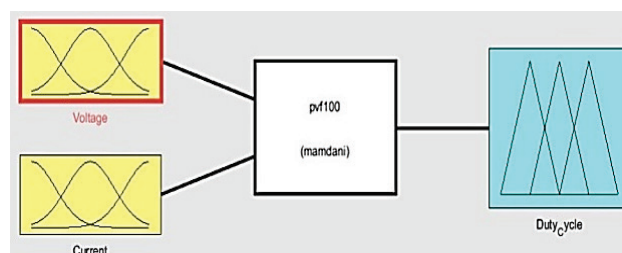


Figure 3 Proposed Fuzzy based MPPT Controller for DC-DC super lift converter

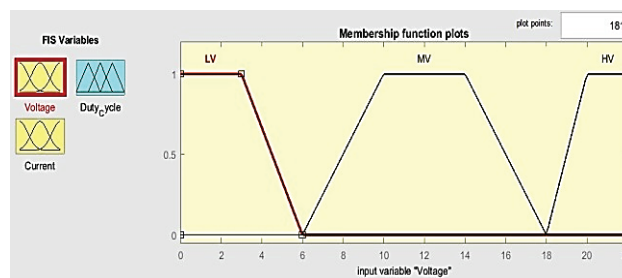


Figure 4 Input fuzzy Membership function-PV Voltage

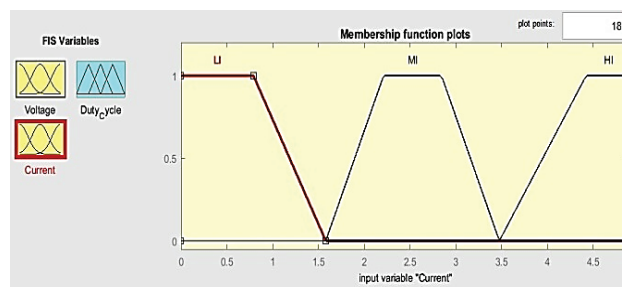


Figure 5 Input fuzzy Membership function - Current

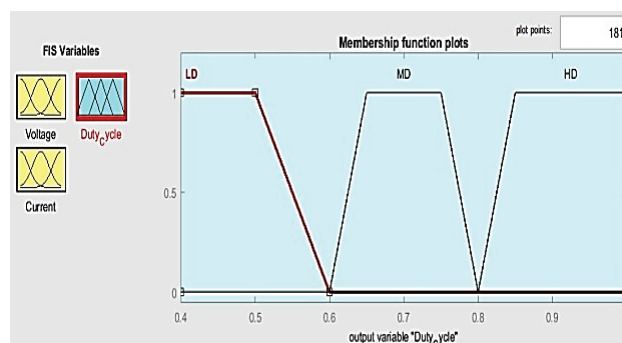


Figure 6 Output fuzzy Membership function - Modulation index (duty cycle)

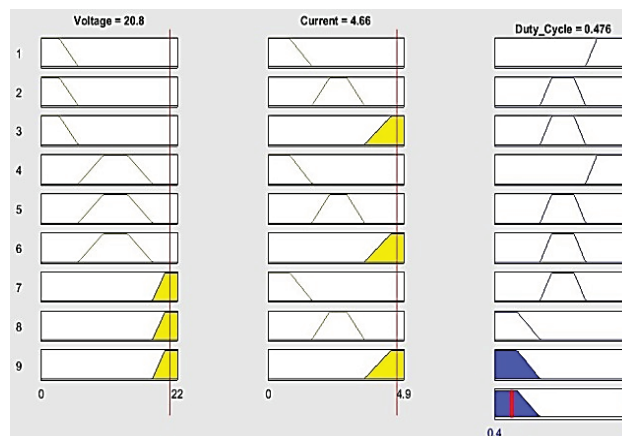


Figure 7 Fuzzy rules for MPPT controller

3.2 ANFIS Based MPPT Controller

In this method, ANFIS logic controller is designed and simulated in MATLAB environment as shown in Fig. 17. The ANFIS controller has two inputs namely; actual PV current, PV voltage and one output called duty cycle is shown in Fig. 8. The proposed ANFIS controller has been trained based on the input parameter and its respected output is presented in Fig. 9. The ANFIS controller has been analyzed based on the error value during training, as shown in Fig. 10. The ANFIS controller automatically selects the input and output membership values based on their training, then it generates the rule for selecting the duty cycle as shown in Fig. 11. Finally, ANFIS output signal is fed into a PWM generator to generate the pulse for super lift boost converter [5].

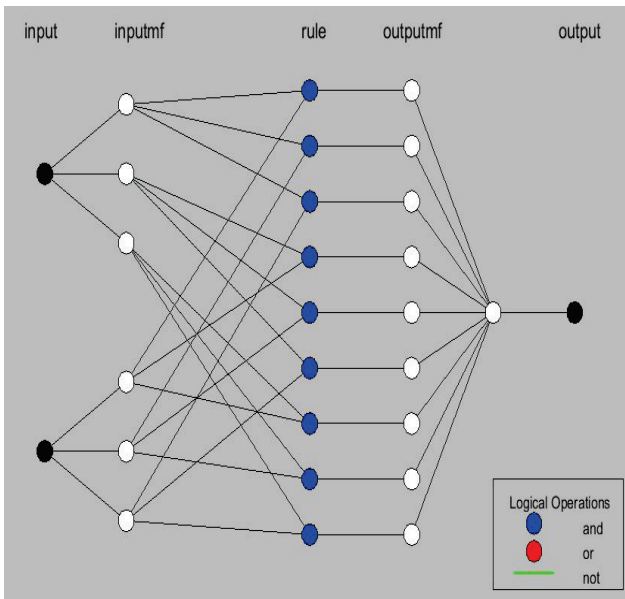


Figure 8 ANFIS Controller Network for MPPT controller

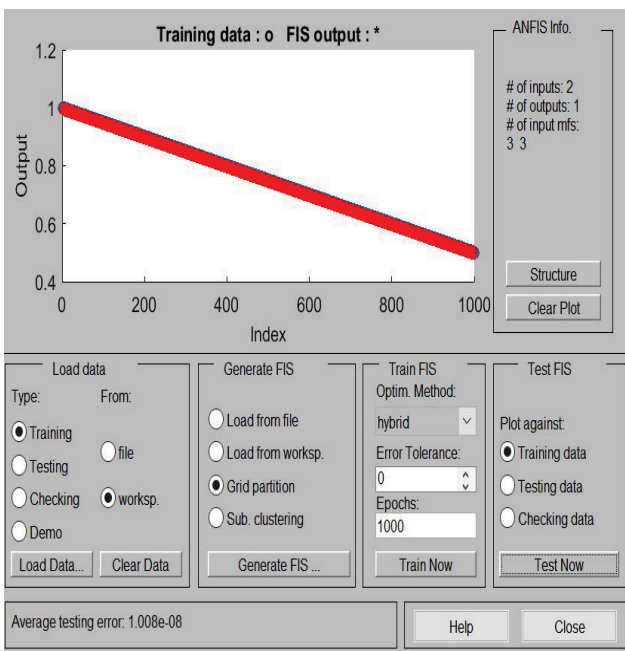


Figure 9 ANFIS training for MPPT controller

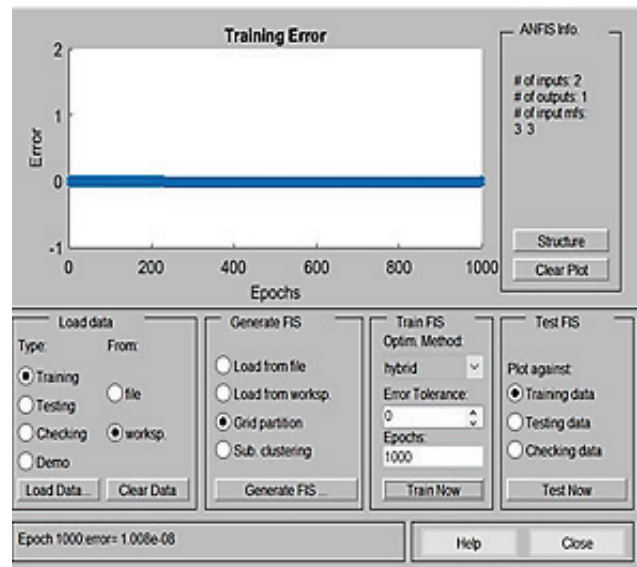


Figure 10 ANFIS training error for MPPT controller

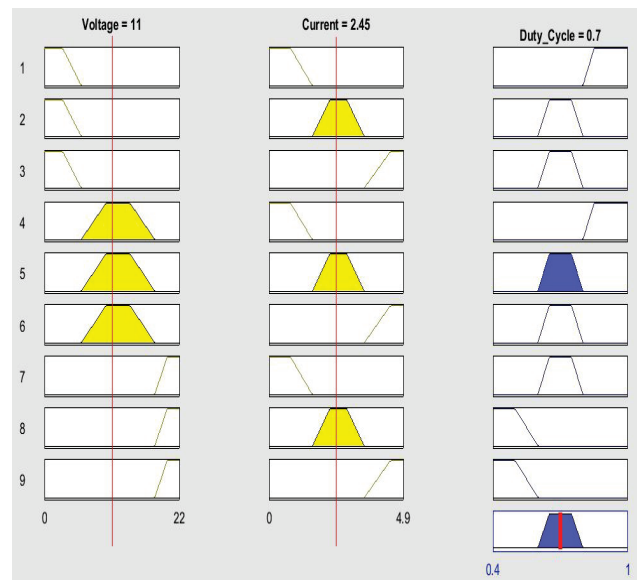


Figure 11 ANFIS rules for MPPT

3.3 Hybrid Firefly and Fuzzy MPPT

The proposed hybrid fuzzy and firefly controller has been designed for MPPT controller (100 W PV systems) and is shown in Fig. 12. The two major intelligent controllers have been designed to optimize the duty cycle of the DC-DC converter and achieve the objective of MPPT techniques [15-17]. The following steps are used for MPPT controller design:

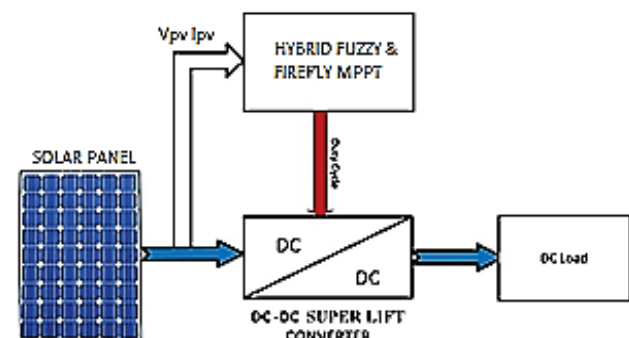


Figure 12 Hybrid firefly and fuzzy based MPPT

The FLC has two inputs such as PV voltage and PV current as well as one output signal such as duty cycle of PWM generator. The fuzzy controller has one output signal such as duty cycle of PWM generator. The fuzzy output signal is converted from the crisp set into a fuzzy set by using the trapezoidal method. Fuzzy interference rules are developed, using IF-THEN condition, after designing input and output membership function of the proposed controller. Finally, the fuzzy controller output signal (duty cycle - d_{max}) is fed to firefly controller. Fix the constants of firefly algorithm, namely β_0 , γ , m , α , population size N as below [16].

$$\beta(r) = \beta_0 e^{(-\gamma r^m)}, m > 1 \tag{7}$$

where: β_0 - initial attractiveness, γ - light intensity, α - random movement factor, r is distance between two fireflies using Cartesian distance. The projected technique regulates the super-lift boost converter in the optimum duty cycle operation which relates to MPP. By using the following steps, the required MPPT has been achieved.

1) Step 1: Initialization of β , α and population size N . Here the duty cycle of converter is denoted as a position of firefly.

2) Step 2: The firefly 1 moves to firefly 2 to attain the maximum brightness.

3) Step 3: Repeat the operation of the projected technique till the required maximum brightness.

4) Step 4: The optimization procedure repeats till the final iteration

In this projected technique, the level of the Firefly is considered as a duty cycle d of the super lift boost converter. The brightness of every firefly is assigned as spawned power P_{PV} of the PV system, corresponding to the position of this firefly. The fireflies are marked in the permissible limit of the duty minimum (d_{min}) to duty maximum (d_{max}).

4 RESULTS AND DISCUSSION

The proposed strategy has been modeled using MATLAB / Simulink for the PV based super lift boost converter with different MPPT controllers. By choosing all inductors and capacitors, values such as 0,1 mH, 0,1 mF, $R = 10 \Omega$, $q = 1$ and $f = 3 \text{ kHz}$ are used in the simulation environment.

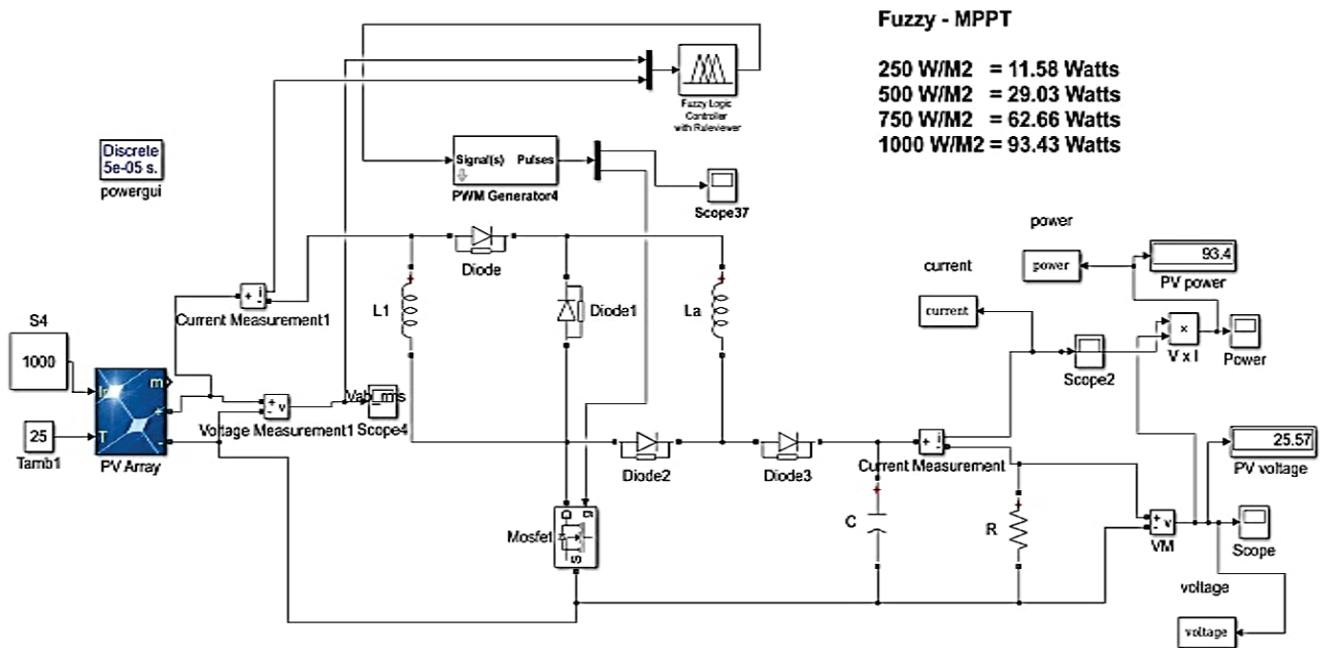


Figure 13 MATLAB simulation model using super- lift boost converter

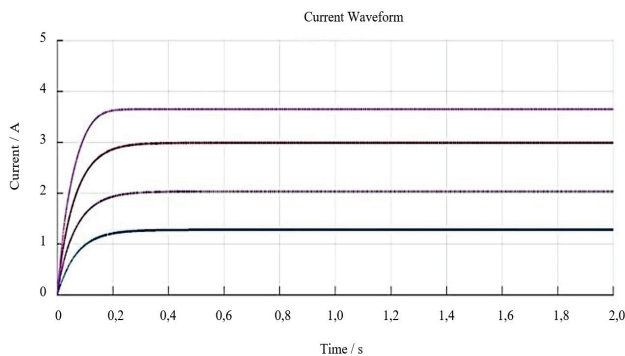


Figure 14 Photovoltaic Current curves with MPPT controller at various irradiances

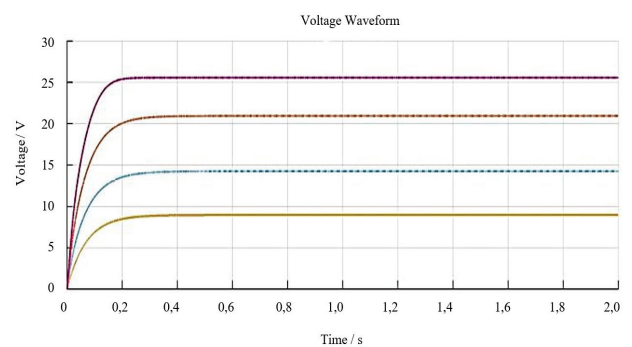


Figure 15 Photovoltaic Voltage curve with MPPT controller at various irradiances

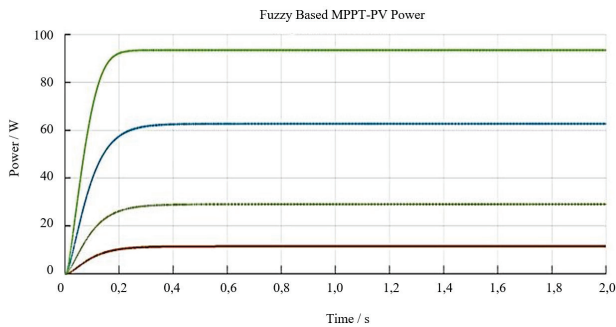


Figure 16 Photovoltaic Power curve with MPPT controller at various Irradiations

The proposed fuzzy logic control based MPPT of DC-DC super lift converter has been developed in MATLAB environment for 100 watts PV panel as shown in Fig. 13. The proposed MPPT control of super lift boost converter has been simulated and analysed with different irradiance condition such as 250 W/m², 500 W/m², 750 W/m², and 1000 W/m². The simulation results of current, voltage and power are presented in Fig. 14, Fig. 15 and Fig. 16.

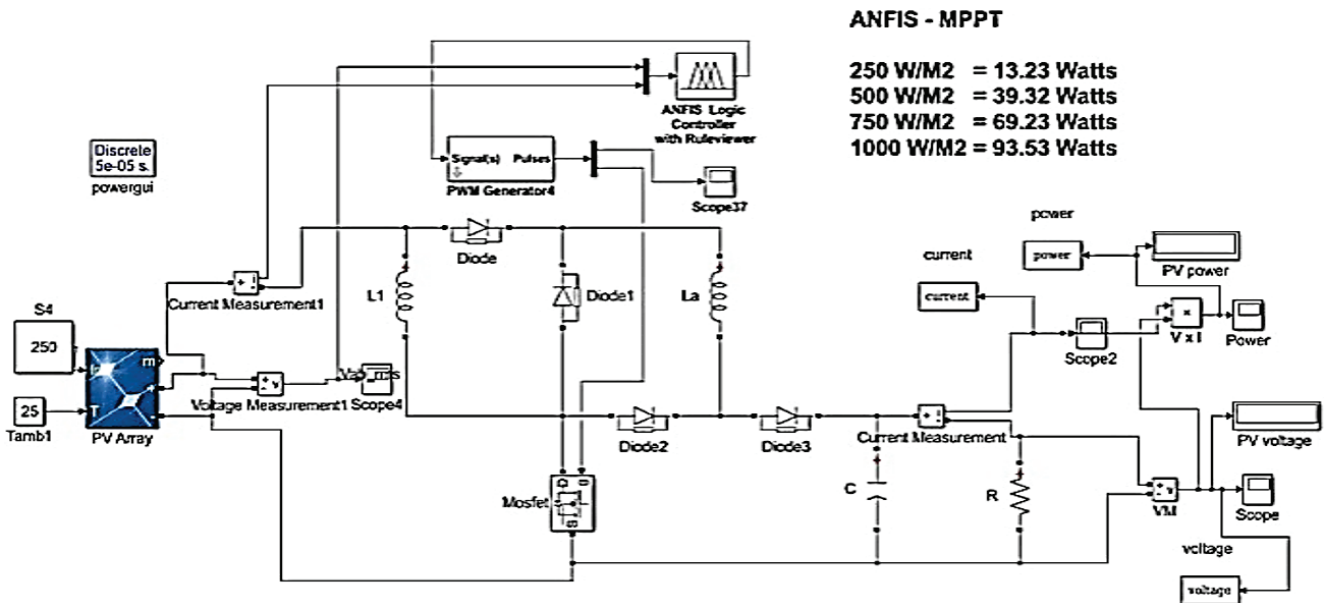


Figure 17 MATLAB simulation model using super lift converter (ANFIS)

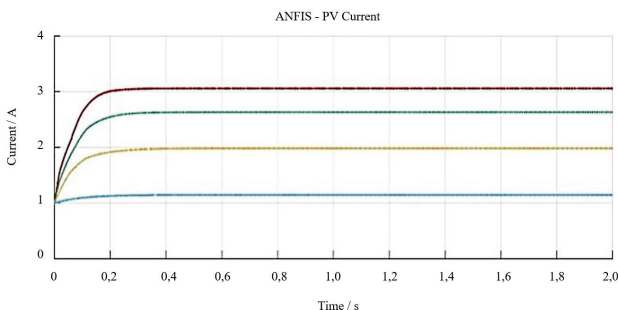


Figure 18 Photovoltaic current curves with MPPT controller at various Irradiations (ANFIS)

The proposed MPPT control of super lift converter has been simulated and analyzed with different irradiance conditions such as 250 W/m², 500 W/m², 750 W/m², 1000 W/m². The simulation results of current, voltage and power are presented in Fig. 18, Fig. 19 and Fig. 20.

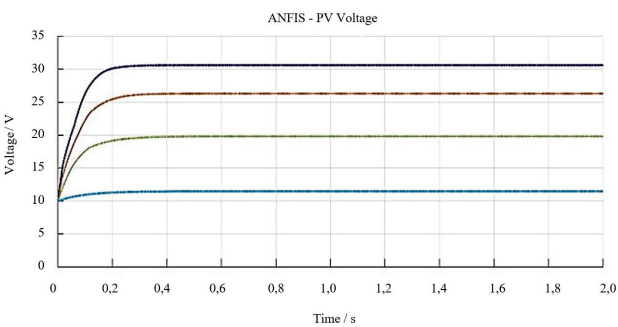


Figure 19 Photovoltaic voltage curve with ANFIS - MPPT controller at various Irradiations

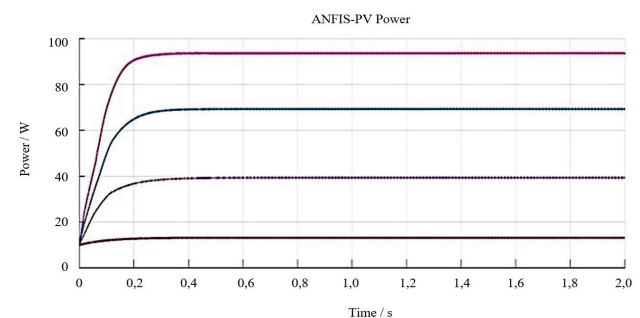


Figure 20 Photovoltaic Power curve with ANFIS - MPPT controller at various Irradiations

The proposed hybrid fuzzy and firefly control based MPPT of DC-DC super lift boost converter has also been developed in MATLAB environmental for 100 watts PV panel as shown in Fig. 21 and Fig. 22. The proposed MPPT control of Super lift converter has been simulated and analyzed with different irradiance condition such as 250 W/m², 500 W/m², 750 W/m², 1000 W/m². The simulation results of current, voltage and power are presented in Fig. 23, Fig. 24 and Fig. 25.

The proposed ANFIS control based MPPT of DC-DC super lift boost converter has been developed in MATLAB environmental for 100 watts PV panel as shown in Fig. 17.

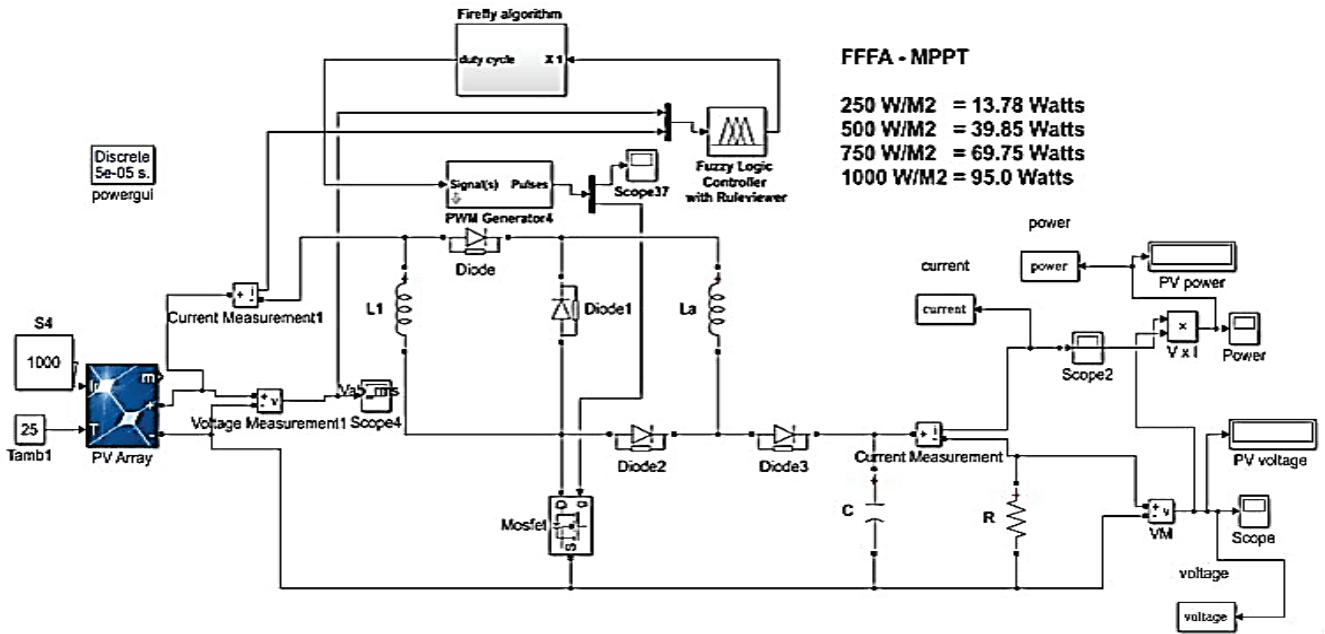


Figure 21 MATLAB simulation model using super lift boost converter (HFFFA)

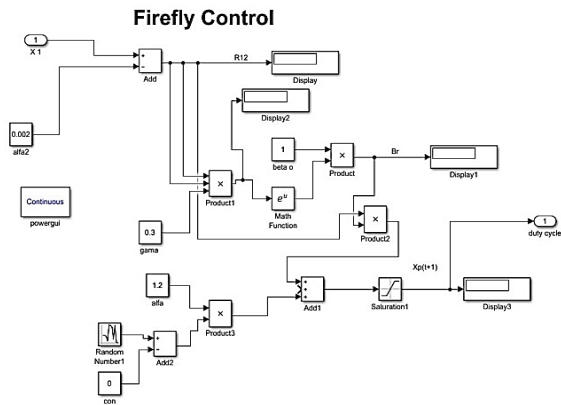


Figure 22 Firefly Controller model for MPPT

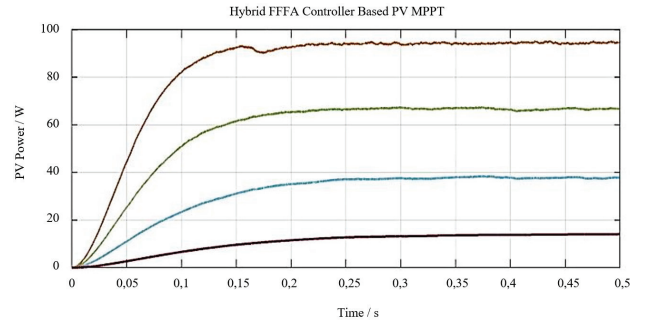


Figure 25 Photovoltaic power curve with HFFFA - MPPT controller at various Irradiances

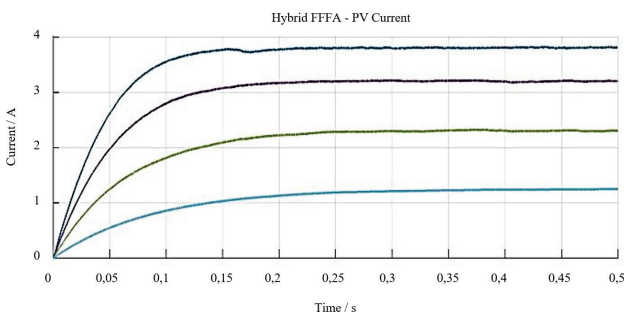


Figure 23 Photovoltaic current curve with HFFFA - MPPT controller at various Irradiation

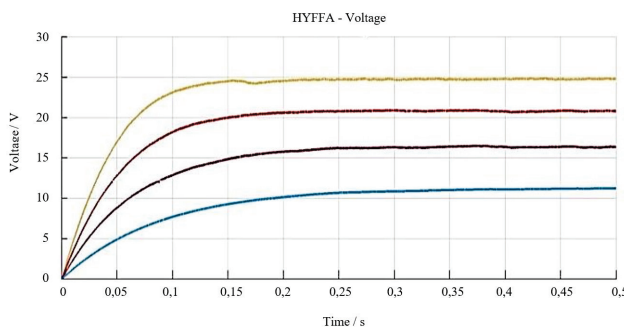


Figure 24 Photovoltaic Voltage curve with HFFFA - MPPT controller at various Irradiances

Table 2 Comparative analysis of different MPPT Controllers

Irradiation / W/m ²	Fuzzy based MPPT of Super lift converter / W	ANFIS MPPT of Super lift converter / W	Hybrid Firefly and Fuzzy MPPT of Super lift converter / W
250	11,58	13,23	13,78
500	29,30	39,32	39,85
750	62,66	69,23	69,75
1000	93,43	93,53	95,00

5 CONCLUSION

The proposed work has been discussed with a high gain DC-DC super-lift boost converter. This converter has been investigated for photovoltaic applications. The proposed super lift boost converter with an intelligent controller based MPPT has simulated for 100 Watts PV system in MATLAB / Simulink. The modelled system was tested with the different weather (irradiance) conditions. Thereby, the obtained results were compared with Fuzzy, ANFIS and Hybrid fuzzy and firefly based MPPT. The comparative analysis of different intelligent controller based MPPT performances is presented in Tab. 2. The obtained results using various MPPT in the super-lift boost converter show that the converter has a high gain conversion with reduced ripple voltage in the output. Based on the investigation the result obtained using MATLAB / Simulink for the proposed SLBC with different MPPT

shows that the Hybrid Fuzzy and Firefly algorithm is more superior to the Fuzzy and ANFIS.

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