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Modelling and Simulation of MPPT Based Solar Photovoltaic System for Voltage Lift LUO Converter

S. Vijai Ananth[1] and S. Singaravelu[2]

[1]*Research Scholar, Department of Electrical and Electronics Engineering, Annamalai University, Tamilnadu, India, vijaisva@gmail.com*

[2]*Professor, Department of Electrical and Electronics Engineering, Annamalai University, Tamilnadu, India, ganapss@yahoo.com*

***Correspondence:** S. Vijai Ananth: Email: vijaisva@gmail.com

ABSTRACT- Several maximum PowerPoint tracking techniques have been proposed to achieve optimal matching between solar photovoltaic arrays to load for extracting maximum available power from photovoltaic source. These techniques differ in terms of tracking speed, complexity, cost, accuracy of tracking, number of sensors used etc., This article proposes an Adaptive Neuro Fuzzy-Inference System (ANFIS) based maximum PowerPoint tracking for positive-output voltage lift LUO converter based on solar (PV)system for resistant load application. Performance analysis of proposed (MPPT) technique has been evaluated in MATLAB/Simulink environment for four different cases of input radiation and temperature patterns. These test input patterns have been chosen based on European standard EC50530.Simulation results revealed that proposed ANFIS maximum PowerPoint tracking technique effectively captures the maximum PowerPoint in a faster way with good accuracy under both steady state and dynamic climatical conditions. Moreover, a comparative study has been presented between conventional (P&O) -technique and proposed ANFIS MPPT technique. Comparative study reveals that ANFIS MPPT technique has higher tracking efficiency with lesser tracking time without any oscillation around maximum power point.

Keywords: ANFIS, LUO converter, MATLAB/Simulink, MPPT, (PV) array.

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1. INTRODUCTION

Solar energy is a reliable source of energy that is abundant in nature repletion in a short period of time, this is called "Renewable Energy" or "Sustainable Energy". The energy harvested from solar cells are mainly depend on two factors like temperature & insolation. These ambient physical parameters reduce the photovoltaic array output power. In addressing the poor efficiency of PV systems, an electronic subsystem named solar maximum PowerPoint tracker has been included in the PV system for maximising available power from a solar PV source. This MPPT tracker comprises of a power electronic DC-DC converter along with maximum PowerPoint (MPP) computing algorithm. Several maximum PowerPoint tracking techniques have been proposed to achieve optimal matching between solar photovoltaic array to load for extracting maximum available power from photovoltaic source. These techniques differ in terms of tracking speed, complexity, cost, accuracy of tracking, number of sensors used etc., DC-DC converters in MPP tracking system is used for impedance matching between solar photovoltaic module and the connected load.

Commonly used Buck-Boost converter is suitable for optimal operation in maximum power point tracking under varying climatical conditions [1]. However, it has the serious disadvantage of poor conversion efficiency and higher ripple content. Hence in this paper a higher order DC-DC converter named LUO converter having two inductors and capacitors is proposed for solar PV system.

Conventional MPPT techniques are associated with lower tracking efficiency, oscillation around maximum power point, slow response to capture maximum power point [2][3]. They above said limitations restrict the application of conventional MPPT techniques at low-cost imprecise applications. But some precious applications needed quick capturing of MPP without cost considerations. So, it is necessary to propose an effective MPPT technique for such precious applications especially in aerospace applications [4]. Through this paper an Effective MPPT technique such as (ANFIS) based maximum PowerPoint tracking's proposed for positive-output voltage lift LUO converter based on solar (PV) system for resistant load application [5].

The following is how this article is structured: *Section 2* discusses the circuit model of a photovoltaic cell, *Section 3* discusses conventional P&O MPPT, and *Section 4* discusses proposed MPPT. ANFIS based maximum PowerPoint tracking and *Section 5* deals with simulation results and inference of output [6][7].

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2. PROPOSED SYSTEM

The block diagram of proposed system shown in *figure 1*. Proposed LUO converter has non-inverting characteristic with voltage lifting technique in buck-boost version. The desirable feature of this converter is the connection of switch control terminal to ground which simplifies the gate-drive circuitry. Since, the input current of the LUO converter is relatively continuous it draws low ripple current from a source. This plays a vital role in effective implementation of maximum power point tracking [8]. LUO converter doesn't have an on-operating region in the I-V curve of PV panel.

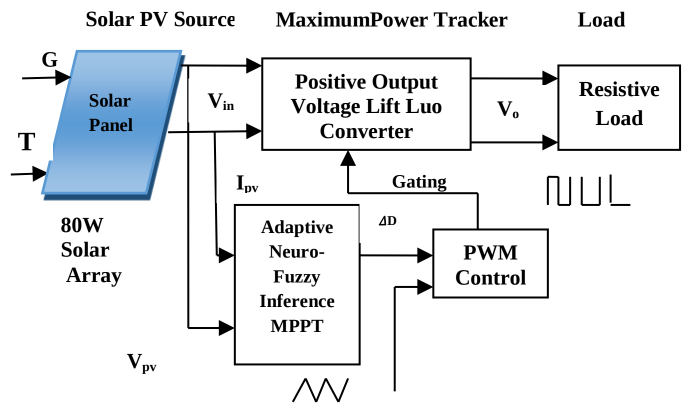

Figure 1: Block diagram of the proposed system

2.1 Modelling of Solar Array

The shown in *figure 2*. Consists of a diode, a current source, series and parallel resistance, (R_{se}) & (R_{sh}). To account for the effect structure resistances of photovoltaic cell a series resistance is involved in the model which is called as four parameters modelling of solar cell. The model then incorporates parallel resistance to account for a, leakage current which is called as five parameters modelling of solar cell [9][10]. The (R_{se}) & (R_{sh}) influences are stronger in the voltage source region & current source regions respectively. The photovoltaic cell is given in *equation (1)*.

$$I = I_{ph} - I_o\left(exp\left(\left(\frac{qV}{akT}\right)\right) - 1\right) \qquad (1)$$

where,
I_{ph} = Photogenerated current (Amps), I_o= Saturation current a= Ideality factor, q=Electron charge, k= Boltzmann constant= Photo-voltaic cell voltage (Volts), I= Load current (Amps).

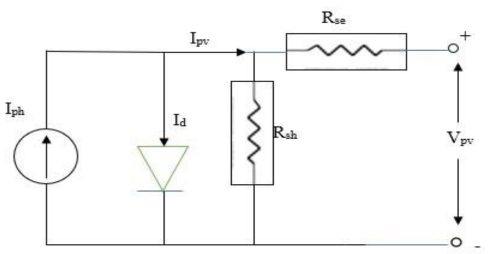

Figure 2: Equivalent circuit model of solar cell

In this article an 80Wsolar-array is used as energy source which has to be modelled in MATLAB simscape. A couple of ELDORA40W solar-modules are connected in parallel to form80W photovoltaic array. This module is made up of 36 multi crystalline silicon cells connected in series, with a maximum power of 40W at STC. *Table* 1 depicts the module's datasheet.

Table 1: Specifications of a 40Wsolar panel

Parameter	Quantity
Nominal Power (Pmax)	40 W
Open circuit voltage (Voc)	21.9 V
Short circuit current (Isc)	2.45 A
Voltage at maximum power (Vmpp)	17.4 V
Current at maximum power (Impp)	2.3 A
Number of cells in series (Ns)	36
Temperature co-efficient of Voc (Kvoc)	-0.123 V/oK
Temperature co-efficient of Isc (Kisc)	0.0032 A/oK

2.2 Modelling of Positive Output Voltage lift-LUO Converter

The converter diagram is shown in *figure 3*. Switch is ON, the source current, i_{in}=i_{L1}+i_{L2} IL_1 store energy-from the source.

During this ON period the inductor store energy from source & capacitor *C*. Because of these both currentsi_{L1} and i_{L2}increase towards maximum value. When switches in Offstage, the source current i_{in} is zero. Due to this, currenti_{L1} flows through the freewheeling diode D which charges the capacitorC_1. During this OFF period the current$\boldsymbol{i_{L2}}$ flows through the capacitorC_2 and load resistance R and freewheels throughthe diode D to keep the converter in continuous conduction mode. So, both currentsi_{L1}andi_{L2} are decreased towards minimum value. The variation in inductor currents i_{L1}andi_{L2} are small, hence the assumptions are as,(i_{L1}≈I_{L1})andi_{L2}≈I_{L2}, where,I_{L1}&I_{L2} are mean inductance values currentL_1&L_2.

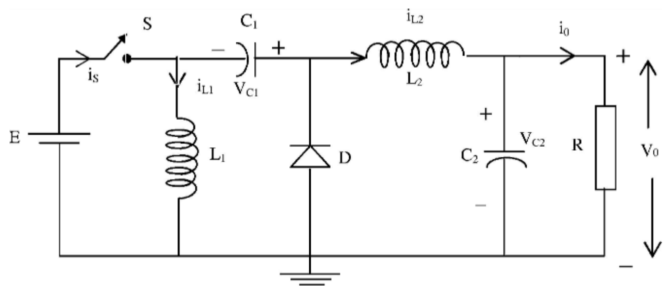

Figure 3: Circuit diagram of voltage-lift LUO converter

The output -voltage is 48Vat80Wpower. The duty cycle of power converter switch is considered in the range from 0.83 to 0.72. However, due to the MPP tracking process, the duty cycle is not fixed. Inductors were chosen based on a 10% ripple value of maximum current input at minimum voltage input of 0.16667A. The maximum-to-maximum ripple voltage of the capacitance is calculated to be 4% of the output-voltage, or 1.92V. *Table 2* lists the naming of the output LUO converter elements.

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Table 2: Components of LUO converter

Components	Specifications
Inductance(L1)	402mh
Inductance(L2)	5mh
Coupling - Capacitor	100µf
Output - Capacitor	10µf

2.3 P&O MPP-Tracking Technique

This is the most widely used conventional method of maximum PowerPoint tracking. The advantage of P&O technique is shown in *figure 4*. simple requirements of software and hardware. This technique is based on the perturbation (increase or decrease) of panel voltage via duty cycle tuning. If the output power is increased after perturbation, then the perturbation is continued in the same direction. If the output power decreases, the direction of perturbation is made in the Opposite direction. This technique necessitated current voltage and current measurements to calculate the change in power over time (*Δ*P) and duty cycle (*Δ*D) of pulse width modulated pulses sent to the gate terminal of the power electronic switch in the DC-DC converter *table 3*.

Table 3: P&O Algorithm duty cycle chart

ΔP	ΔD	Duty Cycle
Positive	Positive	Increase
Negative	Positive	Decrease
Positive	Positive	Decrease
Negative	Negative	Increase

The performance evaluation of P&O MPPT has been done in simulation for static and dynamic test input patterns of solar irradiance and panel temperature. The observations obtained in simulation are tabulated in *table 4*.

Table 4: System output for P&O MPPT tracking

Parameter	Variable	Values
(PV)Voltage	Vpv (V)	19.01
(PV)Current	Ipv(A)	4.047
(PV)Power	Ppv(W)	76.94
Converter out-put (V)	Vo(V)	47.44
Converter out-put (A)	Io (A)	1.581
Current power output	Po (W)	75.02
Voltage ripple	Δ Vo (V)	1.35
Current ripple	Δ Io (A)	0.045
Settling time	t (s)	0.08
Tracking efficiency	η (%)	93.77

Simplicity and ease of implementation makes this technique a commonly used one. P&O with a narrow step size in normal climatical condition has tracking efficiency as like other complex techniques. However, the main disadvantage of this technique is that the operating point of the PV array oscillates around the maximum power point. Because of this there is a power loss. On the other hand, when the irradiance changes rapidly, the P&O method likely to fail to track the maximum PowerPoint. Also, this technique cannot locate the maximum PowerPoint when the irradiance decreases, because the panel curve flattens out

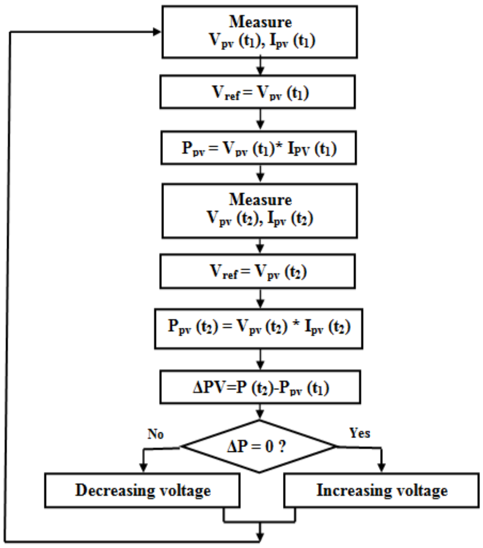

Figure 4: P&O algorithm flow chart

3. ANFIS MAXIMUM POWER POINT TRACKING TECHNIQUE

3.1 MPPT Design

ANFIS is a control technique for Sugeno-type fuzzy systems. It is a combination of two learning algorithm that is ANN and FUZZY logic system into a single machine. ANN is based on statistics training, Fuzzy logic, on the other hand, is based on expert knowledge. When trained with a sufficient number of epochs, ANFIS includes an input-output mapping feature for training data sets. [11][12]. After the values of membership functions are adjusted one, the developed ANFIS model becomes a learned model which is ready to be used for the solar maximum PowerPoint tracking application [13]. This technique has six layers including 0^{th} layer (input layer).

They are as follows:
Layer 0: Input layer which is passive in nature. In this layer PV array voltage and current are provided as the input.

Layer 1: Inputs are provided for each individual nodes N1 to N7 *i.e.*, for 7 nodes. It is also called as membership layer, where all the neurons are provided with the membership data pattern values. 7 linguistic variables that are used for the fuzzy theory to describe the membership functions. Relation between input and output membership functions of this layer are denoted by *equation (2)* and *equation (3)*

$$Y^1{}_{1i} = \mu_i \; N_i \; (\theta) \; i = 1,2 \dots 7 \qquad (2)$$

$$Y^1{}_{1j} = \; \mu_j \; N_j \; (\theta') \; j = 1,2 \dots\dots 7 \qquad (3)$$

where, $Y^1{}_{1i}$, $Y^1{}_{1j}$ represents the layer 1 output nodes and, $\mu_i \, N_i$, $\mu_j N_j$ represents the layer 1 membership functions. Memberships are bell shaped with maximum value 1 and minimum value 0. Bell shaped membership functions represented by *equation (4)* and *equation (5)* with the required parameters.

$$F(\theta; A\ B\ C) = \frac{1}{1+\left|\frac{\theta-C}{A}\right|^{2B}} \quad (4)$$

$$F(\theta'; A\ B\ C) = \frac{1}{1+\left|\frac{\theta'-C}{A}\right|^{2B}} \quad (5)$$

Where, A, B and C parameters are also said to be as premise parameters. This layer checks the weight of each membership function. It takes all its inputs from the 0th layer and computing the membership values specified the degree to all the input pattern values. Here all crisp values are converted into fuzzy sets by the process called fuzzification.

Layer 2: Pre-condition matching of fuzzy rules is performed using *equation (6)* in this layer, i.e., activation level of each rule gets computed in this layer. Number of fuzzy rules decides the number of layers in the model. All pattern values are fired and those fired values are normalized in this layer. Neurons receive the input information from the previous layers, which represents the fuzzy sets. If neurons have a greater number of inputs, then the conjunction of all rules is processed by fuzzy operation. This operation is used to combine the multiple inputs to form suitable fuzzy rules. Here, the numbers of neurons that are processed are 49.

$$Y'_2 = \mu\ M_i\ (\theta)\ And\ \mu\ M_i\ (\theta') \quad (6)$$

Layer 3: That is Norm layer, which provides the output values from the weighted sum of previous inputs from inference of the rules. Each neuron of this layer performs the normalization, and those outputs are called normalized firing strengths that are given by *equation (7)*

$$Y_3' = \frac{Y'_2}{\sum_i Y'_{2i}} \text{ where } i=1,2\dots M \quad (7)$$

It is a fixed node where it also calculates the ratio of i^{th} rule activation level to that of all fuzzy rules.

Layer 4: This layer integrates the weighted sum of previous inputs. It is an adaptive node that calculates the contribution of the i^{th} rule to the overall output, i.e., in the fuzzy system defuzzification process takes place with the weighted average method. So, it gives the crisp output by defuzzifying of the entire layer's fuzzy output. ANFIS applies a standard defuzzification process by including the centroid technique [14]. And the overall output is represented in *equation (8)*. In this layer all the neurons are trained by least square estimation to produce the optimum output.

$$Y_4' = Y_3' = \sum_{i-1}^{M} M_i\,\theta + N_i\theta' + R_i \text{ where i} = 1,2\dots M \quad (8)$$

where, M_1, $M_2 \dots M_M$, N_1, $N_2 \dots N_M$ and R_1, $R_2 \dots R_M$ are the consequent parameters of the layer.

Layer 5: It has a single neuron that produces the final output that has the weighted sum of all integrated outputs of the previous layers and hence termed as an Output layer. Then the final output is given by *equation (9)*

$$Y_5' = \sum_i Y_4' \quad (9)$$

Where,
Y_5' is the 5th layer output and Y_4' is the 4th layer output.

The output of ANFIS model is the change in duty cycle *ΔD*. ANFIS MPPT coding is done on MATLAB m-file to create ANFIS file [15][16]. The ANFIS structure created in simulation's shown in *figure 5*. The steps involved for creating a simulation model is as follows:

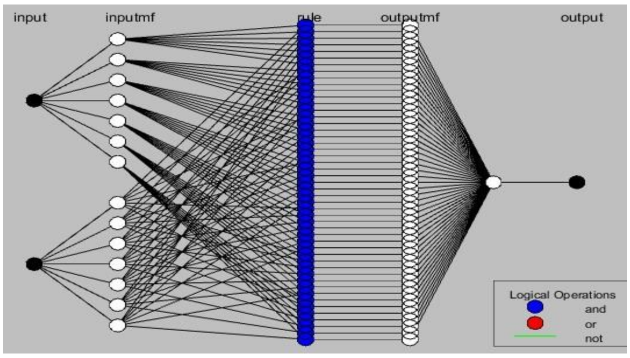

Figure 5: ANFIS structure generated by the MATLAB

Step 1: Generation of Training and Checking Data
80W solar array with load resistance is simulated in MATLAB/ Simscape which is presented in chapter 2 for the condition from open circuit to short circuit by varying load resistance from 0 to Giga ohm. Input-output pairs of 57 data sets i.e., panel voltage, current and duty cycle are generated for the condition from open circuit to short circuit. *Table 5* displays a sample of training data. *Figure 6* shows the training and checking data correlation curve.

Table 5: Input and output data patterns

Panel Voltage (Volts)	Panel Current (Amps)	Anfis Model Duty Cycle Output
9.348	4.8991	-0.006056
12.214	4.8786	-0.003634
14.1608	4.8698	-0.003244
15.5045	4.8204	-0.003
16.9164	4.6798	-0.0044239
17.3969	4.5887	-0.0045838
17.7958	4.4852	-0.0044239
18.7951	4.0491	-0.004999
19.191	3.7695	-0.00464
20.976	0.558	-0.01373

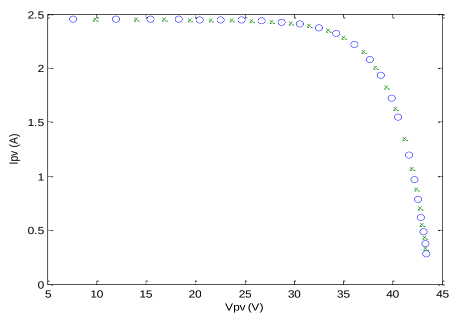

Figure 6: Training and checking data plot

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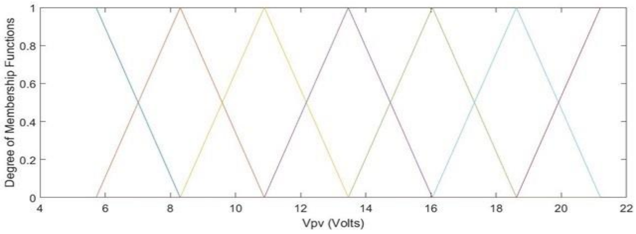
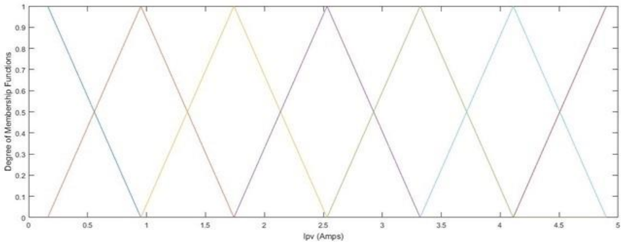
Step 2: Configuration of Fuzzy System for Training
Seven numbers of triangular membership functions are chosen for input and output control parameters [17][18]. The plotted membership functions of2' numbers of input such as V_{pv} and I_{pv} are shown in *figures7a* and *7b* respectively.



(a)



(b)

Figure 7: ANFIS MPPT membership functions a) Vpv and b) Ipv

Step 3: ANFIS-Training
ANFIS training is done for 40 epochs; rule viewers are shown in *figure 8*. The 49 rules are shown in *figure 8*. The ANFIS generated surface's shown in *figure 9*. which is a 3D plot between PV voltage PV current and change in duty cycle.

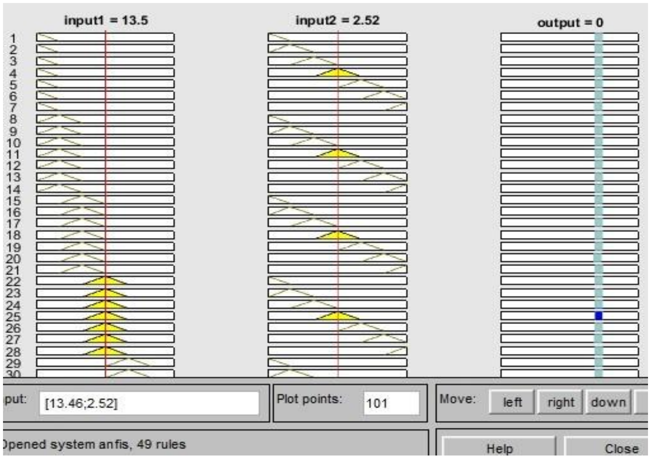


Figure 8: ANFIS MPPT rule viewer

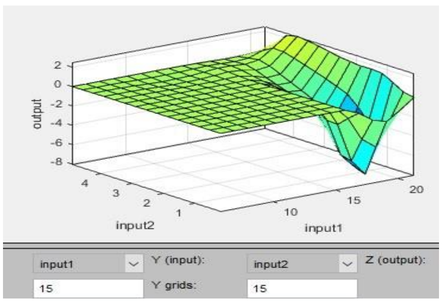


Figure 9: ANFIS MPPT surface viewer

Step 4: Checking data command (chkdata) through MATLAB is used to prevent MPPT model form over fitting during training. *Figure 10 & 11* shows the training and checking error profile for 40 epochs. The result of the training is as follows: trnRMSE = 0.00104; chkRMSE = 0.075.

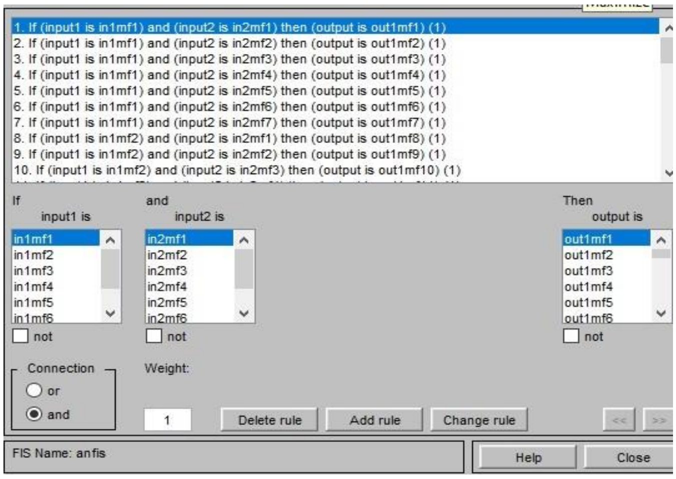


Figure 10: ANFIS MPPT rules

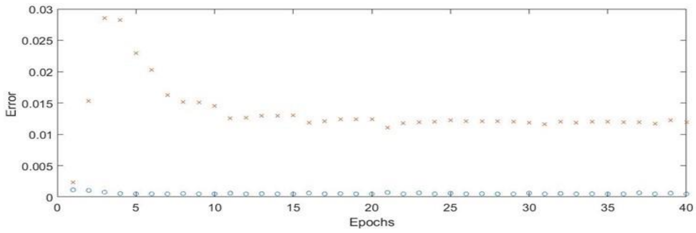
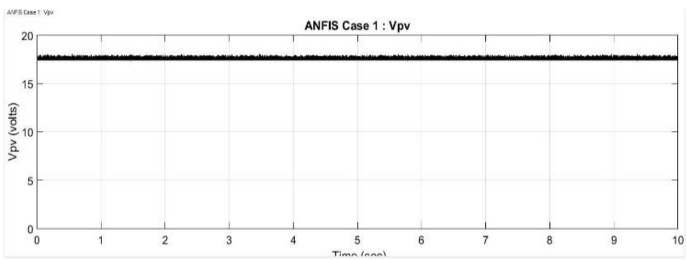


Figure 11: Epoch Vs training error 'o', check error 'x'

3.2 Performance Evaluation in Simulation

The performance evaluation of ANFIS MPPT investigations is done under four scenarios that mimic the real-world sudden changes in solar insolation and working temperature. These four cases are, *Case 1*: Standard test condition, is listed in *table 6*. *Case 2*: Gradual rise and fall in irradiance with constant temperature, is listed in *table 7*. *Case 3*: Step change in temperature with constant irradiance, is listed in *table 8*. And *Case 4*: Random weather condition is listed in *table 9*. Since, the time required by LUO converter to attain steady state condition is 0.002 sec, the sampling frequency of the MPP tracker has been chosen as 500 Hz. *Figures 12* shows the simulation results for various static and dynamical input patterns. Observation for case 1 is tabulated in the *table 6*. The results revealed that static efficiency of ANFIS MPPT technique is 98.725%.



(a)

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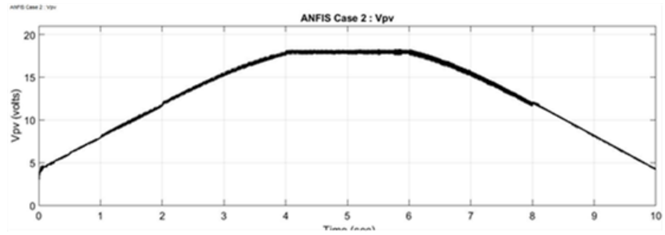

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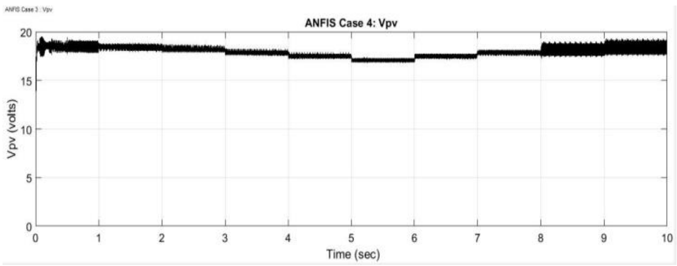

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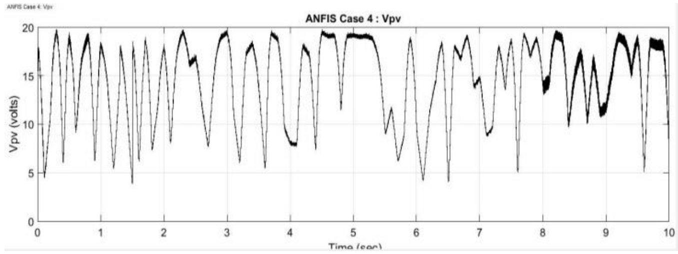

(d)

Figure 12: Simulated PV array voltage for ANFIS MPPT technique (a) Standard test condition (b) Gradual variation in irradiance with constant temperature (c) Step change in temperature with constant irradiance (d) Rapid climatic change

Table 6: Simulation result of Case 1

Parameter	Variable	Values
(PV)Voltage	Vpv(V)	17.56
(PV)Current	Ipv(A)	4.554
(PV)Power	Ppv(W)	79.968
Converter out-put (V)	Vo(V)	48.68
Converter out-put (A)	Io(A)	1.623
Current out-put (W)	Po(W)	78.98
Voltage ripple	Δ Vo (V)	1.2
Current ripple	Δ Io (A)	0.04
Settling time	t (s)	0.02
Tracking efficiency	η (%)	98.725

Table 7: Simulation Results of dynamic Case 2

MPPT	Simulation Time (Secs)						Convergence Time(Secs)	Tracking Efficiency (%)
	t:3		From t:4 to t:6		t:8			
	Ppv (Watts)	Vpv (Volts)	Ppv (Watts)	Vpv (Volts)	Ppv (Watts)	Vpv (Volts)		
P&O	34.65	19.57	73.82	19.04	37.76	20.01	0.0991	92.58
ANFIS	42.05	14.56	79.97	18.81	54.12	16.89	0.0116	99.69

Table 8: Simulation Results of Case 3

MPPT	Simulation Time (Secs)												Converge nce Time (Secs)	Tracking Efficiency (%)
	0-1		1-2		2-3		3-4		4-5		5-6			
	Ppv (Watts)	Vpv (Watts)	Ppv (Watts)	Vpv (Watts)	Ppv (Watts)	Vpv (Watts)	Ppv (Watts)	Vpv (Watts)	Ppv (Watts)	Vpv (Watts)	Ppv (Watts)	Vpv (Watts)		
P&O	76.11	19.98	73.32	19.87	68.95	19.47	66.96	18.86	65.16	17.29	59.95	17.79	0.0723	92.08
ANFIS	81.02	18.39	80.53	18.12	79.15	17.93	76.31	17.78	72.57	17.53	70.77	16.86	0.0086	99.58

Table 9: Simulation results of Case 4

MPPT	Simulation Time (Secs)								Convergence Time (Secs)	Tracking Efficiency (%)
	t:0.7		t:2.3		t:5.1		t:7.6			
	Ppv (Watts)	Vpv (Volts)	Ppv (Watts)	Vpv (Volts)	Ppv (Watts)	Vpv (Volts)	Ppv (Watts)	Vpv (Volts)		
P&O	63.13	17.91	76.84	20.01	74.03	19.58	48.19	18.07	0.1126	81.44
ANFIS	66.46	16.67	94.09	19.31	85.62	18.98	52.14	14.76	0.0252	94.09

ANFIS at higher level of irradiance *i.e.*,700-1000W/m^2 is' marginally great than that of conventional in constant climatically conditions. On the other hand, efficiency is lower at low irradiance values i.e.,100-200W/m^2. But for the values which beyond their training and membership boundary they exhibited a poor performance. The observation of simulation for case 4 is listed in *table 9*. The comparison simulation results shows the better tracking of MPP *i.e.*, P_{max} is obtained by ANFIS MPPT. Its dynamic efficiency is around 99.58%. The performance and efficiency of ANFIS is better which is proved at computation *i.e.*, percentage of error in reference value is 0.002. Variation in power and maximum power point is high is around 4.8W with respect to 80W panel in P&O and least in ANFIS is about 1.6W. ANFIS took least time *i.e.*, 0.01 sec to reach MPP.

4. SIMULATION RESULT

The positive output LUO converter implementation in solar photovoltaic array maximum PowerPoint-tracking application in simulation was successfully done. The performance evaluation and controllability of LUO converter is verified in simulation in both open loop and closed loop. An efficient MPPT algorithm using ANFIS soft computing technique was successfully proposed and implemented in standalone PV system. Steps adopted for ANFIS MPPT implementation is done sequentially according to the established procedures. The simulation results of ANFIS MPPT is the best in both steady state and transient climatical conditions.

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