

FUZZY BASED MPPT TECHNIQUE FOR PHOTOVOLTAIC SYSTEM WITH BOOST AND SUPER-LIFT BOOST CONVERTERS

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Abstract: *In present scenario, deficiency of power generation due to lack of fossil fuel and lack of cost-effectiveness in rural areas has become a challenge. One of the solutions is to rely on renewable energy such as solar energy to generate electricity. Accordingly, the efficiency of the photovoltaic (PV) system can be optimized by implementing the fuzzy-logic based Maximize Power Point Tracking (MPPT) algorithm. In this work presents the simulation results of the fuzzy logic control based MPPT by using MATLAB/SIMULINK for 55W capacity of Boost and Super-Lift Boost Converters (SLBC). The evaluated performance of the converters with different irradiance applied in photovoltaic system are presented based on the parameters current, voltage and power in detail. The performance of both converters are analysed and compared. The tracking speed of FLC-based MPPT is superior to that of the conventional MPPT method. It is clearly observed that the proposed SLBC is more suitable for Photo voltaic application.*

Key words: Super-Lift Boost Converter (SLBC), fuzzy logic, MPPT, photovoltaic, MATLAB

1. Introduction

The use of fossil fuel has inevitably led to the emission of greenhouse gases such as CO₂. Due to the drastic fluctuation of fuel price, many countries have resorted to renewable and sustainable energy such as solar power [1]. However, the V-I characteristics of photovoltaic (PV) cell varies with respect to factors such as irradiation and temperature in a non-linear fashion. Hence, it is difficult to attain maximum energy efficiency while operating a PV system [2-4]. As reported in the literature, method such as Maximum Power Point Tracking (MPPT) algorithms supplemented by Perturb and Observe (P&O) and Fuzzy Logic Control (FLC) method have been formulated to maximize the energy efficiency [5-6]. Nevertheless, the MPPT algorithm

is reliable only in the normal weather condition because it may behave differently even there is a slight change in the irradiation level. For instance, the P&O method of MPPT predicts the direction of perturbations such as PV voltage and PV current of the system based on the power extracted in the past/current state. In this method, large perturbation step is imposed to shorten the tracking time of PV system at the expense of significant power loss. In contrast, smaller perturbation step leads to the reduction of tracking speed of the MPPT. Therefore; it is of utmost importance to determine the optimal perturbation step [7-9], [28-29]. In order to address this issue, MPPT methods of variable perturbation step size have been proposed. Smaller perturbation steps are chosen when MPP is closer to the point of operation. However, this working principle may become invalid as the PV system is nonlinear in nature. Hence, the use of scaling factor is necessary for this class of MPPT method. Also, it has been found that Fuzzy Logic Control (FLC) can be used to track MPPT. The performance (i.e. tracking speed) of FLC-based MPPT is superior to that of the conventional MPPT method [12-17]. However, the computational complexity increases because the error variations are now considered as inputs for any FLC-based MPPT [31-35]. In the current work, a FLC-based MPPT technique that incorporates different converters such as Boost and Super-Lift Boost Converters (SLBC) is developed to maximize the output power of the PV panel. The new FLC-MPPT technique uses intelligent techniques for designing the fuzzy-based input and output membership functions. SIMULINK is then adopted to model the FLC-based MPPT [28][32-35]. Subsequently, the performance of the proposed model is evaluated at different solar irradiation levels.

In section II, presents the analysis of Boost and Super Lift Boost Converters. Section III explains the mathematical model of PV cell. In section IV, the details of different MPPT controllers along with fuzzy based technique have been discussed and its results are presented in section V. Lastly, the verdicts of the different converters are stated in Section VI.

2. DC-DC Converters

Solar power is very important in the field of clean power generation due to its sustainability. In a PV system, the DC-DC power converters are normally adopted to alter the output voltage from one level to another [25-27]. In the current work, Boost converter and Super Lift Boost Converter (SLBC) are used and its corresponding circuits are shown in Fig.1a and Fig.1b respectively.

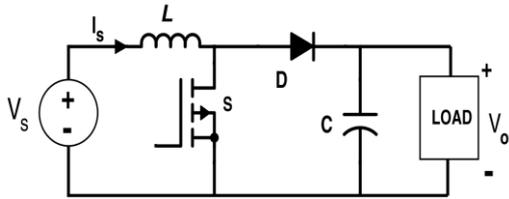


Fig.1a. Circuit diagram of Boost converter

The Boost converter can be regarded as a switch mode DC to DC converter. It is also known as the step-up converter due to the fact that the output voltage (V_{out}) is larger than the input voltage (V_{in}) [26]. The specifications of DC-DC converter are reported in Table I.

Table I: Specifications of DC-DC boost converter

Parameters	Value
Inductor (L)	160 mH
Capacitor(C)	550 μ F
Load Resistance	12 Ω
Switching frequency	3KHz

SLBC increases the voltage transfer gain in a stage-by-stage manner (also known as geometric progression). Also, it augments the voltage transfer gain [1-2] in the super-lift operation. As compared to the CUK and SPIC converters, SLBC is more efficient and powerful. The SLBC and its equivalent circuit are shown in Fig.1b for different operations. In

order to increase the voltage, extra inductor L_a and diodes D_2 – D_4 are added (the original components are L_1 , D_1 , C_1 and R). The inductance of L_a must be similar to that of the inductor L_1 . It is crucial to attain current continuity as the switch is deactivated. The

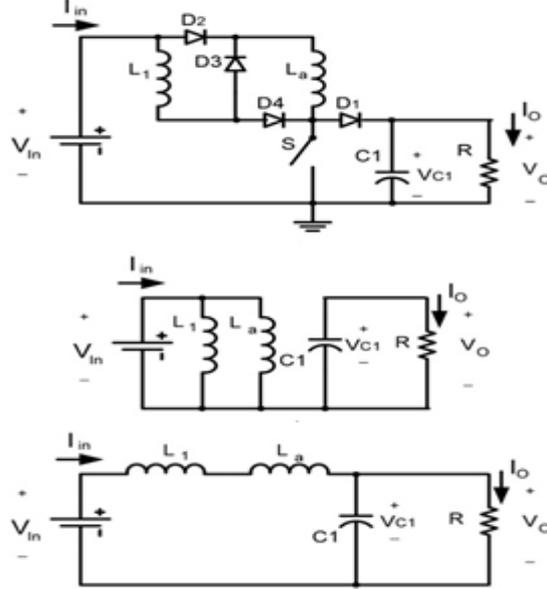


Fig.1b. Circuit diagram of Super lift Boost Converter

current i_{L1} (through L_1) increases with respect to V_{in} during the switching-on period. The diodes D_2 and D_4 are conducted and the diodes D_1 and D_3 are blocked. During the switching-off period, the current i_{L1} (through inductors ($L_1 + L_a$)) decreases with voltage $-(V_o - V_{in})$. Now, the diodes D_1 and D_3 are conducted and the diodes D_2 and D_4 are blocked. Therefore, the voltage transfer gain is expressed as:

$$G = \frac{V_o}{V_{in}} = \frac{1+k}{1-k}$$

The specifications of SLBC are given in Table II.

Table II: Specifications of Super Lift Boost Converter (SLBC)

Parameters	Value
Inductor (L_1)	10 mH
Inductor (L_a)	10 mH
Capacitor(C_1)	10mF
Load Resistance(R)	12 Ω
Switching frequency	3KHz

3. Mathematical Design of Photovoltaic System

PV cell consists of semiconductor designed to absorb solar energy. Single diode is commonly adopted due to its simplicity and accuracy [3]. The circuit diagram of single diode PV panel is shown in Fig.2. The mathematical models of electrical characteristics [13, 14] are used to design the 55W PV panel. The Fig.8 and Fig.9 presents the output voltage and power of the proposed system, respectively [3][32].

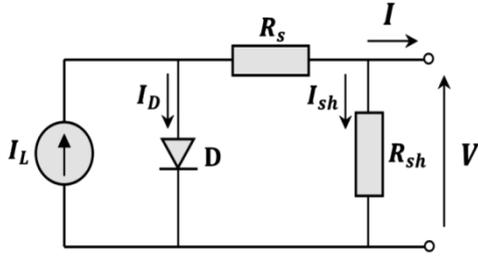


Fig.2. Equivalent Circuit of single diode PV cell

a. Open circuit voltage

The voltage of the cell at night can be calculated by:

$$V = \left(\frac{NKT}{Q} \ln \frac{I_L - I_o}{I_o} + 1 \right) \quad (1)$$

Here, V - the open circuit voltage, N - the diode ideality constant, K - the Boltzmann constant, T - the temperature, Q - the electron charge, I_L - the light-generated current (= transverse photocurrent I_{ph}) and I_o - the saturation diode current.

b. Light generated current (Radiation)

Light generated current is the amount of current necessary to generate electric power due to sunlight. Initially, the light glow principal of PV cells induces the creation of light generated carriers. These carriers perform the adsorption process of photons that are incident on the PV cells for creating electron-hole pairs. If the generated carriers have the capacity of recombination, the light generated electron-hole pairs are lost and hence no load current or power is dissipated. In contrast, if the recombination of the generated carriers is unsuccessful, the light generated electron-hole pairs tend to produce full load current expressed as:

$$I_L = \left(\frac{G}{G_{ref}} * (I_{Lref} + \alpha_{isc} (T_C - T_{Cref})) \right) \quad (2)$$

where G - the radiation, G_{ref} - the radiation under standard condition, I_{Lref} - the photoelectric current

under standard condition, T_{Cref} - the module temperature, α_{isc} - the temperature coefficient of the short circuit current and I_L - the light generated current.

c. Reverse saturation current

Reverse saturation current represents the constant flow of electrons at any time. In other words, the number of induced electrons stimulated from the cathode side of PV cell is constant when the number of photons incident on it is non-varying. This reverse saturation current of any photo-electron may become zero when the kinetic energy of photons is minimum. In contrast, the reverse saturation current becomes one if the kinetic energy is maximum. This reverse saturation current computed based on the difference between the amount of energy possessed by the photons to the estimated work-energy function of any PV material can be represented via:

$$I_o = I_{or} * \left(\frac{T}{T_{ref}} \right)^3 \exp \left(\left(\frac{QE_g}{KN} \right) * \left(\frac{1}{T} - \frac{1}{T_{ref}} \right) \right) \quad (3)$$

$$I_{orn} = \frac{I_{sc}}{\exp \left(\frac{V_{ocn}}{N * V_{th}} \right)} \quad (4)$$

Where,

I_o - the reverse saturated current, I_{or} - the saturation current, N - the ideality factor 1.5, E_g - the band gap for silicon, V_{th} is the thermal voltage.

d. Short circuit current

Short circuit current refers to the photocurrent of PV cells as they are induced without any externally applied load. This photocurrent is generally a reverse bias current as the electrons flow from cathode region to anode region during the reverse bias condition. If any external voltage is applied, the forward biasing condition tends to neutralize the photocurrent generated (current becomes zero). During the dark conditions, the emitted photons are dissociated and absorbed, leading to $I_{sh} = I_L$ (see Equation (5)) which is the peak current generated by a cell through the short circuit condition (as $V = 0$).

$$I_{sh} = I_L - I_o \left(\exp \left(\frac{Q * (V - IR_s)}{NKT} \right) - 1 \right) \quad (5)$$

e. Irradiation

Irradiation is defined as the degree of exposure of an object towards radiation. The degree

of irradiation depends on parameters such as non-ionizing radiation, water vapour and carbon dioxide available in the atmosphere. Irradiation depends on the latitude level as the density of irradiation varies from North to South Pole represented by Equation (6):

$$I_D = 1.353 * 0.7^G \quad (6)$$

Where, G is the irradiation level.

4. MPPT Controller

It is important to note that PV energy generation is inconsistent (highly dependent on the weather condition). PV is inefficient in the absence of MPPT (the efficiency is ranging from 9-17% in regions of low irradiation) [6, 13-14,[30][34]. In order to maximize the power generation, MPPT method is developed in this work.

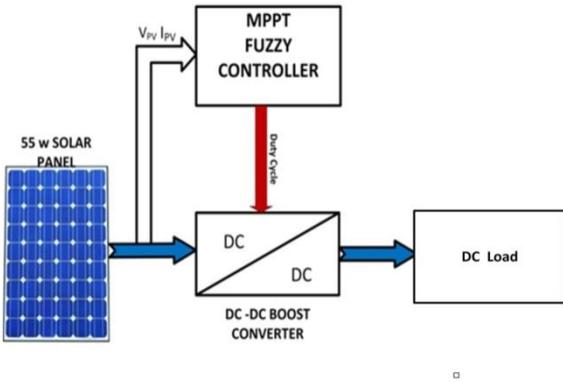


Fig.3a. Proposed Fuzzy based MPPT Controller for DC-DC Boost converter

a. Feedback voltage and current method

This technique is adopted exclusively in PV power system. The error between the output voltage/current and the desired voltage/current of the PV panel are calculated. Subsequently, the PWM signal of DC-DC converter is generated based on the error value. Hence, the efficiency of the PV panel can be optimized.

b. Voltage and Frequency (P-Q) method

Here, various controllers are used to control the inverter and the battery power. Based on the variation of the PV power, PI controller is used to generate the duty cycle for DC-DC converter.

c. Feedback voltage and current method

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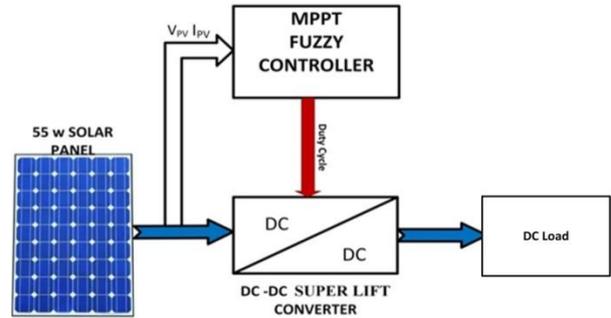


Fig.3b. Proposed Fuzzy based MPPT Controller for DC-DC super lift Boost converter

d. Voltage and Frequency (P-Q) method

Here, various controllers are used to control the inverter and the battery power. Based on the variation of the PV power, PI controller is used to generate the duty cycle for DC-DC converter.

e. Feedback of power variation with voltage and current

This technique is analogous to the feedback voltage and current method. Also, $\left(\frac{dp}{dv}\right)$ and $\left(\frac{dp}{dl}\right)$

are nulls under power feedback condition [7]. Instead of calculating the power of PV panel, the power is computed from the load terminal as there is a loss in power conversion attributed by the converter.

Therefore, the PWM signal are adjusted for $\left(\frac{dp}{dv}\right)$ or

$$\left(\frac{dp}{dl}\right).$$

f. Perturbation and Observation

In this technique, the PV power P_1 is determined from the duty cycle. Then, the calculated PV power P_2 is compared with P_1 (perturbation is activated when $P_2 > P_1$). However, this technique suffers from some limitations due to occasional deviation from the maximum power[29-30].

g. Incremental conductance method

Here, the voltage and current values are measured from the PV cell. The term $\left(\frac{dI}{dV}\right)$ is

calculated from the measured values and compared with the previous value [31]. Subsequently, the controller generates the duty cycle and feeds the PWM generator based on the calculated $\left(\frac{dI}{dV}\right)$.

h. Intelligent control based MPPT method

In this paper, the FLC MPPT technique has been developed. This controller requires inputs such as actual current and voltage of PV panel as shown in Fig.4 and Fig.5, respectively. These parameters are transformed to fuzzy set by applying the trapezoidal method. From the knowledge-based system, the reference voltage has been compared with the observed value [6, 16-24]. Based on the error, IF-THEN (3X3) rules are used to choose the duty cycle for converters. Lastly, the centre of gravity method is used to transform the fuzzy set value into a crisp set. The fuzzy controller output signal is subsequently sent to a PWM generator in order to produce the pulses for DC-DC converter [7, 17-23,32] and Super Lift Boost Converter (SLBC) as shown in Fig.3a and Fig.3b, respectively. Finally, the simulation results are evaluated.

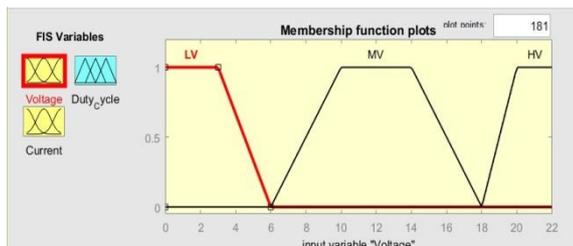


Fig.4. Input fuzzy Membership function-PV Voltage

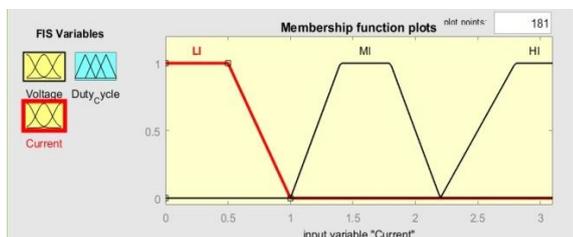


Fig.5. Input fuzzy Membership function -Current

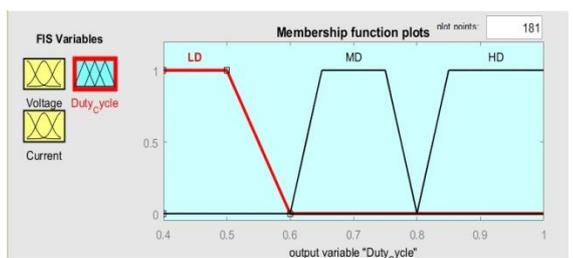


Fig.6. Output fuzzy Membership function - Modulation index (duty cycle)

5. Simulation Results and Discussion

In this Section, the new FLC-based MPPT is simulated by using SIMULINK. Different converters such as Boost and Super-Lift Boost Converters (SLBC) are considered. The irradiation level varies from 0 to 1000 W/m². The current increment in FLC-MPPT is estimated via the trial and error technique. The MPPT control consists of two main parts, i.e. FLC-MPPT control component and current control component. The new FLC-based MPPT with boost converter is simulated by using SIMULINK as shown in Fig.7.

To analyze the performance of the new FLC-based MPPT with boost converter scheme, a simulation study is carried out. Here, a case study is considered where the irradiance level is unsteady. Here, the irradiance level is altered after each second; hence, a new duty cycle can be produced. Then, the new maximum voltage, power and current can be obtained.

The proposed FLC-based MPPT of DC-DC boost converter is developed for a 55W PV panel. The P-V and V-I characteristics of PV system at different weather conditions are shown in Fig.8 and Fig.9, respectively.

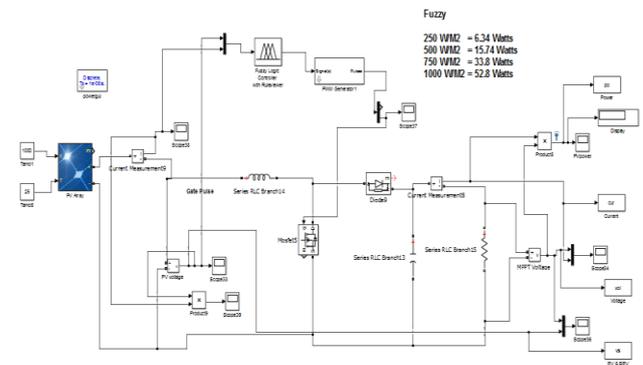


Fig.7. Simulation model using Boost converter

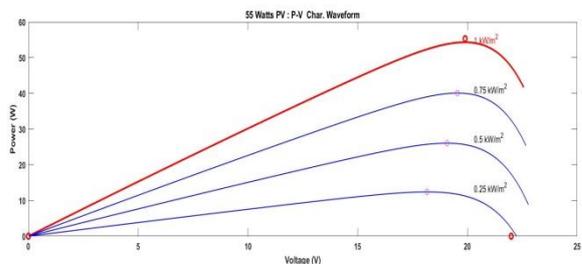


Fig.8. PV Module P-V Characteristics

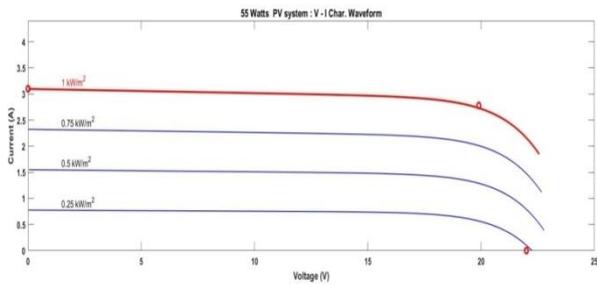


Fig.9. PV Module V-I Characteristics

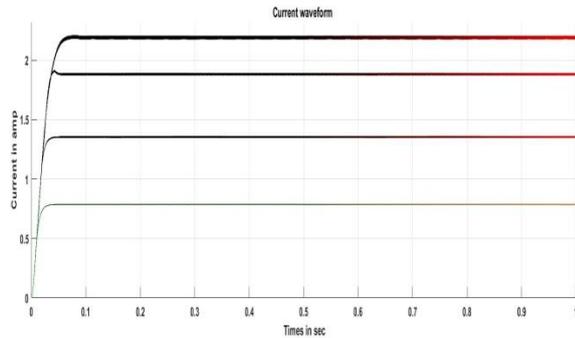


Fig.10. Photovoltaic Current curve with MPPT controller at various Irradiations

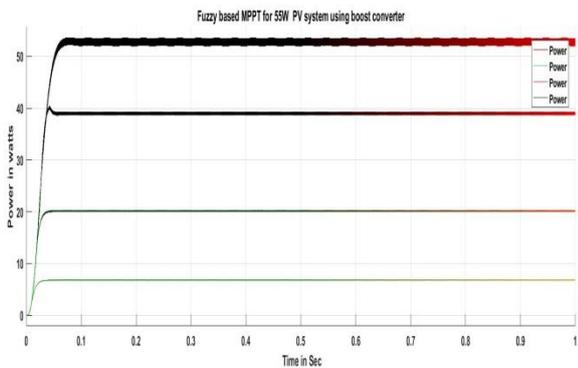


Fig.11: Photovoltaic Power curve with MPPT controller at various Irradiations

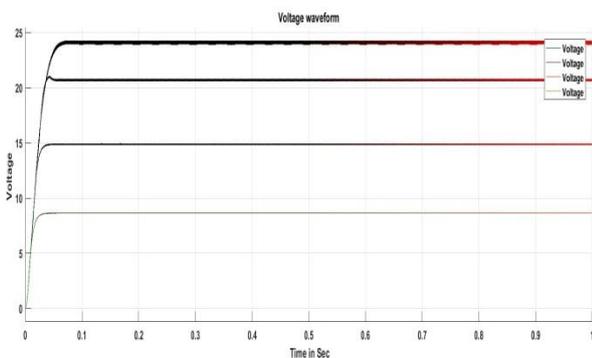


Fig.12. Photovoltaic Voltage curve with MPPT controller at various Irradiations

The proposed MPPT control of a DC-DC boost converter is simulated and analyzed with different irradiance levels. The simulated current, voltage and power are reported in Fig.10, Fig.11 and Fig.12, respectively. In the simulation, the FLC with boost converter shows good performance when the controller works under different conditions more interestingly, the controller can track the new MPP based on the new solar irradiation level.

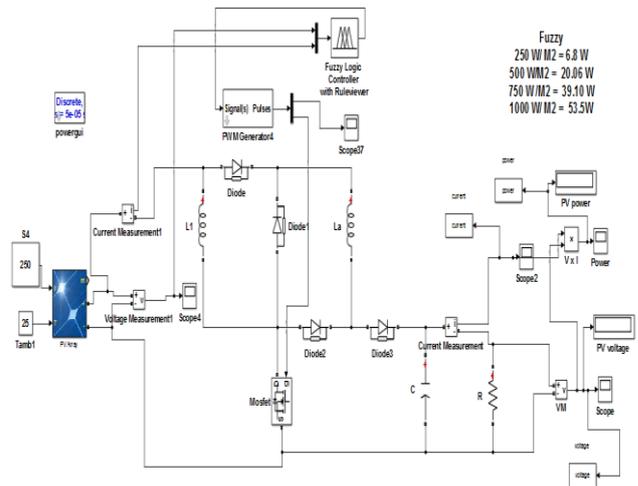


Fig.13. Simulation model using Super lift Boost converter

The Simulink model of the new FLC-based MPPT with SLBC is reported in Fig.13. The proposed FLC-based MPPT SLBC model for a 55W PV panel is simulated by using SIMULINK.

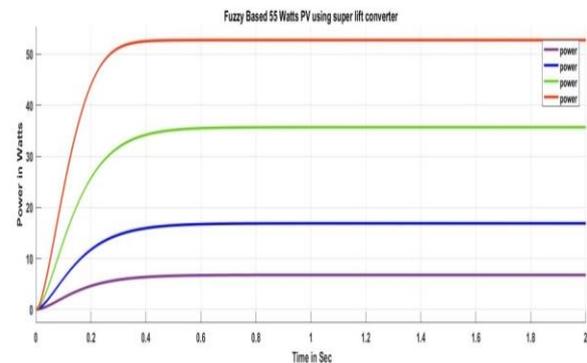


Fig.14. Photovoltaic Power curve with MPPT controller at various Irradiations

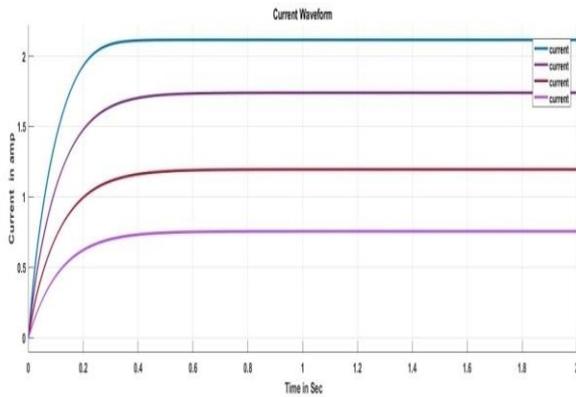


Fig.15. Photovoltaic Current curve with MPPT controller at various Irradiations

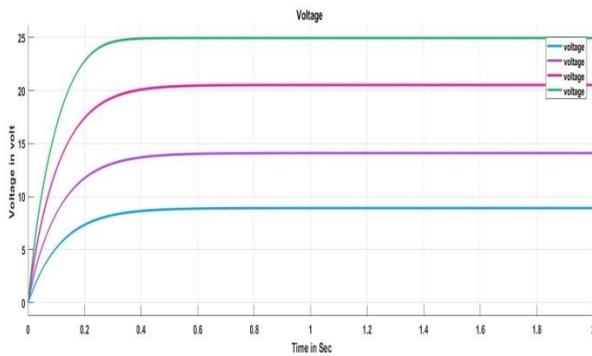


Fig.16. Photovoltaic Voltage curve with MPPT controller at various Irradiations

The proposed MPPT control to SLBC is simulated and analysed at different irradiance levels. The output current, output voltage and output power are shown in Fig.14, Fig.15 and Fig.16, respectively. The results obtained for FLC-based MPPT PV using different converters are compared and shown in Table III.

Table III: Comparative analysis of Boost converter and super lift boost converter

Irradiation w/m ²	Fuzzy based MPPT of Boost Converter	Fuzzy based MPPT of SLB converter
250	6.74 Watts	6.8 Watts
500	16.84 Watts	20.06 Watts
750	35.66 Watts	39.10 Watts
1000	52.8 Watts	53.5 Watts

6. CONCLUSION

The proposed work has been modelled and simulated for the 55W PV panel in MATLAB/SIMULINK environment under various weather conditions. The fuzzy logic based MPPT method is applied in Boost Converter and Super Lift Boost Converter. The response of the both converters are analysed and compared under different irradiance conditions. The obtained simulation result clearly shows that though the Super Lift Boost Converter involves more components, its output power is superior as compared to the boost converter.

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