ANALYSIS OF NOVEL ANFIS BASED MPPT ALGORITHM UNDER PARTIALLY SHADED PHOTOVOLTAIC SYSTEM

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ABSTRACT

This paper presents a compare performance two novel maximum power point tracking technique (MPPT) of incremental conductance (INC) and adaptive neural fuzzy inference system (ANFIS) algorithms has been proposed for a two stage interleaved boost converter powered by a set of two photo voltaic panels. Compare the output power of photovoltaic (PV) system under uniform and partial shade condition (PSC). Under PSC, both control methods can eliminate interference of the local maximum power point (MPP) to make the PV array operating at closer to the global MPP. A comparison of the use of the INC algorithm for the individual PV units has also been carried out and the novel methodology using the ANFIS algorithm proves to be better. Detailed simulation has been carried out in the MATLAB SIMULINK environment and a hardware setup has also been devised and tested to validate the proposed technique.

Keywords: PV system, MPPTs, Microcontroller, cascade ISSBC

INTRODUCTION

The multiple PV modules feeding to a common load form power distribution used in solar photovoltaic system. The power-voltage chacteristics of PV array are affected by temperature, solar irradiation and partial shaded condition. In such systems, a PV non-linear characteristic exhibits multiple local MPP during partial shading condition. Many MPPT algorithms have been proposed in recent years, such as perturb and observation (P&O) [1], INC [2-4], fuzzy logic (FLC) [5-7], artificial neural network (ANN) [8-9], particle swarm algorithm (PSO) [10], ANFIS [11-12], In this work providing individual INC and ANFIS MPP tracking schemes for each of the PV modules used to extract the maximum DC power from PV module. In recent times, ISSBC topologies have received more attention to the use in PV applications. This leads to minimize switching losses in the converter. In this work cascaded interleaved soft switching boost converter (ISSBC) is used [13]. The proposed controller has been validated with experiment results. The block digram of the proposed technique is shown in Figure 1.A 150 Watts rated PV panel consisting of 72 multi-crystalline silicon solar cells in series parallel connected combination is used for the application. The embedded simulink model is developed based on PV module current equation and manufacturer's data sheet parameter of BP SX 150S PV module [14].

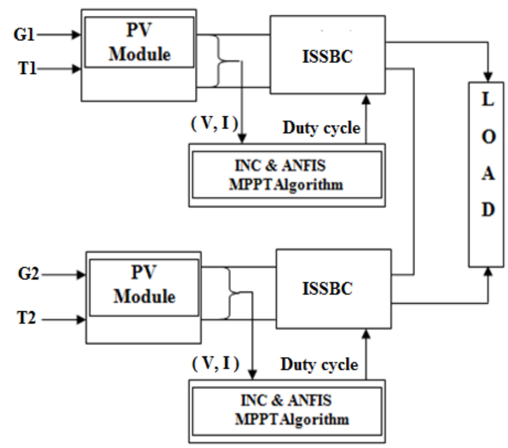


Figure-1 Block diagram of the proposed system

MPPT CONTROL ALGORITHMS

The MPPT algorithm is used for extracting the maximum power from the PV module and passes it on to the load. A DC-DC converter serves the purpose of transferring maximum power from the solar PV module to the load by varying the duty cycle. The load impedance, as seen by the source, is varied and matched at the point of the peak power with the source to load to transfer the maximum power. many MPPT algorithms are dicussed in detail in previous lituratures. In this work INC and ANFIS MPPT algorithms are used for MPP tracking. In order to implement these MPPT algorithms, a cascaded ISSBC has been used.

INC MPPT Algorithm

This method tracks the maximum power point by comparing the solar array incremental (ΔG) and instantaneous conductance (G), the operation of this technique. This method focuses directly on power variations of the PV array. This scheme tracks the maximum power point by comparing the solar array incremental conductance ($\Delta G = dI_{pv}/dV_{pv}$) and instantaneous conductance ($G = I_{pv}/V_{pv}$). The PV panel voltage and current are measured at fixed sampling intervals and fed to the controller to calculate the PV panel power. The PV panel incremental conductance is predictable by measuring miniature changes in array voltage and current. The PV panel instant conductance is calculated by dividing the array current by the voltage. Once these variables are updated, the method tracks the maximum power point by comparing the incremental and instantaneous conductance of the solar array until the MPP is reached i.e where $dP_{pv}/dV_{pv} = 0$, as illustrated in Equation (1).

$$\left.\begin{array}{lll} \dfrac{dP_{pv}}{dV_{pv}} = 0 & \dfrac{I_m}{V_m} = -\dfrac{\Delta I_{pv}}{\Delta V_{pv}} & G = \Delta G \\ \dfrac{dP_{pv}}{dV_{pv}} > 0 & \dfrac{I_m}{V_m} > -\dfrac{\Delta I_{pv}}{\Delta V_{pv}} & G > \Delta G \\ \dfrac{dP_{pv}}{dV_{pv}} < 0 & \dfrac{I_m}{V_m} < -\dfrac{\Delta I_{pv}}{\Delta V_{pv}} & G < \Delta G \end{array}\right\} \quad (1)$$

ANFIS MPPT Algorithm

The ANFIS system is used to formulate the ANN architecture in the inference engine of a FLC controller. The functional block diagram and flow chart of ANFIS is shown in Figure.2 and Figure.3 respectively. The structure comprises of three distinct layers namely input layer, hidden layer and output layer.

The ANFIS controller implemented in this work consists of fuzzifier section which comprises of the input signals error (*e*) and change in error signal (*ce*) and the membership functions are selected as Gaussian membership function. The defuzzifier of the ANFIS is the output function that is the modulation index (*d*).

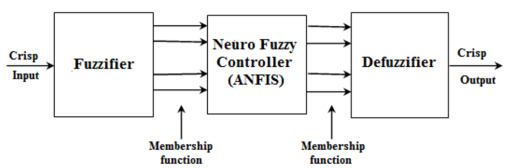


Figure-2 Adaptive neuro fuzzy control system

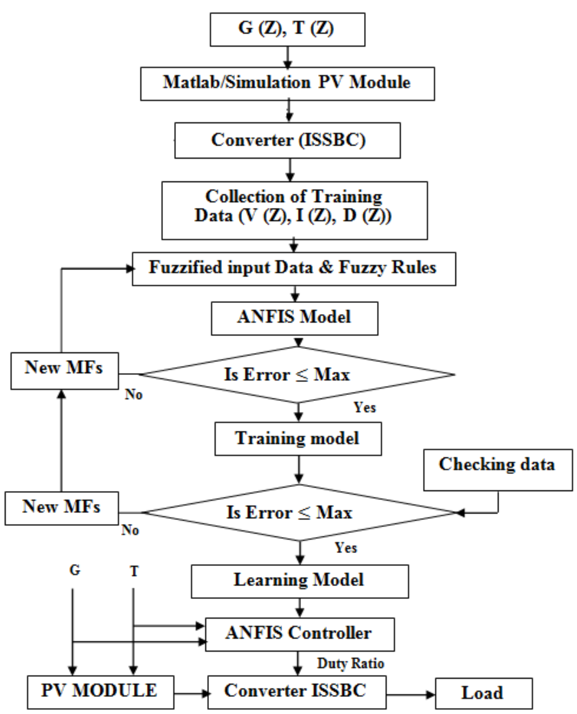


Figure-3 Flowchart of ANFIS based MPPT

The input membership functions are mapped to the output membership function by 25 rules through grid partitioning method using the FIS generator in MATLAB Simulink. The 2500 data sets used to train ANFIS are obtaining from workspace from the previous INC MPPT algorithm. The learning data is trained through back propagation technique for 500 epochs for minimum error tolerance. The network training is performing repeatedly until the performance indices are reduced below a specified value ideally to zero. In other words when performance indices leads to zero, then the trained ANFIS connecting weights are adjusted in such a way that the estimated array voltage is identically equal to the MPP voltage. The trained surface rule phase and ruler view are shown in Figure.4 and Figure .5 respectively. The trained data set are exported to the simulation and performance of the ANFIS MPPT controller under different partial shading condition is analyzed.

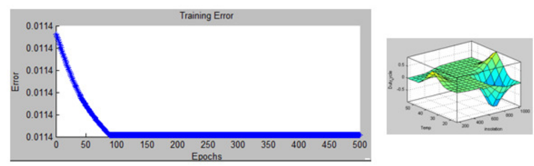


Figure- 4 ANFIS training error and surface view

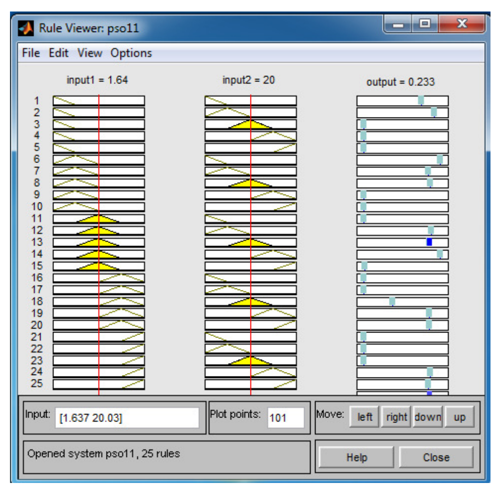


Figure-5 Trained ruler view of ANFIS MPPT

SIMULATION MODEL

The simulink software validates the performance of the MPPT techniques under different operating conditions. The PV module parameters are obtained from the 150-Watts SX 150S PV module data sheet. The performance of MPPT algorithms are tested under standard testing condition. The parameters considered in the Standard Test Condition are irradiance of 1000 W/m^2 and cell temperature of 25°C. The simulation diagram is shown in Figure.6. The V-P and I-V characteristics curves of the PV module considering solar radiation changes are simulated and are shown in Figure.7 and Figure.8 respectively. Diodes introduce multiple steps in I-V characteristics and multiple peaks in V-P characteristics.

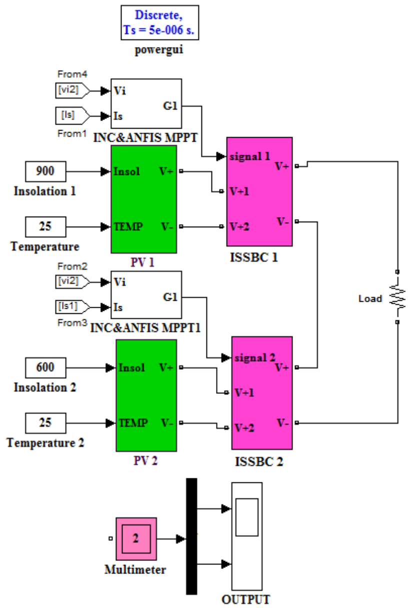


Figure-6 Simulation block diagram of the system

In order to achieve the maximum power point of PV modules, INC and ANFIS MPPT controller has been developed using Matlab Simulink model

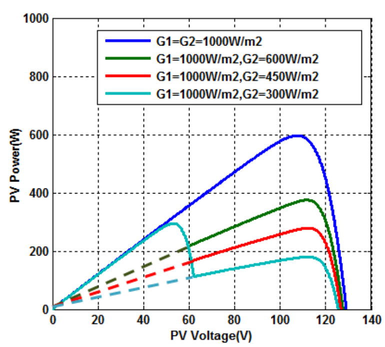


Figure-7 V-P Curves at 25°C

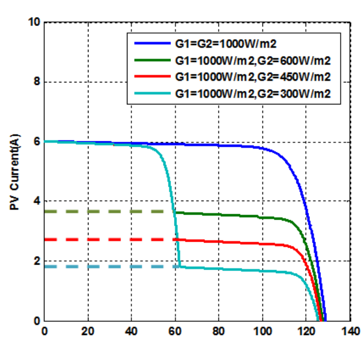


Figure-8 V-I Curves at 25°C

Effect of Dynamic Variation in the Solar Irradiation

The PV module is simulated with cascaded interleaved ISSBC controlled by INC and ANFIS MPPT algorithms under dynamically changing solar irradiations at constant temperature of 25°C. The shading patterns PD1 and PD2 are shown in Table.1. For PD1, the irradiance on the two PV panels is uniform with insolation of 900W/m^2, as a result, only one peak exists in the V-P characteristics curve of the PV array. For PD2, there are two peaks in the V-P characteristics with insolation of G_1=900 W/m^2 and G_2=450 W/m^2. The detailed simulation results are shown in Figure .9. From Figure.9, it is observed that when the shading pattern changes from uniform condition to partial shading condition at 200s (middle of the x-axis), the proposed MPPT algorithms can find the global MPP for the new shading pattern. When the case change from PD1 to PD2, the power changes from 240 W to 137.2 W for INC MPPT algorithm and the power changes from 240.1 W to 144 W for ANFIS MPPT algorithm. From the Figure.9 (c), it is reveal that ANFIS algorithm tracks the MPP with negligible oscillations. The INC MPPT algorithm also tracks the MPP nearer to ANFIS MPPT but in INC method, there is oscillations around the MPP and economically less effective as it requires more sensors. The credible efficiency, power and duty cycle rate of each technique under the rapidly changing conditions of irradiance are presented in Table .2. From Table .2, it is inferred that the efficiency for ANFIS MPPT is comparitively higher than the INC algorithm.

Table-1 Dynamic response of shadedinsolation pattern

Pattern	Time configuration(*s*)	Insolation (W/m^2)	
		G 1	G 2
PD1	from t=0*s* to t=200*s*	900	900
PD 2	from t=200*s* to t=400*s*	900	450

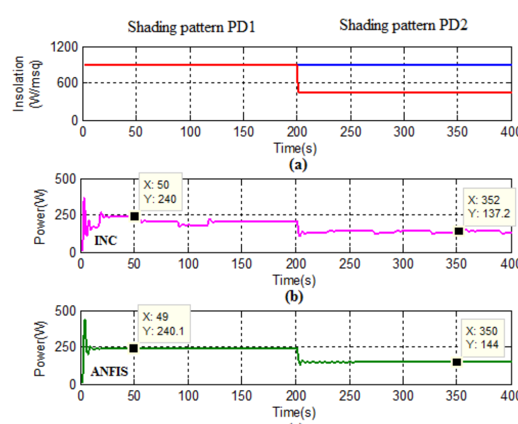


Figure-9 Dynamic changes in irradiation
(a) Insolation (b) output power (INC)

(c) Output power (ANFIS)

Table-2 Dynamic response of simulation

MPPT	Pattern	Power (W)	MI	Efficiency (%)
INC	PD1	240.00	0.22	96.82
	PD2	137.20	0.21	98.52
ANFIS	PD1	240.10	0.23	98.60
	PD2	144.00	0.22	98.70

Effect of Partial Shading on Solar Panels

In order to verify the performances of the INC and ANFIS algorithm, the cascaded ISSBC is connected to a resistive load (R=20 ohm) with switching frequency of 30 kHz. Under non- shaded (balanced) condition the solar irradiance of both PV arrays are constant ($G_1 = G_2 = 900$ W/m^2). Under the partial shaded (unbalanced) condition the solar irradiance of two PV modules are G_1 =900 W/m^2 and G_2=600 W/m^{2}respectively. The simulation results are tabulated in Table.3. When the solar modules are non-shaded; the total converter output power is 207.4W for INC algorithm and 240.1W for ANFIS algorithm. When the second PV module is partially shaded with G2=600 W/m^2, then the total converter power decreases to 145.7W for INC algorithm and 144W for ANFIS algorithm. The output voltage, current and power under non-shaded (balanced) condition for INC and ANFIS algorithms are shown in Figure.10 and Figure.11 respectively. The output voltage, current and power, under shaded (unbalance) condition for INC and ANFIS algorithms are shown in Figure.12 and Figure.13 respectively. From the Figures, it can be noted that the INC algorithm gives oscillations around the MPP. From Table.3, it is inferred that the efficiency for ANFIS MPPT and INC MPPT algorithm varied from 96% to 98%. By comparing the INC and ANFIS MPPT algorithms, it can be seen that ANFIS MPPT algorithm tracks the MPP with negligible oscillations.

Table-3 Simulation result of partially shaded and non-shaded condition

MPPT	Insolation (G_1/G_2) W/m^{2}at T= 25°C	ISSBC Output power			
		PV_1	PV_2	Total Power	Efficiency (%)
INC	900/600	89.68	34.30	140.40	96.50
	900/900	105.20	105.20	207.40	97.50
ANFIS	900/600	95.64	46.87	144.00	97.50
	900/900	118.50	118.50	240.10	98.41

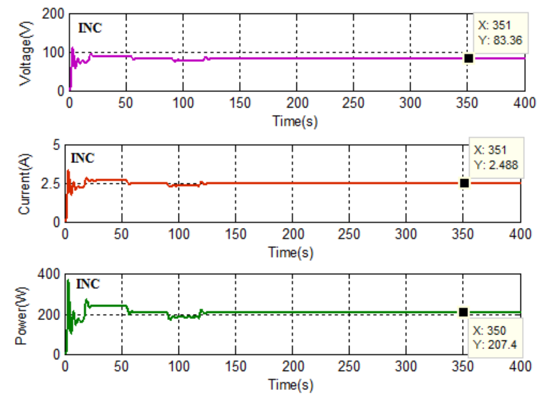


Figure-10 Simulation results for INC MPPT under balanced condition output voltage, current and power

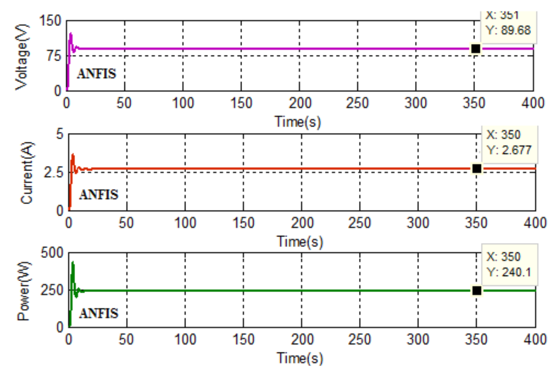


Figure-11 Simulation results for ANFIS MPPT under balanced condition output voltage, current and power

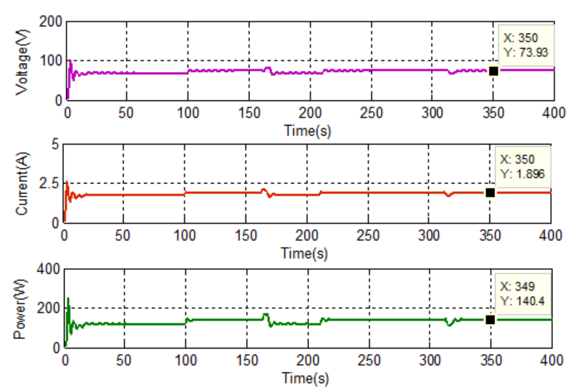


Figure-12 Simulation results for INC MPPT under unbalanced condition

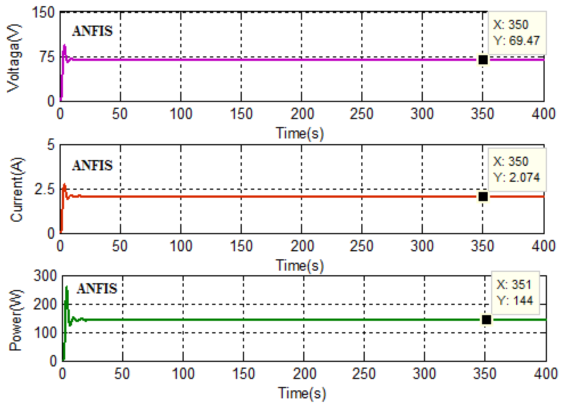


Figure-13 Simulation results for ANFIS MPPT under unbalanced condition

EXPERIMENTAL VALIDATION

Experimental verification of the proposed MPPT is achieved using the appropriate hardware configuration as shown in Figure.14. The experimental setup consists of cascaded ISSB converter with 30 kHz switching frequency to boost the output voltage and track the MPP. The PIC 16F877A microcontroller is used to realize the proposed MPPT. The power extracted by the INC and ANFIS MPPT algorithms can be observed as an exposition with different PV insolation and cell temperature under partially shading conditions. Actually, experiment measurement obtained from different MPPT algorithms are conducted on six different sunny days. These experiment results are validated by comparing it with simulation results.

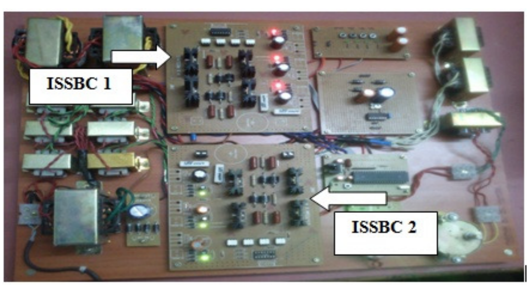


Figure-14 Experimental arrangements

In real time, the solar insolation frequently varies from time to time. In order to depict the performance of INC and ANFIS MPPT algorithm on cascaded ISSBC fed PV modules under suddenly changing irradiation condition, the experimental patterns tabulated in Table .4 are considered. In pattern D1, the insolation of two PV panels are kept same at 900W/m^2, whereas in pattern D2 the insolation of second PV module is dynamically changed from fully illuminated condition of 900W/m^2 to 30%-50% shaded condition of 400W/m^2 at t=200s (middle of x-axis). The cell temperature is maintained constant at T=37^{0}C. From Table. 5, it is observed that when pattern suddenly changes from D1 to D2, the output DC power also decreased with decrease in insolation. The experimental result is validated by comparing it with simulation results and it is shown in Table.6. For INC algorithm, when the pattern changes from D1 to D2, the experimental output power changes from 197.60 W to 114.26 W as shown in Figure .16 (a) and the simulated power changes from 232.6W to 130.5W as shown in Figure.5.19 (a). For ANFIS MPPT, the experimental power extracted changes from 228.5W to 125.90W as shown in Figure.16 (b) and the simulated power changes from 232.6W to 135.2W as shown in Figure.16 (b). This analysis shows that ANFIS algorithm outperforms the INC algorithm with negligible oscillations even under rapidly changing irradiation condition. The comparative bar chart of extracted DC power is shown in Figure.17. The experimental measurements are taken through four channels DSO (make UNI-T).

Table-4 Non-shaded and shaded pattern for experimental condition

Pattern	Insolation G_1 (W/m^2)	Insolation G_2 (W/m^2)	Cell Temperature (°C)
D1	900	900	37
D2	900	400	37

Table-5 Experimental results under dynamic variation in insolation

MPPT	Pattern	Converter power in Watts			Efficiency (%)
		PV1	PV2	Total	
INC	D1	100.2	100.2	197.60	97.40
	D2	80.07	36.09	114.20	96.90
ANFIS	D1	112.80	112.80	228.50	98.00
	D2	88.76	38.52	125.90	97.43

Table- 6 Comparison of simulated and experimental power under dynamic variation in insolation

MPPT	Pattern	Converter Power in watts	
		Simulated value	Experimental value
INC	D1	232.3	197.60
	D2	130.5	114.20
ANFIS	D1	232.6	228.50
	D2	135.2	125.90

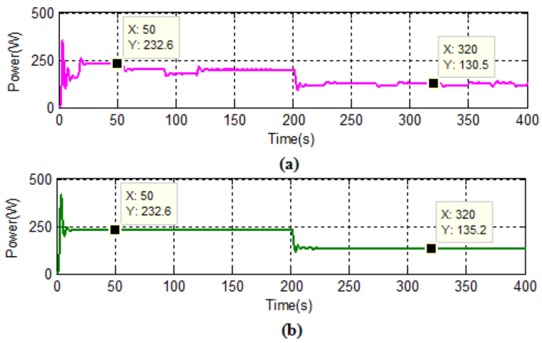
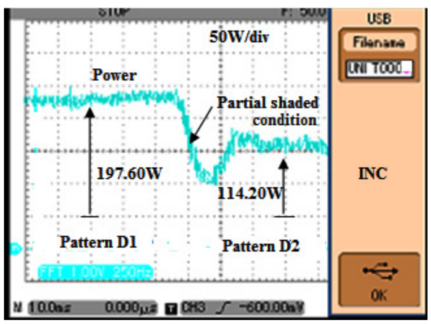


Figure-15 Simulated DC output power of experiment 2 a) INC b) ANFIS



(a)

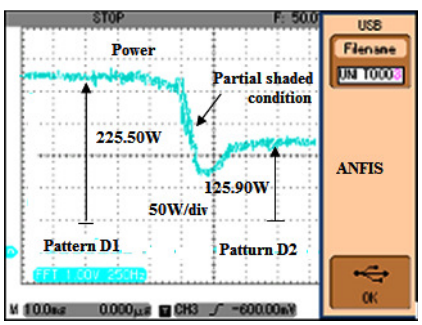


Figure-16 Experimental DC output power of experiment 2 a) INC b) ANFIS

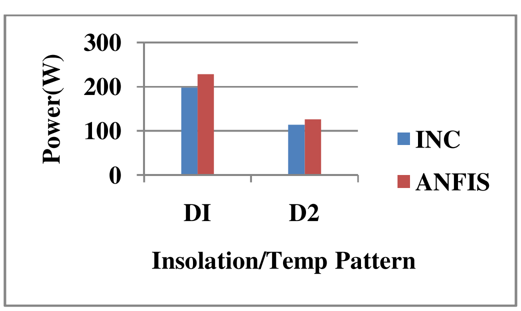


Figure-17 Comparison of DC output power for experiment

CONCLUSION

This work analyzes the performance of INC and ANFIS MPPT algorithms cascaded ISSBC fed PV system. The configuration for the proposed system is designed and simulated using MATLAB/Simulink and implemented in 16F877A microcontroller.

- The proposed system shows a good dynamic performance algorithm to track the MPP of the PV units even under the rapid change of the irradiation cell temperature and partial shaded condition.
- ANFIS can provide the overall efficiency higher than INC algorithms.
- The cascaded ISSBC integrate with MPPT technique reduce switching loss improved output voltage quality.

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