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ANFIS based MPPT and Load regulation in paralleled connected LUO converters for standalone photovoltaic system

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ABSTRACT
Due to scarcity of fossil fuel and increasing demand of power supply, it is forced to utilize the renewable energy resources. Considering easy availability and vast potential, world has turned to solar photovoltaic energy to meet out its ever increasing energy demand. This paper proposes adaptive neuro fuzzy inference system (ANFIS) based maximum power point tracking and load regulation in paralleled connected positive super lift LUO converter for standalone photovoltaic system. Connection of two or more converters in parallel results in unequal sharing of load current. For ensuring equal sharing of load current a new current sharing scheme without a dedicated current sharing controller is proposed. Regulation of load voltage is implemented using ANFIS and its performance is compared with PID controller. The entire proposed system has been simulated using MATLAB/Simulink software. Simulation results show that proposed system is simple, efficient and low cost.

1. INTRODUCTION
Photovoltaic generation is becoming increasingly important as a renewable source and it will make one of the biggest contributions to electricity generation among all renewable energy candidate by 2040.To overcome the power crisis in the country the best way is to make use of renewable energy sources such as solar and wind[1-3].
The photovoltaic (PV) cell exhibits nonlinear behaviour, while interfacing the load to photovoltaic modules DC-DC converters. To get maximum efficiency of the PV module it must be operated at maximum point. Therefore it is necessary to operate the PV module at its maximum power point for all irradiance and temperature conditions[4-6]. To obtain maximum power from the photovoltaic array, photovoltaic power system usually requires maximum power point tracking (MPPT) controller. The proposed MPPT is ANFIS based constant voltage reference method.
ANFIS integrates the neural network and fuzzy logic. The power delivered from PV module is stored in lead acid battery through buck boost converter. This power is delivered to load using paralleled connected positive super lift LUO converters(PSLLCs)
The positive output super lift Luo converter (PSLLC) is a new series of DC-DC converters possessing high voltage transfer gain, high power density, high efficiency and reduced ripple voltage and current[7-10].
The objective of this paper is to fed the output of PV array to PSLLCs through buck boost converter and battery to get higher output current. Since two equal rated converters may not be identical practically, the output currents of two converters may not share equally. To ensure equal sharing of output current, a control scheme is used[11-14].
Control scheme consists of a voltage controller and a current controller. Voltage controller regulates output voltage using ANFIS. But current controller is not using a dedicated current sharing controller. Instead it ensures current sharing by sensing power input voltage, output voltage and individual output currents. The performance of ANFIS is compared with PID controller and validated through simulation results.
In the following, PV cell characteristics are presented, the circuit configuration and control scheme is described, Luo converter operation and its mathematical model is given and the design of ANFIS and PID controllers are presented. The design of controllers is then verified by MATLAB simulation.

2.MODELLING OF PV CELL
A solar PV cell consists of the semiconductor material which converts solar radiation into the dc current using the photovoltaic effect [2]. The most important qualities of a solar cell are described by the Voltage-current characteristic. The equivalent circuit of the general model which consists of a photo current, a diode, a parallel resistor expressing a leakage current, and a series resistor describing an internal resistance to the current flow, is shown in Fig.1. The voltage-current characteristic equation of a solar cell is given as follows:

$$I = I_{ph} - I_s\left(exp\frac{q(V+R_sI)}{NKT} - 1\right) - (\frac{V+R_sI}{R_{sh}}) \quad (1)$$

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 14 (2015) pp 34792-34798

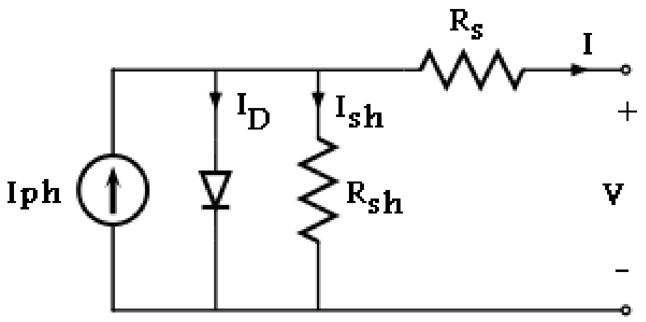

Fig. 1. Equivalent circuit of a PV Cell

In the above equation, I_{ph} is the photocurrent, I_s is the reverse saturation current of the diode, q is the electron charge, V is the voltage across the diode, K is the Boltzmann's constant, T is the junction temperature, N is the ideality factor of the diode, and R_s and R_{sh} are the series and shunt resistors of the cell, respectively. From above equation it is known that the PV,VI and IV characteristics of PV cell will be changed when solar illumination changes.

Fig.2(a) and (b) shows I-V and P-V characteristics of PV array for various solar illumination. The characteristic curves indicate that PV cell is a non linear DC power Supply.

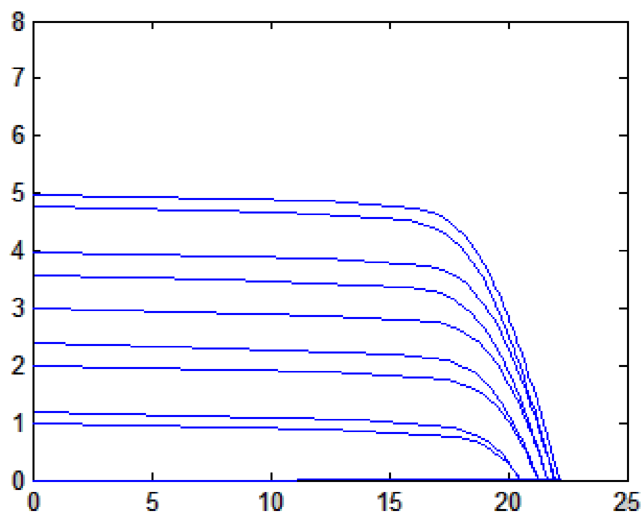

Fig. 2(a).I-V Characteristics Curve of PV Array

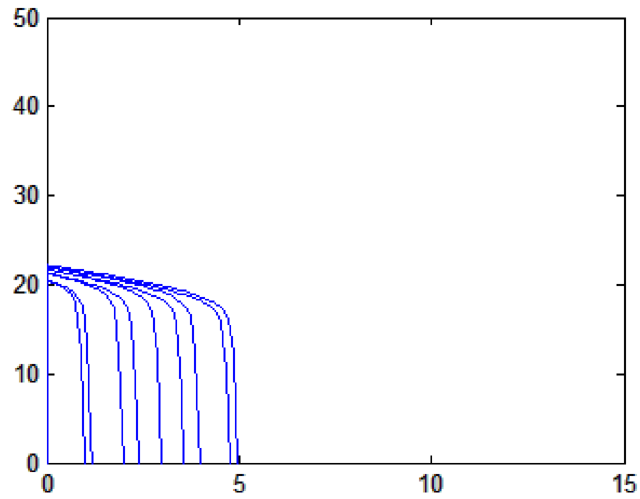

Fig. 2(b).V-I Characteristics Curve of PV Array

Fig.3 shows maximum power point tracking from PV array. To track maximum power from PV array, ANFIS based constant voltage reference method is used. The output voltage (V_{pv}) from PV array is sensed and compared with the reference voltage to generate error signal. This error signal is given as input to ANFIS controller. It generates a signal proportional to error signal and adjust the duty ratio of buck boost converter for tracking of maximum power.

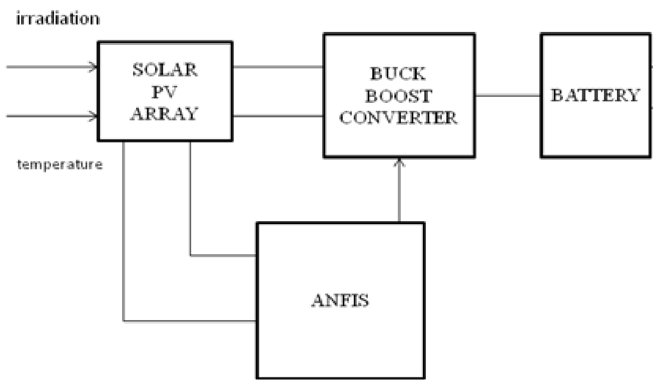

Fig. 3. MPPT from PV array

3. CIRCUIT CONFIGURATION AND CONTROL SCHEME

A main trend in switch mode power supplies is the requirement of very low output voltages with very high currents. With the proposed system high output currents can be achieved by connecting two converters in parallel at the output[15].

3.1. Circuit Configuration

The block diagram of the proposed system is shown in Fig 4.It has solar PV array, buck boost converter, ANFIS, battery, PSLLC and ANFIS. In the presence of radiation, the voltage and current are measured from PV array. Based on the error between the actual voltage and reference voltage the ANFIS

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 14 (2015) pp 34792-34798

adjusts the duty ratio of the buck boost converter to obtain the desired output voltage. The output of the buck boost converter is given to the battery. The nominal voltage of the battery is 12V. Battery used here is lead acid battery.

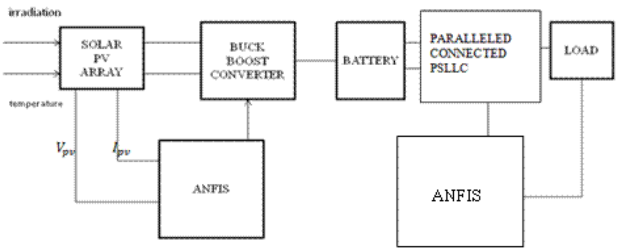

Fig. 4. Proposed block diagram

The output from the battery is given to the load through paralleled connected PSLLCs. Paralleled connected converters results in generation of higher output current. But the difficulty is unequal sharing of output current between converter modules take place due to parameter mismatches. Hence to ensure equal sharing of load current a new current sharing scheme is proposed and is shown in Fig 5. It consists of two loops. One is current loop and another one is voltage loop.The output voltage loop generates error signal which is proportional to the difference between actual output voltage ($\hat{v}_0$) and the reference voltage ($\hat{v}_{ref}$). The output ($\hat{\imath}_c$) from output voltage loop acts as reference for current loop. The current loop ensures equal sharing of load current which depends on power input voltage ($\hat{v}_g$), output voltage ($\hat{v}_0$) and individual output currents ($\hat{\imath}_L$) of converter modules. Hence no dedicated current sharing controller is needed. This reduces system complexity. The load voltage is regulated using ANFIS.

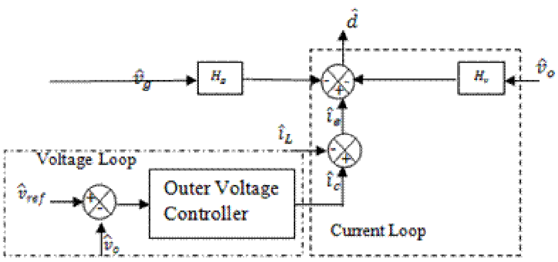

Fig. 5.Proposed Control Scheme

4. MATHEMATICAL MODELING OF PSLLC

Positive Super Lift Luo Converter is shown in Fig 6.It increases its output voltage in geometric progression stage by stage. It consists of an input supply voltage V_{in}, the capacitors C_1 andC_2, the inductor L_1, the power switch$S$, the freewheeling diodes D_1 and D_2 and the load resistance R.Assume that the PSLLC operates in Continuous conduction mode (CCM).

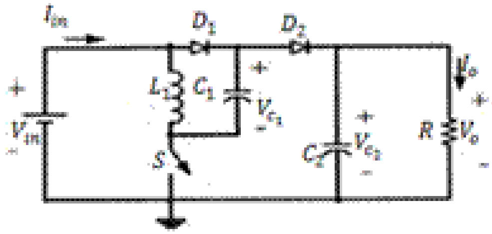

Fig. 6.Circuit of PSLLC

There are two modes of operation in PSLLC. When the switch is closed the circuit of Fig 6(a) is obtained

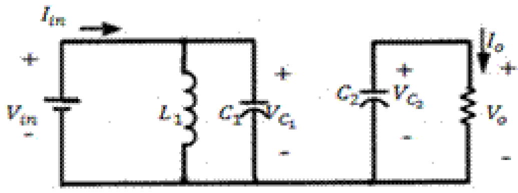

Fig. 6(a). Mode 1 operation of PSLLC

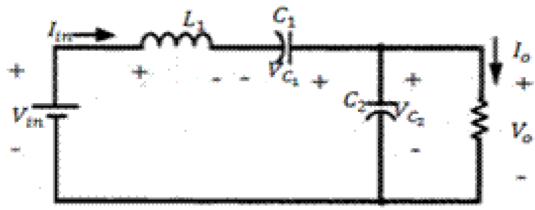

Fig. 6(b) Mode 2 operation of PSLLC

Let i_1 be the inductance current and V_{C_1} and V_{C_2} be the voltage across capacitances C_1 and C_2.Therefore the assumed state variables are $i_1 = x_1$,$V_{C_1} = x_2$,$V_{C_2} = x_3$. With the assumed state variables the state space equation is expressed as

$$\dot{x_1} = \frac{u}{L_1} \quad (2)$$

$$\dot{x_2} = \frac{u}{C_1 R_{in}} - \frac{x_1}{C_1} \quad (3)$$

$$\dot{x_3} = \frac{x_3}{RC_2} \quad (4)$$

Similarly when the switch is open the circuit of Fig 6(b) is obtained.

The state space equation of Fig.6(b) is given as

$$\dot{x_1} = \frac{u}{L_1} - \frac{x_2}{L_1} - \frac{x_3}{L_1} \quad (5)$$

$$\dot{x_2} = \frac{x_1}{C_1} \quad (6)$$

$$\dot{x}_3 = \frac{x_1}{C_2} - \frac{x_3}{RC_2} \quad (7)$$

By using state-space averaging method the state model of PSLLC is given as

$$\begin{bmatrix} \frac{di_{L1}}{dt} \\ \frac{dV_{C1}}{dt} \\ \frac{dV_{C2}}{dt} \end{bmatrix} = \begin{bmatrix} 0 & \frac{-(1-d)}{L_1} & \frac{-(1-d)}{L_1} \\ \frac{1-2d}{C_1} & 0 & 0 \\ \frac{1-d}{C_2} & 0 & \frac{2d-1}{RC_2} \end{bmatrix} \quad (8)$$

Here R_{in} is the internal resistance of the source and d is the duty cycle

The output equation of PSLLC is given by

$$y = x_3 \quad (9)$$

The state model of equation (9) is given as

$$y = [0\ 0\ 1]\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} \quad (10)$$

5. ANFIS AND PID CONTROLLER

5.1 ANFIS

Artificial intelligence(AI) based methods are increasingly used in renewable energy systems due to flexible nature of control offered.The AI techniques are highly successful in nonlinear systems due to the fact that once properly trained they can interpolate and extrapolate the random data with high accuracy.

The neural network is the powerful technique for mapping the input output nonlinear function; however it lacks the heuristic sense and it works as a black box. On the other hand fuzzy logic has the capability of transforming heuristic and linguistic terms into numerical values through fuzzy rules and membership functions. It also provides the heuristic output by quantifying the actual numerical data into heuristic and linguistic terms. The shortcoming of fuzzy computation is obtaining fuzzy rules and functions which heavily rely on the prior knowledge of the system. ANFIS integrates both neural network and fuzzy logic.

For various irradiances and temperature the voltage is measured from the PV array and it is given to the ANFIS controller. The main objective of this work is to investigate the suitability of artificial intelligent systems (neural network and fuzzy logic) for validating the proposed PV system under variable climatic condition.

The training data for ANFIS is obtained and is shown in Fig 7.The training data is a required argument to ANFIS. The training error is the difference between the training data output value and the output of the fuzzy interference system corresponding to the same training data input value. The training error records the root mean squared error of the training data set at each epoch. The ANFIS editor plots the training error versus epochs curve as the system is trained.

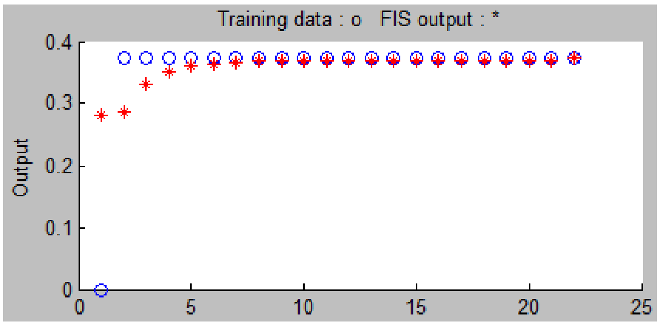

Fig. 7. Training Data

In Fig 8 the testing data for ANFIS is shown. The testing data set helps to check the generalization capability of the resulting fuzzy interference system. Testing of the trained fuzzy interference system model against the checking data is done to complete the task. To do it select the checking data in the test fuzzy interference system portion of the GUI and then click the test now.

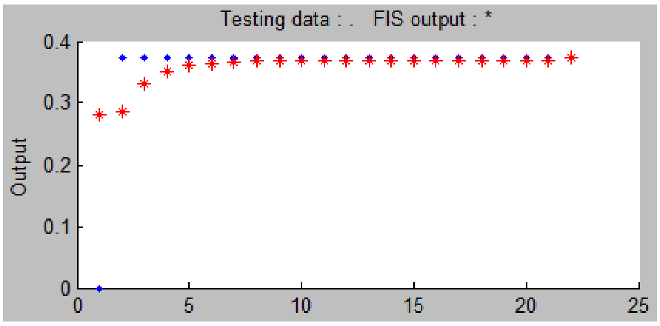

Fig. 8. Testing Data

Fig 9 gives the checking data for ANFIS. The checking data is used for testing the generalization capability of the fuzzy interference system at each epoch. The checking data has the same format as that of the training data and its elements are generally distinct from those of the training data. The checking data is applied to the model at each training epoch. The FIS membership function parameters computed using the ANFIS editor when both the training and checking data are loaded and are associated with the training epoch that has a minimum checking error.

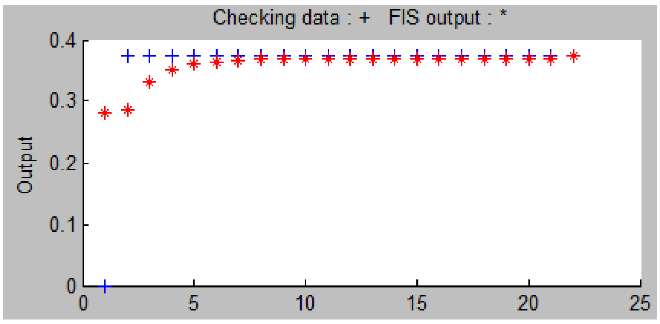

Fig. 9. Checking Data

5.2 PID CONTROLLER

The P,PI and PID controllers are used in order to achieve regulated output. The parameters of three controllers are obtained from open loop response of proposed converter. The controller parameters can be tuned to meet given performance specifications. This process is referred to as controller tuning. In this paper Zeigler-Nichols tuning was used to determine proportional gain K_p, integral T_I and derivative time T_d based on the transient response characteristics of a proposed converter. Table.1 lists out Zeigler-Nichols tuned controller.

Table.1.Zeigler-Nichols Tuned Controller Parameters

controllers	K_p	T_I	T_d
P	0.175	∞	0
PI	0.1575	0.0023	0
PID	0.21	0.00139	0.0003475

6. RESULTS AND DISCUSSIONS

A stand-alone PV system is used to test the feasibility of the proposed method. Paralleled connected LUO converters is used as the power electronics interface between the PV array and the load to obtain the regulated output.

Two equal rated LUO converters are connected in parallel at the output to obtain higher output current. A new current sharing scheme without a dedicated current controller is proposed in order to share the output current equally between two converters. To obtain regulated output voltage ANFIS controller is used.

Table 2. PV module specifications

Parameter	Specification
Peak Power (P_{PV})	110 W
Peak power voltage (V_{PV})	22V
Current at peak power (I_{PV})	5A
Open circuit voltage (V_{OC})	22.2 V
Short circuit current (I_{SC})	5.45A

This section discusses the simulation studies of paralleled connected PSLLCs with controllers for PV system. The validation of the system performance is done for start-up transients.

Simulations are performed on paralleled connected PSLLCs for PV system with parameters listed in Table.2 and Table 3 using MATLAB/ Simulink software.

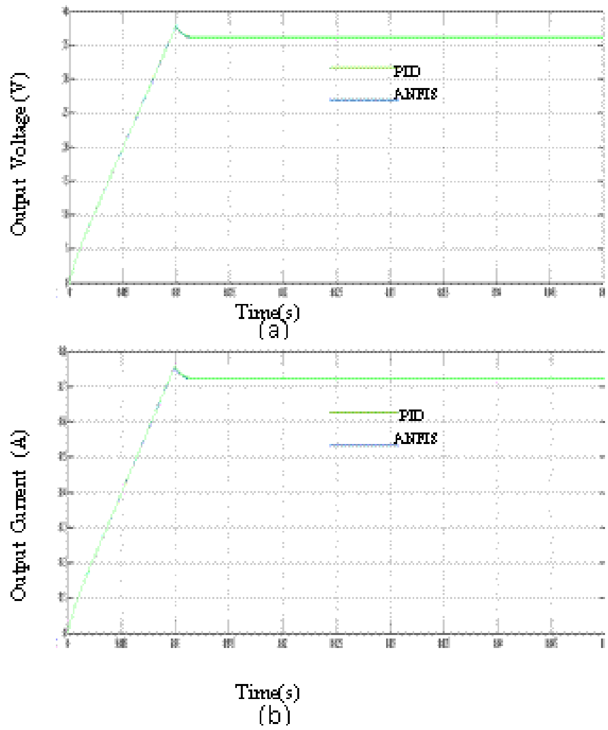

Fig. 10. Simulation results for various solar radiations and load resistance R=50Ω with parameter mismatches between converter modules. (a)Response of average output voltage of paralleled connected PSLLCs (b) Response of average output current of paralleled connected PSLLCs

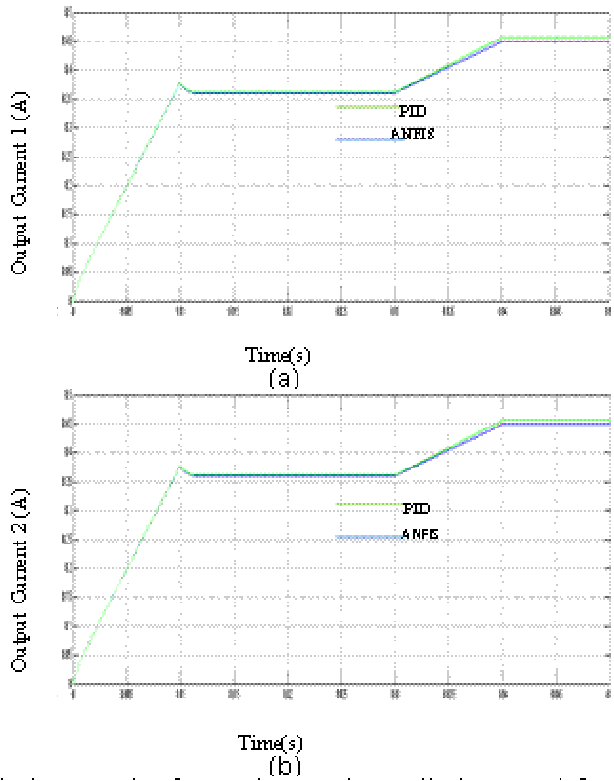

Fig. 11. Simulation results for various solar radiations and for change in load resistance from R=50Ω to R=40Ω with

parameter mismatches between converter modules. (a) Response of average output current 1 of paralleled connected PSLLCs (b) Response of average output current 2 of paralleled connected PSLLCs

Fig. 10 (a) shows the dynamic behaviour at start-up for the output voltage of paralleled modules for various values of solar irradiations input with ANFIS and PID controllers. It indicates that the output voltage for ANFIS is 36V and for PID controller it is 36.05V. Also the response for ANFIS controller settles faster for ANFIS than PID controller.
Fig. 10 (b) shows the dynamic behaviour at start-up for the output current of paralleled modules for various values of solar irradiations input with ANFIS and PID controllers. It shows that the output current is 0.72A for ANFIS controller and 0.721A for PID controller. Here also the settling time is better for ANFIS than PID controller.

Table 3. Parameters of Paralleled connected PSLLCs

Parameter Name	Symbol	Value
Input Voltage	V_{in}	12v
Output Voltage	V_O	36v
Inductor	L_1, L_2	100uH
Capacitors	$C_{11}, C_{12}\ C_{21}, C_{22}$	30uf
Nominal switching frequency	f_s	100KHz
Load resistance	R	50
Output current	I_O	0.72
Range of duty ratio	d	0.3 to 0.9

Fig.11 (a) and (b) shows the dynamic behaviour of the average output current of module 1 and module 2 for various values of solar irradiations input and for change in load resistance from R=50Ω to R=40Ω with parameter mismatches between converter modules. It indicates the response deviates for PID controller and settles effectively for ANFIS controller for change in load resistance. Also average current is 0.36A for ANFIS controller and 0.3605A for PID controller. Fig.11(a) and (b) indicates that equal sharing of output current takes place in presence of parameter mismatches.

Table 4. Performance of PSLLC with controllers

Various solar radiations and load resistances	ANFIS				PID			
	V_o	I_o	I_{o1}	I_{o2}	V_o	I_o	I_{o1}	I_{o2}
40Ω	36	0.9	0.45	0.45	36.05	.901	.4505	.4505
50Ω	36	0.72	0.36	0.36	36.05	.721	.3605	.3605
60 Ω	36	0.6	0.3	0.3	36.05	.601	.30	.30

7. CONCLUSION

This paper has proposed a current sharing in paralleled connected PSLLCs for PV system using ANFIS and PID controllers. The system has been proved to be effective in current sharing without a dedicated current sharing controller. Due to this cost and complexity of proposed system is reduced.
Advantage PID controllers, it is robust to large variations in line and load disturbances. Several simulation results are presented to study the performances of controllers. Simulation results show that ANFIS controllers maintain a regulated output voltage and proper current distribution under load variations.
The proposed method is suitable for an efficient power supply for satellite communication, Uninterruptible power supplies etc.

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