Performance Analysis of FIS and ANFIS based MPPT for Solar PV System with Boost, SEPIC and CUK Converter Topologies

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ABSTRACT
This paper works on the performance comparison of PV system implemented with three different DC/DC converter topologies named Boost, Cuk and SEPIC converters. Along with these three converters the MPPT techniques used for maximum power point tracking are FIS and ANFIS. The whole PV system is incorporated with these two soft computing techniques and three converters and voltage variation results have been obtained accordingly, then these results are compared simultaneously to evaluate the overall performance of the PV system in each case

Keywords
PV panel, MPPT techniques, FIS, ANFIS, Boost converter, cuk converter, SEPIC converter

1. INTRODUCTION
Solar PV system is a very broad and very relevant topic. Many research papers have already been published in the field of MPPT algorithms such as comparison of classical MPPT approaches such as Perturb and Observe Technique and Incremental conductance, or Fuzzy logic and neural network, some of the research has also be completed in suggesting the new algorithms for MPPT, also work has been done in the field of converters related to PV system and grid connected PV array. In paper[1] the study of battery charge controller used in standalone photovoltaic system has been done as it is a major component of standalone PV system. In [2] a soft computing technique that is adaptive neuro fuzzy inference system has been studied, in [3] also same soft computing technique ANFIS has been covered whereas [4] presents the application of ANFIS on the intelligent systems however [5] talks about the MPPT techniques when implemented on solar vehicle the complete simulation with analysis has been covered in this research work, now [6] covers the controlling of induction motor drives used in various types of applications, in [7] MPPT tracking using fuzzy logic controller when applied to a grid connected PV system has been discussed, however [8] works on the designing and proper selection of parameters of PV system for the production of electricity in Malaysia, in [9] application of large number of PV modules for distribution of energy in urban areas has been covered whereas in [10] a complete case study on the renewable power of malyasia has been studied, in next [11] neural based MPPT for PV system connected with boost converter was studied

2. MAXIMUM POWER POINT
Maximum Power Point Tracking, generally referred to as MPPT, drives solar PV array to operate in such a manner that maximum power which can be generated by PV module or array can be extracted fully to transfer it further. MPPT is not any mechanical device or mechanical technique to extract power but it works on control algorithm specially designed for a particular task. MPPT can be used along with with a mechanical tracking system, but both the systems act differently in case of power tracking. MPPT algorithms use the variation of irradiance and temperature to obtain or extract the maximum power from solar PV array. The voltage at which PV array can gives maximum power is called 'maximum power point' (or peak power voltage). Maximum power depends on solar radiation, ambient temperature and varies accordingly to the changes of these parameters. A characteristic PV module generates power having maximum power voltage of around 17 V measured when temperature of the cell is 25 degree Celsius, it can go down up to 15 V on a very hot day and it can also elevate to 18 V on a very cold day. The first and foremost principle of MPPT is to extract maximum power from the PV module by the application of suitable algorithm. MPPT Algorithm operates on the simple logic that, MPPT calculates the output of PV module, then compares it to voltage of battery then fix the optimum power which can be generated by PV module which helps in charging of battery and then converts it to the suitable voltage to obtain maximum current into battery. It can also use to supply power to a DC load, which is connected directly to the battery. MPPT is generally used to charge the deep discharged batteries mostly on cloudy days or time of faults

3. MPPT TECHNIQUES
3.1 Fuzzy Inference System
Fuzzy logic controller is generally composed of three independent processes which are: fuzzification, second is the rule base operation, and finally defuzzification as we have to convert fuzzy data again into crisp form. In whole fuzzification process, crisp or numerical data that is input variables are transformed into linguistic variables with the help of a membership function. Some of the linguistic variable used in this project are: NB (Negative Big), ZE (Zero) and PB (Positive Big). In Figures 1, 2, 3 given below we can clearly observe the membership functions for two inputs and output. The inputs to a Fuzzy system used as MPPT are generally an error E and the second one is change in error CE.. As dP/dV diminish at the maximum power point, the following approximation can be made.

$$E(n)=P(n)-P(n-1)/V(n)-V(n-1) \quad (1)$$
$$CE(n)=E(n)-E(n-1) \quad (2)$$

Once the value of E and CE are evaluated the rules can be applied to these linguistic variable according to the form stated in rule base the value of output which is usually a duty cycle that is provided to converter can be obtained. The inference system used in this case is mamdani. The selection of linguistic variables that are used to represent dD for the different combinations of E and CE is totally depends on the data collected or analysed by the user. In the final defuzzification process, the fuzzy controller output which is obtained from linguistic variable is converted again to numerical value or crisp data with the help of membership functions. The defuzzification process generates an analog function in the form of output which is given to the converter in the form of duty cycle to drive the system. MPPT implemented using fuzzy logic controller gives best results when operate under atmospheric conditions. But their overall efficiency depends majorly on the data of controller or engineer or the user by correct computation of error using the rule base as shown in figure 4.

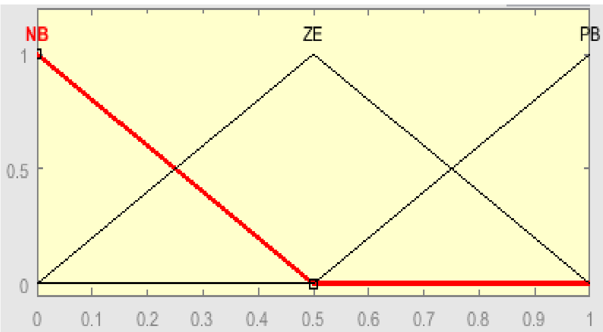

Figure 1: Membership functions for input variable (E)

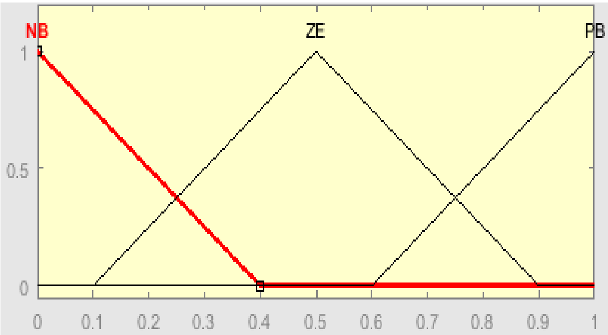

Figure 2: Membership function of input variable (CE)

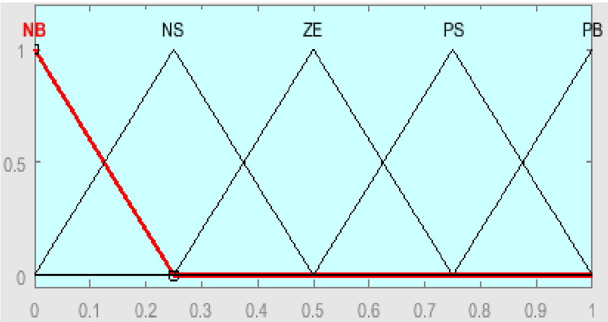

Figure 3: membership function of output variable (dD)

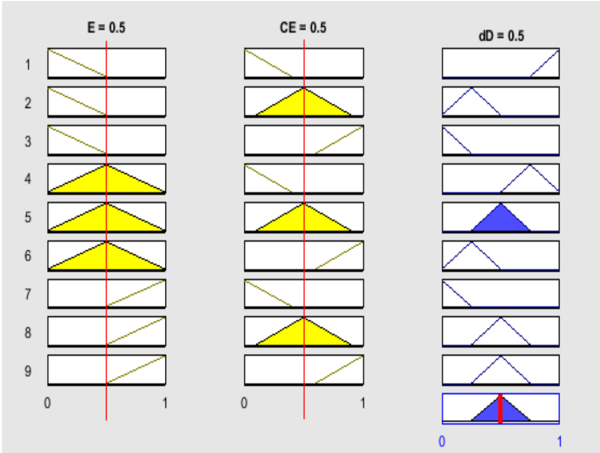

Figure 4: Rule viewer of rule base

3.2 ANFIS based MPPT

Over the past few years there has been a great development in the field of information based on non-linear network. These complex and broad systems cannot be explained or made to work with only one of the controlling techniques hence we require some more efficient way to complete this. One of the algorithm to manage these complex issues is combination of two or more system to accomplish a pre define goal and to overcome the shortcomings of previous controlling methodology. Fuzzy logic is a good tool for displaying uncertainties and approximate reasoning, on the other hand neural network is the best machine in field of learning. Adaptive neuro fuzzy inference system combines the point of interests of fuzzy logic and neural network in one and produce enhanced fuzzy framework which is incorporated with learning mechanism of neural network and hence more efficient. For PV cells also we can create a cross breed system that joins fuzzy logic and neural network to detect the maximum power point.

In this firstly we collect the data of different values of irradiance and temperature and output of panel accordingly which is fed into neuro fuzzy designer and with then help of this data sugeno inference system type fuzzy logic is designed with neural network incorporated in that. We can clearly see the trained rule viewer of FIS in figure 5.

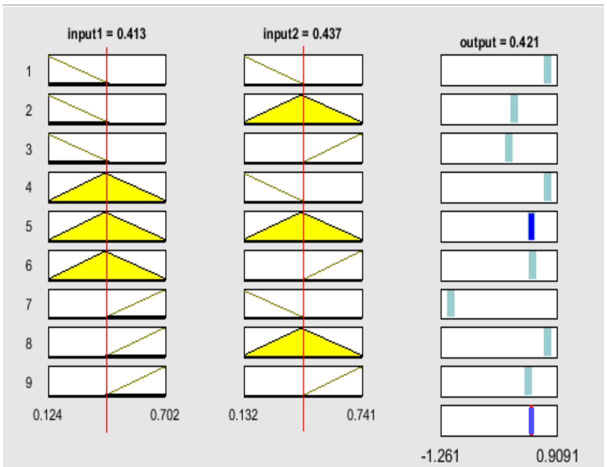

Figure 5: Rule Viewer of trained FIS

The trained ANFIS model is shown in figure 6 along with the final ANFIS system shown in figure 7.

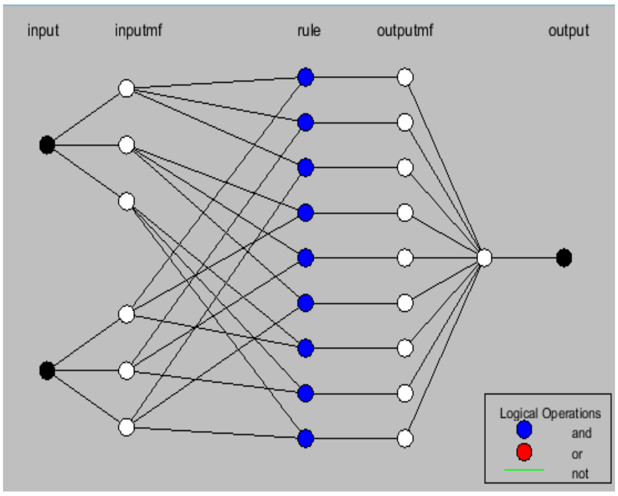

Figure 6: ANFIS model structure

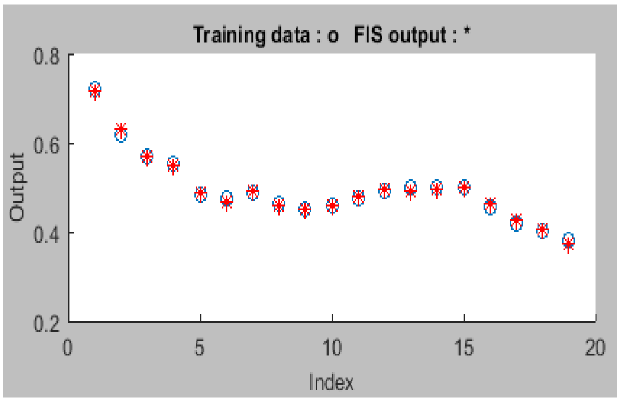

Figure 7: Final Tested ANFIS system

4. DC/DC Converters

A DC to DC converter takes the voltage from a DC source and converts the voltage of supply into another DC voltage level. They are used to increase or decrease the voltage level. The DC/DC converter is mostly used in portable DVD players, automobiles and portable chargers. As most of the equipments need certain range or level of voltage to operate as very high voltage can damage that device and very low voltage cannot make it to run so for such cases a converter is used as it can takes power from the PV panel and varied the voltage by stepping up or stepping down it to a certain level.

4.1 Boost Converter

A boost converter as shown in figure 8 is used to convert the unregulated direct current input voltage, generated by a PV module to a controlled DC voltage with value higher than the input as required by the load that is it boost the voltage value of input and hence named as boost converter. This conversion of voltage is generally perform by applying a DC voltage across an inductor, for a period of time (usually in range of 20kHz to 5MHz) that produces current which flow through it and stores energy magnetically, and then we switch OFF this voltage which results in the transfer of stored energy to the output voltage in controlled way. This voltage is regulated by adjusting the duty cycle. To achieve this fast switching power electronics component like IGBT or MOSFET is used as they dissipate least power. Pulse width modulation (PWM) technique is use to control and regulate total output voltage. The ideal boost converter possess 100% efficiency but in general 70% to 90% of efficiency is obtained.

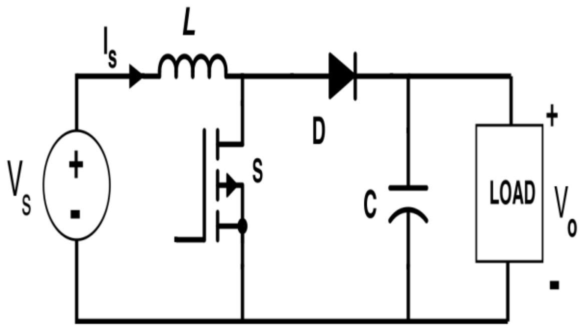

Figure 8: Boost converter

The boost converter as shown in the figure has a constant DC input voltage source Vs, boost inductor L, controlled switch S, diode D, filter capacitor C and a load.

DC voltage gain of converter is given as:

$$G = \frac{V_0}{V_s} = \frac{1}{1-\alpha} \tag{3}$$

Selection of inductor—Inductor with large value increases the startup time slightly whereas low inductance value allow the coil current to increase up to very high values before the switch turns OFF. It is selected on the basis of the maximum allowed ripple current at minimum duty cycle and maximum supply voltage. Boost converter works in continuous conduction mode for inductor value $L>L_c$ where L_c is a critical inductance value and is given by

$$L_c = \frac{(1-\alpha^2)*\alpha*R}{2f_s} \tag{4}$$

where R is the load resistance and f_s is the switching frequency of converter.

Selection of capacitor—the current supplied to the RC circuit is discontinuous that's why a larger filter capacitor is required to decrease the ripples in output voltage. The primary way to select filter capacitor is its capacitance and it's series resistance as this series resistance affects efficiency, low ESR-capacitors is used for best performance. The filter capacitor is use to decrease the ripples in output voltage. Minimum value of filter capacitor that allow current to flow through load when diode is OFF is given by

$$C_{min} = \frac{V_O*\alpha}{f_s*\Delta V_O*R} \tag{5}$$

Where ΔV_O is the ripple in output voltage which is generally 5% of output voltage

4.2 Cuk Converter

A CUK converter as shown in figure 9 is an another type of DC/DC converter which produce output voltage either greater or lesser than the input voltage. It is actually a boost converter which is followed by a buck converter. The main difference is that it consists of an additional capacitor to store energy. As the buck-boost converter produces an inverted output similarly cuk converter also produces an inverted output which can be either higher or lower than the input. As most of the converters use inductor as their main energy storage element it uses an additional capacitor to store energy

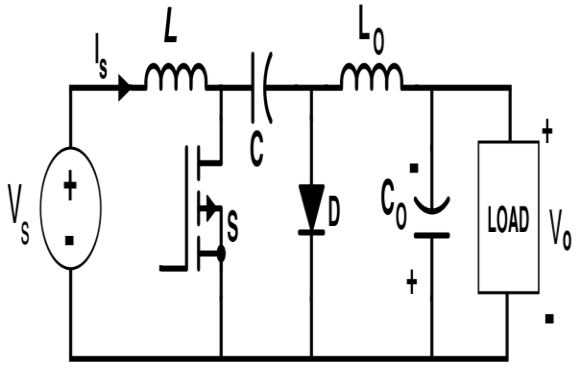

Figure 9: Cuk converter

A cuk converter basically consist of two capacitor, two inductors, one switch and one diode. The transfer of energy is done with the help of capacitor C and two inductors L and L_0 are used to convert input voltage source and output voltage source respectively into current source. The conversion of voltage source into current source is necessary because if capacitor is directly connected to resistance then it will cause high energy loss in the system

Now if we apply voltage sec balance across L

$$V_s\alpha T + (V_s - V_c)(1-\alpha)T = 0 \qquad (6)$$

$$\therefore \quad V_s(1-\alpha)V_c = 0 \qquad (7)$$

Or $$V_c = \frac{V_s}{1-\alpha} \qquad (8)$$

Applying voltage sec balance across L_0 $(V_0 + V_c)\alpha T + V_0(1-\alpha)T = 0$ (9)

$$V_0 + \alpha V_c = 0 \qquad (10)$$

$$V_0 = -\alpha V_c = -\frac{\alpha V_s}{1-\alpha} \qquad (11)$$

Similarly current through two inductors L and L_0 are stated as follow

$$I = \frac{\alpha^2}{(1-\alpha)^2}\frac{V_s}{R} \;,\; I_0 = \frac{\alpha}{1-\alpha}\frac{V_s}{R} \qquad (12)$$

So basically cuk converter combines the features of both boost and buck-boost converter hence it has following advantages

1. It provide continuous input current

2. It provide continuous output current

3. Output voltage obtained can be higher or lower than input voltage.

4.3 SEPIC Converter

A SEPIC converter or single-ended-primary-inductor-converter is also a DC/DC converter that gives output voltage either higher, lower or equal to the input voltage. It is actually a boost converter followed by a buck-boost converter. The major advantage of SEPIC converter over buck boost converter that unlikely buck boost converter it produces a non-inverting voltage output. It uses a series capacitor for energy coupling from input to output and hence can give better results when used in short circuit condition. Unlike cuk converter it has pulsating output which is one of the disadvantage of SEPIC converter, also its fourth order nature make it suitable for slow varying systems only. A detailed circuit diagram of SEPIC converter is shown in figure 10.

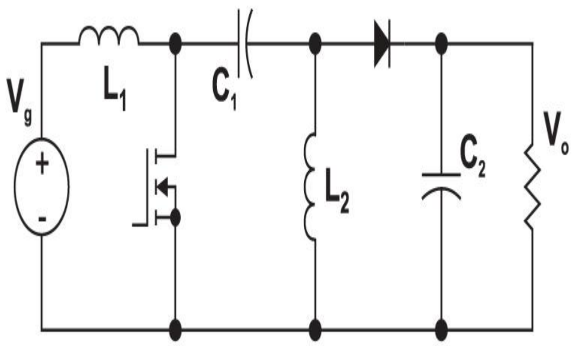

Figure 10: SEPIC converter

During the turn ON time the diode gets reverse biased and coupling capacitor has negative polarity which helps in charging of inductor L_1 and L_2 via source and coupling capacitor gets discharge on the other hand in case of turn OFF time the diode gets forward biased and inductor L_1 helps in the charging of coupling capacitor whereas inductor L_2 transfer its stored energy to the output and this is how an SEPIC converter works.

Duty cycle selection-for continuous mode operation duty cycle is given by

Output of a SEPIC converter is given by

$$V_0 = \frac{\alpha * V_g}{1-\alpha} \qquad (13)$$

If we consider losses due to voltage drop across diode then output can be stated as-

$$V_0 + V_D = V_0 = \frac{\alpha * V_g}{1-\alpha} \qquad (14)$$

Due to this final expression of duty cycle becomes

$$\alpha = \frac{V_0 + V_D}{V_g + V_0 + V_D} \qquad (15)$$

Inductor calculation- inductors are basically used in converters to produce a ripple free output.

The ripple current flowing through L_1 and L_2 is given by

$$\Delta I_L = I_{in} * 40\% = I_0 * \frac{V_0}{V_g} * 40\% \qquad (16)$$

The value of two inductors can be calculated as-$L_1 = L_2 = L = \frac{V_{g,min}}{\Delta I_L * f_s} * \alpha_{max}$ (17)

Coupling capacitor calculation- The value of capacitor depends on RMS current whose expression is given as-

$$I_{c1,rms} = I_0 * \sqrt{\frac{V_0 + V_D}{V_{g,min}}} \qquad (18)$$

Peak to peak ripple voltage can be given as

$$\Delta V_{cs} = \frac{I_0 * \alpha_{max}}{C * f_s} \quad (19)$$

5. SIMULATION AND RESULTS

The basic Block Diagram of whole system on which analysis is done is shown in figure 11 below, it is divided into three parts the first one is PV array then the second art is DC/DC converter which is getting the gate pulse through the MPPT technique which has been applied to extract maximum power from the PV panel and the third segment is conversion of converter output into AC supply through which is supplied to the grid.

Table 1. Technical Specifications of PV array

TECHNICAL SPECIFICATIONS	VALUE
Cells Per Module	60
Open circuit voltage (V_{oc})	36.96 V
Short circuit current (I_{sc})	8.49 A
Maximum power	240.694 W
Voltage at MPP (V_{mp})	30.2 V
Current at MPP(I_{mp})	7.97 A

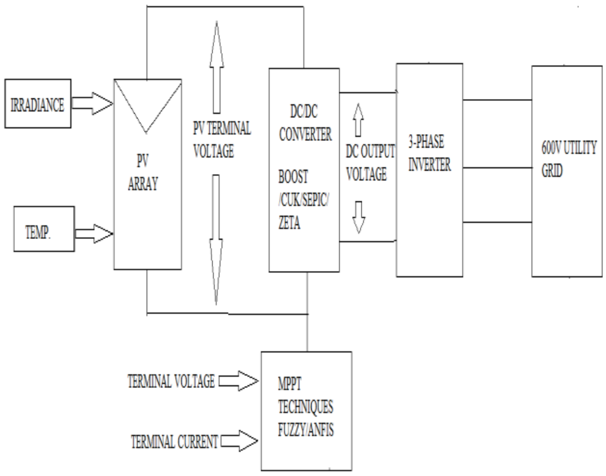

Figure 11: Schematic block diagram of system

The Panel which is selected for analysis is one of the specified panels of MATLAB/SIMULINK library and that is Neo Solar Power D6P240B3A, in this project five parallel string with four panel in series connected in each string is taken into consideration for analysis. Hence we have an array of 20 such modules. Technical specifications of this panel is shown below:

The two major inputs to PV array are irradiance and temperature. In this project analysis is done for three different values of irradiance and temperature. For the daytime the value of irradiance is 600W/m^2 and temperature is 25˚C. For noontime the irradiance value is taken as 1000 W/m^2 and temperature is 45˚C and for evening time the value of irradiance is set at 400 W/m^2 and temperature is taken as 32˚C.These values are plot using signal builder in MATLAB as shown in figure 12 and 13.

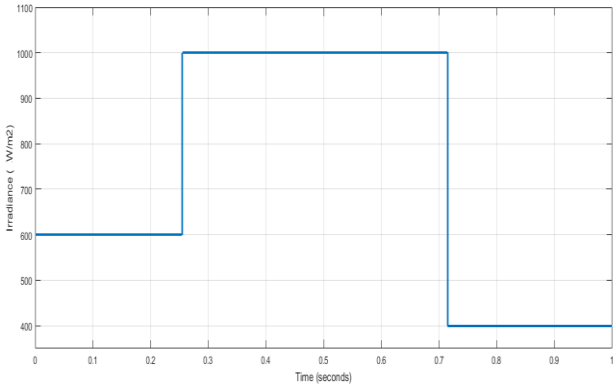

Figure 12: Irradiance plot for three different values

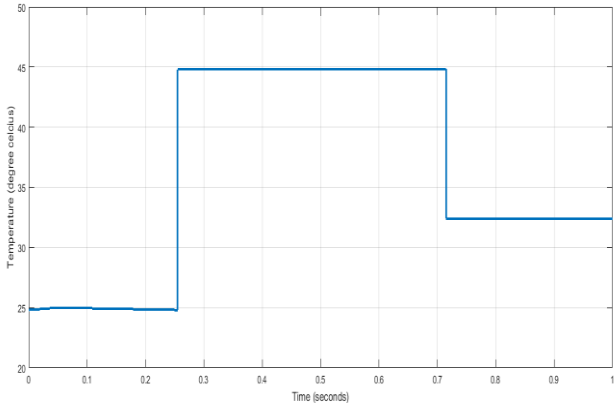

Figure 13: Temperature variation

5.1 PV system with boost converter

The voltage variation of PV output and output of converter is shown in figure 14 for FIS and figure 15 for ANFIS

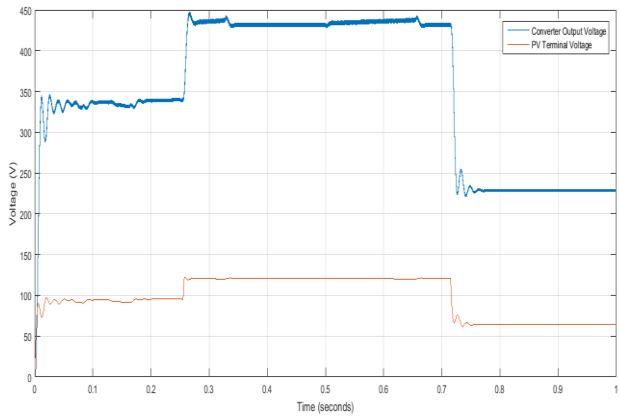

Figure 14: Voltage variation for FIS based MPPT

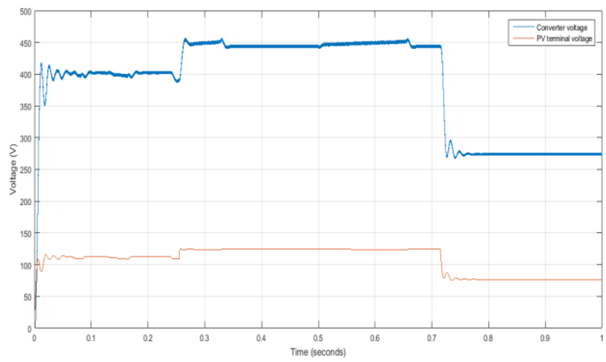

Figure 15: Voltage variation for ANFIS based MPPT

Table 2. Boost converter performance comparison

MPPT TECHNIQUES	IRRADIANCE/TEMP.	PV TERMINAL VOLTAGE (V)	CONVERTER OUTPUT VOLTAGE
FUZZY LOGIC	600/25	99.8	356.42
	1000/45	109.9	392.5
	400/32	80.2	286.42
ANFIS	600/25	108.2	386.42
	1000/45	110	392.85
	400/32	98.6	352.14

5.2 PV system with Cuk converter

Voltage output for cuk converter is shown in figures 16 and 17 for FIS and ANFIS based MPPT respectively

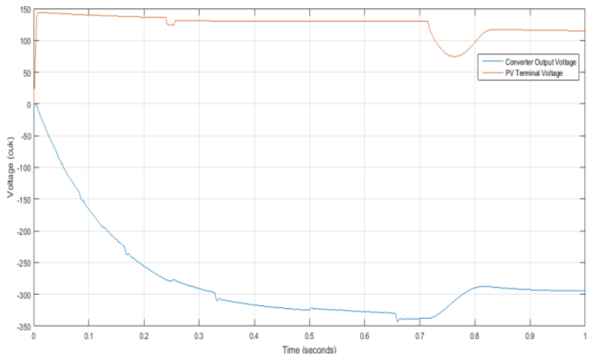

Figure 16: Voltage variation for FIS based MPPT

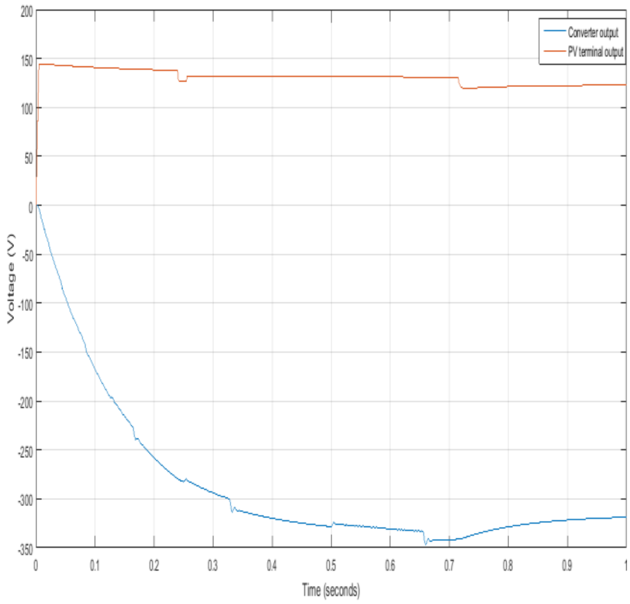

Figure 17: Voltage variation for ANFIS based MPPT

Table 3.Cuk converter performance comparison

MPPT TECHNIQUES	IRRADIANCE/TEMP.	PV TERMINAL VOLTAGE (V)	CONVERTER OUTPUT VOLTAGE
FUZZY LOGIC	600/25	119.1	-338.24
	1000/45	108.2	-307.28
	400/32	105.6	-299.90
ANFIS	600/25	120	-340.8
	1000/45	109.4	310.69
	400/32	107.4	-305.01

5.3 PV system with SEPIC converter

The output waveforms for FIS and ANFIS based MPPT is shown in figure 18 and 19 respectively

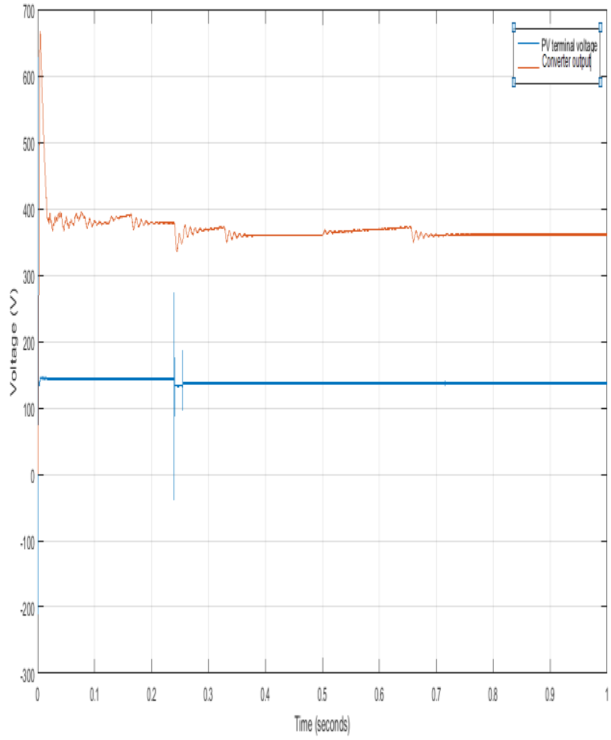

Figure 18: Voltage variation for FIS based MPPT

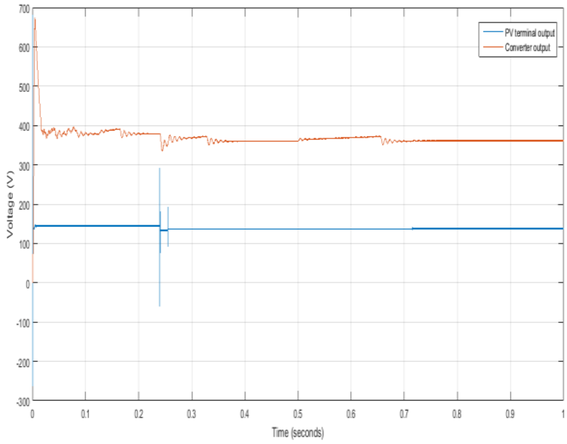

Figure 19: Voltage variation for ANFIS based MPPT

Table 4. SEPIC converter performance comparison

MPPT TECHNIQUES	IRRADIANCE /TEMP.	PV TERMINAL VOLTAGE (V)	CONVERTER OUTPUT VOLTAGE
FUZZY LOGIC	600/25	109.6	356.3
	1000/45	109.7	358.2
	400/32	108.3	349.1
ANFIS	600/25	110	358.4
	1000/45	109.7	370.9
	400/32	109	352.5

6. CONCLUSIONS

From the above work it can be concluded that the performance of ANFIS based MPPT is slightly better than FIS based MPPT in achieving the maximum power point. Also if we talk about the converters then each configuration boost up the voltage according to the parameters of its components and duty cycle but the variations in voltage are more in case of boost converter due to change in values of temperature and irradiance whereas voltage is almost constant in case of cuk and SEPIC converter.in case of cuk converter the output generated is inverted one whereas in case of SEPIC the ripple content is very high hence for stable output we can use cuk converter or SEPIC Converter whereas for ripple free voltage boost converter can be used.

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