INVESTIGATION OF PERFORMANCE OF STANDALONE SOLAR PV SYSTEM WITH KY – SR BUCK BOOST CONVERTER USING FL BASED DIRECT M.PPT CONTROL METHOD

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Abstract: *Energy efficiency and reliability are the major concern in the operation of the Standalone Solar PV Power Systems (SSPVS). These concerns induced to develop the proposed system which includes PV module, positive output KY – SR buck boost converter, Fuzzy Logic Controller (FLC) and a resistive load. In this work, FL based Maximum Power Point Tracking (MPPT) for proposed converter in SSPVS with direct duty cycle control strategy for resistive loads has been employed. The proposed strategy is able to track the maximum power delivered to the load accurately and rapidly without oscillation and satisfied dynamic performance, irrespective of varying solar insolation levels. MATLAB and MULTISIM tools were employed for simulation studies. In addition, both high and low power PV panel of MS24250 and SPP030201200 has been chosen with maxi mum power rating of 252.5 and 20 watts to investigate the system performance. However, the prototype model has been developed and tested using SPP030201200 PV panel installed in our laboratory, wherein the Arduino UNO microcontroller was employed to provide the control signals to the converter. Experimental results shows that the proposed system yields desired output voltages with better efficiency by means of simplified control algorithm.*

Keywords: *Standalone Solar PV systems (SSPVS), Positive KY-SR Buck-Boost converter, Fuzzy Logic based Maximum Power Point Tracking (FLMPPT), Arduino UNO microcontroller, Resistive Load*

1. INTRODUCTION

While concerning world/India, population and their demand is increasing day by day, hence electrical energy becomes the basic need of human activity in all sectors of the world/ country. Especially, the people living in the remote and rural sector of India are still deprived of electrical supply. Nowadays, energy can be generated in eco-friendly manner and cost effective sources has turn out to be one of the major challenges for engineers, researchers and scientists [1]. Among all renewable energy sources, solar power systems draw more consideration because they provide excellent opportunity to generate electricity without CO2 emissions and reduced dynamic losses [1]–[3]. Regarding the endless aspect of solar energy, it is worth saying that solar energy is a unique potential solution for energy crisis. Nevertheless, despite all the above mentioned advantages of solar power systems, they do not present desirable efficiency [4-5] and [14].

However, some of the important factors limit the implementation of photovoltaic systems such as intermittent nature and its nonlinearity, high installation cost and low efficiency of energy conversion. In order to reduce photovoltaic power system costs and to enhance the utilization efficiency of solar energy, the Maximum Power Point Tracking (MPPT) system of photovoltaic modules is one of the effective methods [5-7] used to extract the maximum power from the PV module and deliver it to the load; thereby the efficiency of the entire system is increased.

Many researchers have been suggested different techniques to maximize the output power of the photovoltaic modules [11]. Some of them are simple, such as those based on voltage like open circuit voltage and constant voltage method. In open circuit voltage method, the voltage is measured by frequently interrupting the system, due to this the power losses are high [13 - 15]. In Constant Voltage (CV) method, the measured voltage of the PV module with a reference voltage is being compared to modify the duty cycle of the DC-DC converter and hence operate the PV module at the preset point close to the MPP [6]. Although the CV method is very simple, it cannot track the maximum power point under the temperature changing.

Some are more complicated, such as hill climbing and Incremental Conductance (IC) method. They depend on complexity, sensor requirement, convergence speed, cost, range of operation, popularity, and ability to detect multiple local maxima etc [14], [16], [17]. Having an interested look at the recommended methods, hill climbing and I&C [14]–[16] are the algorithms that were in the centre of consideration because of their simplicity and ease of implementation. The main advantage of incremental algorithm has fast response against P&O method. However, it has the disadvantage of usage of derivative algorithm under low input level consequences stability problem [18], [23], [25-26]. Based on recent reviews, an ANN-based MPPT method requires large amounts of field data to train the network [19]. The main drawback of ANN-based MPPT methods is that it is more system dependent and requires more time to implement the system with different characteristics. Thus, such algorithms are not robust against the rapidly varying temperature and irradiation, as well as partial shading.

Literature says that, some good works based on fuzzy logic has already existed; but in most of the works, a conventional gain block has been added with the fuzzy system for tuning the output [16] which leads to complexity in design. In this paper, the Fuzzy logic control method with direct duty cycle control has been employed, so that the control loop gets simplified, and the computational time also gets reduced. The viability of the proposed system is investigated with a proposed positive output KY – SR dc–dc buck boost converter interfaced with FL based MPPT in order to extract maximum power and also provide voltage regulation so as to step up or step down the input voltage of SPV module with a view to evaluate the improvement in solar conversion efficiency and to get desired power for DC load as shown in Fig.1.

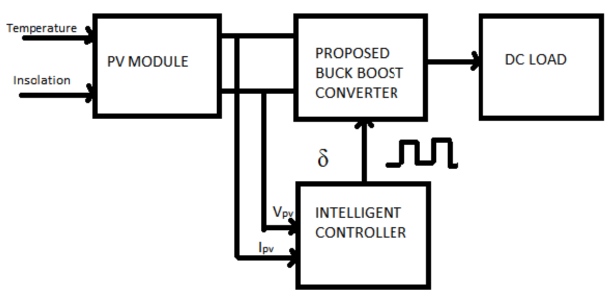


Fig.1 Schematic Block Diagram of Overview of Proposed system

The main objective of this proposed work is to model a most widely used fuzzy logic based direct control algorithm to obtain the desired output of the proposed positive KY –SR buck-boost converter by considering 12 Ω resistors as a DC load from an emerging standalone solar PV system. Also, the investigation has been done by analyzing the performance of the proposed technique with the conventional P & O technique.

This paper is organized as follows: Section 2 illustrates m3odeling of PV panel module and its characteristics, Section 3 introduces the simulation of highly efficient positive output KY – SR Buck Boost dc-dc converter using MULTISIM, Section 4 demonstrates the performance of Fuzzy Logic Controller with its membership function and its rules, Section 5 describes the simulation waveforms with result comparison, section 6 dealt with implementation of hardware and its results and discussions and section 7 presents conclusion.

2. MODELING OF PV PANEL

In general, a photovoltaic module is formed by connecting many solar cells in series and parallel based on the level of voltage and current demand required for our applications [1 – 5]. The first and foremost step needs accurate modelling of the PV module in the simulation process. In the proposed work, single diode solar cell equivalent circuit was used for modelling by utilizing a current source, a single diode, and series and shunt resistors.

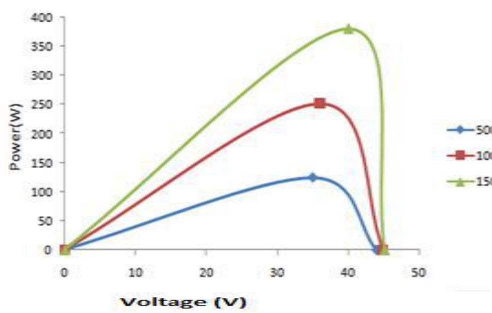
In the proposed system, high power Micro Sun Solar Tech MS24250 PV module and low power SPP 030201200 PV module has been chosen with maximum power of 252.5 and 20 watts to investigate the performance. The empirical mathematical equations governing the system were utilized to model the PV module as well as to obtain the P-V and I-V characteristic curves under different solar irradiation and different temperature using Matlab Simulink [1], [4 – 5], [27].

The essential parameters of an ideal PV module can be obtained from manufacturer's data sheet as shown in Table 1 under Standard Test Condition (STC).

Table 1 Electrical parameters of MS24250 and SPP 030201200 PV module

Parameters	MS24250	SPP 030201200
Voltage at $P_{max}(V_m)$	36.839V	18 V
Current at $P_{max}(I_m)$	6.855A	1.11 A
Temperature coefficient of short circuit current(K_i)	3.81e-3	0.045
Maximum Power(P_m)	252.537W	20 W
Short circuit current(I_{sc})	7.217A	1.23 A
Open circuit voltage(V_{oc})	44.917V	22.5 V
No. Of cells in series(N_s)	48	36

The performance (I-V and P-V) characteristics of the specified modules at different insolation and temperature levels are illustrated in Fig.3 - 6. It gives an idea about the essential parameters like Voc, Isc and Pm at the maximum power point (MPP) under various environmental conditions for a constant resistive load R of 12 Ω.



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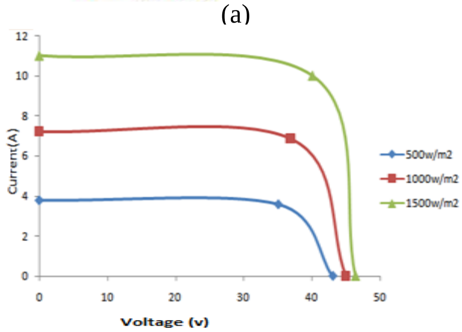

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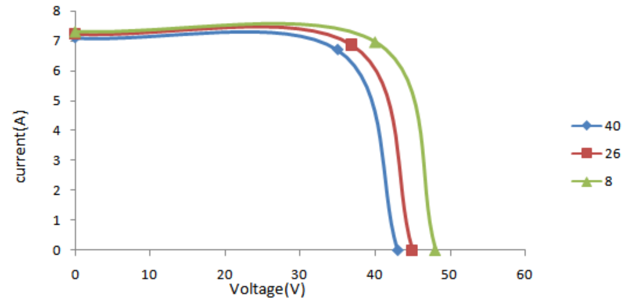
Fig.2 (a) P - V and (b) I – V curves of MS24250 solar module under variation of solar isolation



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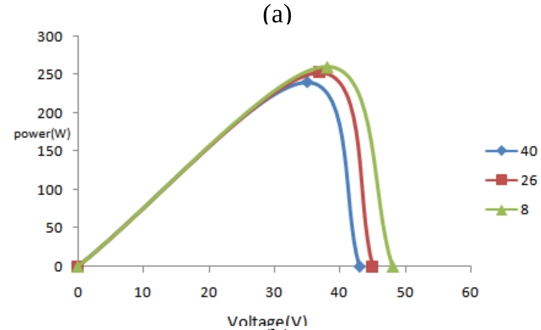

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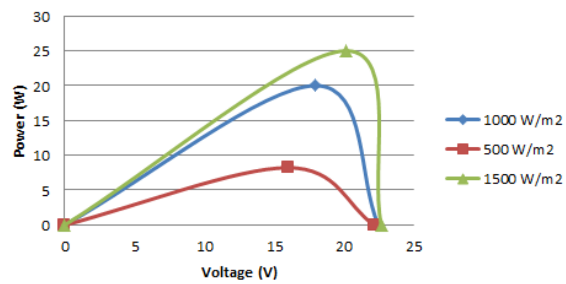
Fig.3 (a) I –V and (b) P – V curves of MS24250 solar module under variation of temperature



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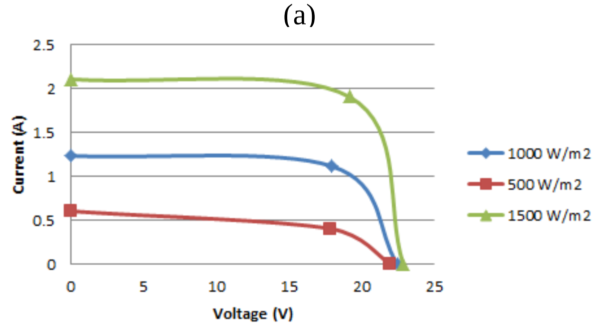


(b)

Fig.4 (a) P - V and (b) I – V curves of **SPP 030201200** solar modules under variation of solar insolation

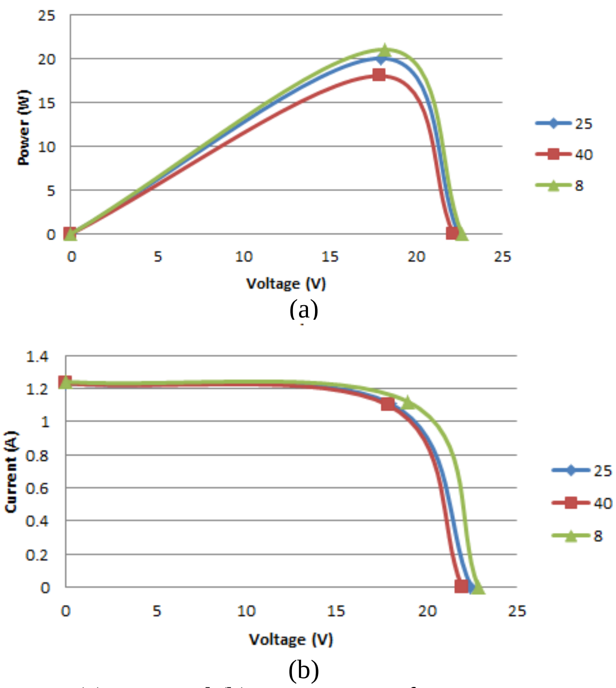


Fig.5 (a) P –V and (b) I – V curves of SPP 030201200 solar module under variation of temperature.

From figures (2-5), it can be observed that the change in irradiation levels mainly affect the PV output current drastically and the change in temperature levels mainly affect PV output voltage not in a drastic manner. Also, it is found that the operating voltage and a current that are V_{mpp} and I_{mpp}, respectively which is highly dependent on solar irradiation rather than ambient temperature [2-4]. Hence, further analysis has been carried out under varying insolation level only.

3. MODELING OF PROPOSED CONVERTER WITHOUT MPPT

Generally, in renewable energy systems, either buck or boost converters are used for modulating the output voltage, in order to improve the energy efficiency [10 -12]. Besides, the energy produced can be stored only in certain levels for future applications, thus the stability plays a vital role while designing the converter which needs to be considered as ref in [6 -9]. Many current works has shown that various types of converters used for different applications [11- 24] to a certain extent. Though, in this work, a positive output KY – SR buck boost converter topology has been selected with an intention to use the system for low and high voltage applications. The proposed buck boost converter is a 2δ converter with a positive output voltage, which combines KY boost converter and Synchronously Rectified (SR) buck converter as shown in fig.6. It consists of only less number of switches Q_1 and Q_2, The operation of the converter can be explained in two modes is given below.

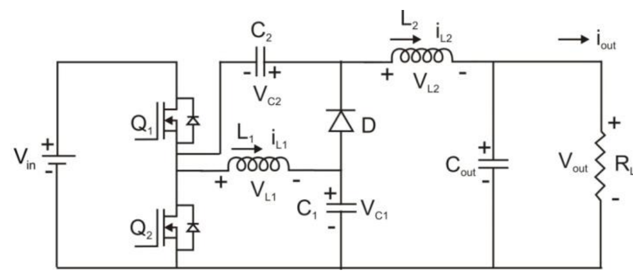


Fig.6. Proposed positive output KY-SR BB converter

3.1. Mode 1 (0 < t < δT)

In this mode, Switch $Q_1$is on and switch Q_2 and the diode D is off, then the output voltage is regulated by controlling the duty cycle of Q_1 switch. The current flowing through Q_1 energizes the inductors L_1 and L_2 and charges the capacitor C_1. Simultaneously, the energy discharging of capacitor C_2 along with input causes the current to flow through the inductor L_2 and the load. The corresponding voltage equations are given by the following equations (1) and (2).

$$V_{in} = L_1 \frac{di_{L_1}}{dt} + V_{C_1} \quad \text{---------------} \quad (1)$$

$$V_{out} = V_{in} + V_{C_2} - L_2 \frac{di_{L_2}}{dt} \quad \text{---------------} \quad (2)$$

3.2. Mode 2 (δT< t < T)

During this mode, Switch Q_1 is OFF and Q_2 is on, the output voltage (V_{out}) is regulated by controlling Q_2 in the Continuous Conduction (CC) mode. The demagnetization of both inductors L_1 and L_2 will occur. The discharging of capacitor C_1 causes the charging of capacitor C_2 because both are connected in parallel. In addition, load receives the output energy through inductor L_2. The relationship between the accumulation of energy in inductors, the charging and discharging of capacitors and the output voltage are given by the equations (3) – (5).

$$L_1 \frac{di_{L_1}}{dt} = -V_{C_1} \quad \text{---------------} \quad (3)$$

$$V_{out} = V_{C_2} - L_2 \frac{di_{L_2}}{dt} \quad \text{---------------} \quad (4)$$

$$V_{C_2} = V_{C_1} \qquad \text{---------------} \qquad (5)$$

3.3. Design Equations

The values of inductors and capacitors are so designed to obtain the output in CC mode according to the basic laws applied in the equivalent circuit of converter.

$$L_1 \geq \frac{\delta_{min}}{\Delta I_{L_1}} \frac{V_{in} - V_{C_1}}{f_s} \qquad \text{---------------} \qquad (6)$$

$$L_2 \geq \frac{\delta_{min}}{\Delta I_{L_2}} \frac{V_{in} + V_{C_1} - V_{out}}{f_s} \qquad \text{--------} \qquad (7)$$

$$C_1 \geq \frac{\delta_{max} \cdot I_{out(rated)}}{f_s \Delta V_{C_1}} \qquad \text{---------------} \qquad (8)$$

$$C_2 \geq \frac{\delta_{max} \cdot I_{out(rated)}}{f_s \Delta V_{C_2}} \qquad \text{---------------} \qquad (9)$$

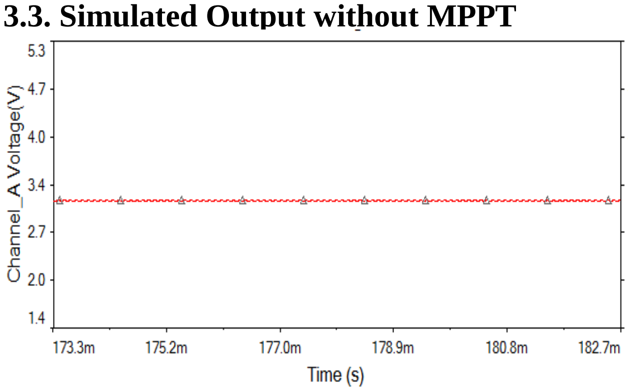
where, V_{out} – average output voltage
f_s – Switching frequency
ΔI_{L1} and ΔI_{L2} – inductor ripple current
ΔV_{C1} and ΔV_{C2} – capacitor ripple voltage
δ – Duty cycle

Based on the detailed analysis, the voltage and current gain of the proposed converter is given by the following equation (1) and (2).

$$\frac{V_{out}}{V_{in}} = 2\delta \qquad \text{---------------} \qquad (10)$$

$$\frac{I_{in}}{I_{out}} = 2\delta \qquad \text{---------------} \qquad (11)$$

3.3. Simulated Output without MPPT



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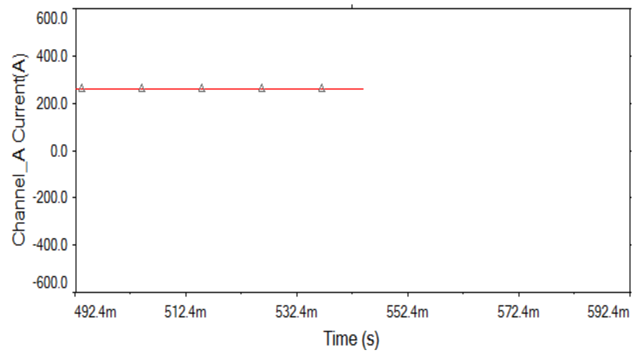


(b)

Fig. 7 In Buck mode (a) Output Voltage Waveform (b) Output Current Waveform (V_{in}=6.7V, δ=0.3, I_{out}=0.312A, V_{out}=3.159V)

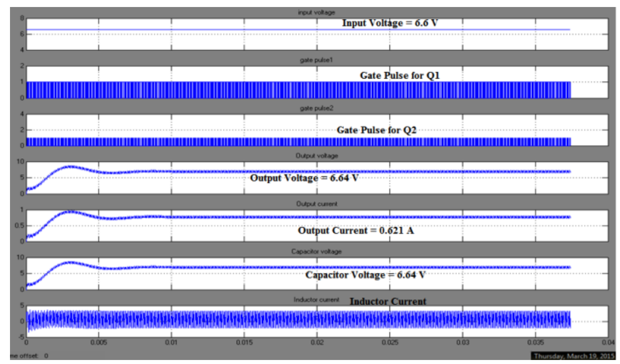


Fig. 8 Output Waveforms of Proposed Converter in Boost mode (V_{in}=6.7V, δ=0.51, V_{out} = 6.84V, I_{out} = 0.621A)

Figures 7 and 8 illustrate the output waveforms of From the output waveforms, it was obvious that for the same input voltage V_{in} = 6.7 V, the output voltage is stepped down to 3.159 V for duty cycle δ = 0.3 and the output voltage is stepped up to 6.84 V for duty cycle δ = 0.51 at a switching frequency of 10 KHz with a load of 12Ω.

4. MODELING OF PROPOSED FUZZY LOGIC BASED MPPT

In general, the PV generation system needs to operate at its maximum power point (MPP) in order to increase system efficiency [14]. In this work, intelligent control technique called FLC is associated with an MPPT algorithm has been employed to extract maximum power from PV System thereby the energy conversion efficiency gets improved.

Here, the PV panel is operating around an open-circuit voltage before connecting to the load through the MPPT circuit. When the PV is connected to the MPPT circuit, it does not work at operating point, and the voltage moves to a new point instantly. This new operating voltage depends on the impedance of the load. In order to move the new operating point to the MPP, the control rules of Fuzzy Logic controller within the direct duty cycle control loop has been executed to carry out the function.

The proposed FLC comprises two inputs from PV panel and one output as a control signal. The two input variables are of error E (k) and change in error CE (k) that can be stated by equations (3) and (4).

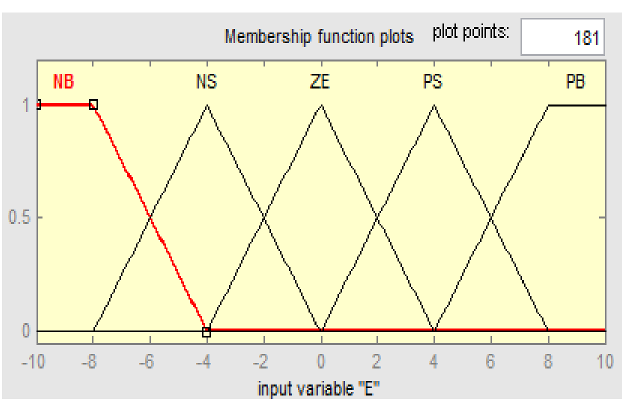
$$E(K) = P_{PV}(K) - P_{PV}(K-1) \qquad \text{---------} \ (12)$$

$$CE(K) = E(K) - [E(K-1)] \qquad \text{---------} \ (13)$$

Where, P_{pv} (k), V_{pv} (k) are the PV power and voltage respectively at instant k. E(k) represents error defines the load operating point at the instant k on the P-V characteristic and it equals to zero at MPP. Similarly, the change in error CE (k) indicates the moving direction at the instant k. In general, FLC includes three steps

In the fuzzification process, the system actual inputs E (k) and CE (k) by using standard triangular and trapezoidal membership function in terms of linguistic fuzzy sets as shown in Fig.9. The concept behind the fuzzy rule framed is, when error and change in error are in same direction there will be no change in duty cycle. When error and change in error are in different direction, the duty cycle obtained is opposite to that of error variable.

Accordingly, 25 fuzzy control rules are listed in table 3, using Mamdani's fuzzy inference method associated with Max-Min operation.



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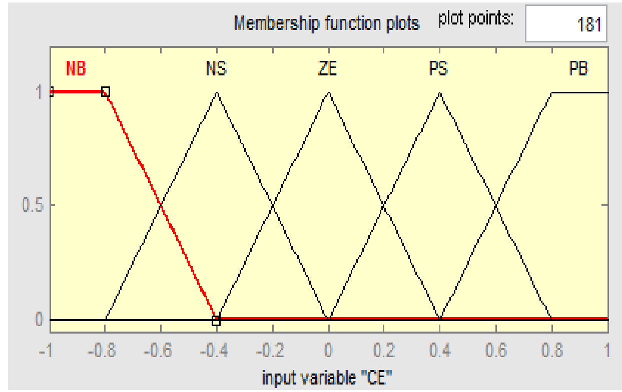

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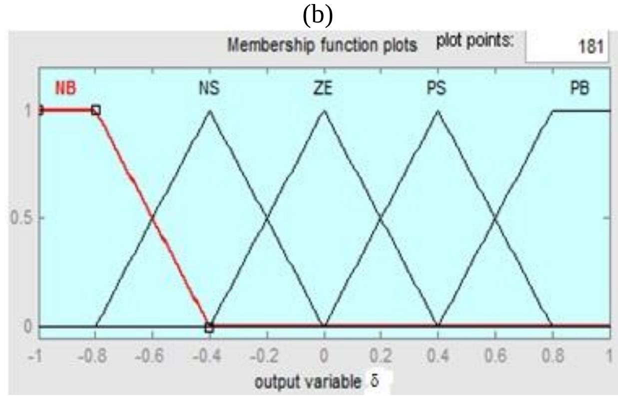


(c)

Fig.9. Membership functions of (a) error E (k), (b) change in error CE (k) and (c) control signal δ

The Center of Area (COA) algorithm is used for defuzzification for obtaining the controlled output parameter such as duty cycle.

Table 2 Fuzzy rules

CE(k) \ E(k)	NB	NS	ZE	PS	PB
NB	ZE	ZE	PB	PB	PB
NS	ZE	ZE	PS	PS	PS
ZE	PS	ZE	ZE	ZE	NS
PS	NS	NS	NS	ZE	ZE
PB	NB	NB	NB	ZE	ZE

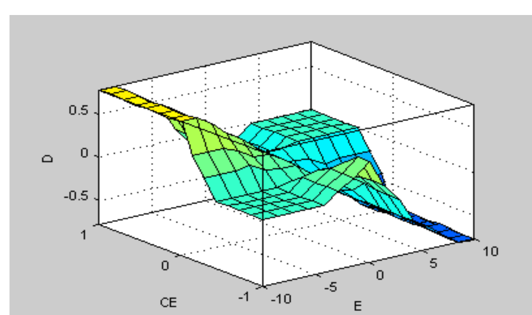


Fig.10. Surface view of Fuzzy Logic MPPT controller

Figure 10 illustrates the surface view of the fuzzy input and output functions which depicts the proper operation of fuzzy controller. From this figure the variation of duty cycle with respect to the error (E) and change in error (CE) is observed clearly.

5. SIMULATION ANALYSIS OF PROPOSED SYSTEM

The performance analysis of overall system for two power levels of solar PV module with proposed positive output KY – SR buck boost converter using both conventional P & O and FL based duty cycle controller with resistive load of 12Ω are done in MATLAB Simulink software package.

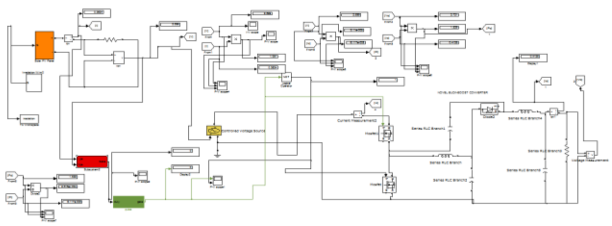
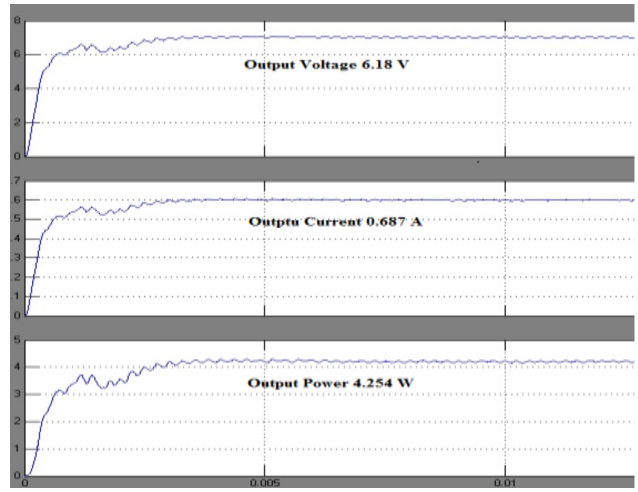


Fig. 11. Simulink Diagram of overall System with FLC subsystem and Load

In Figure 11, the PV module is modelled using manufacturer data to get the output current and voltage of the PV module which are then fed to the proposed converter and controller simultaneously. To examine the performance of the system, the condition of changing insolation levels was modeled with the temperature being maintained constant at 25^0C. For the purpose of analysis, a random value of solar irradiance of 400 W/m2 and also for different insolation levels from 700 to 100 W/m2 at fixed temperature of 25°C has been considered for both techniques. Hence, the simulated analysis of output waveforms with the proposed converter and MPPT technique for both the low power and the high power solar modules were presented in the following sections.

5.1. Analysis using P&O technique:

In this, P&O MPPT algorithm was primarily developed due to its ease of implementation [15 – 17] and the respective results were shown in fig (12-13).



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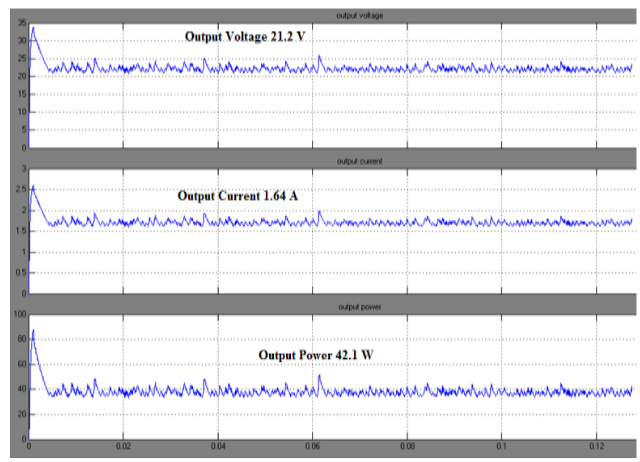
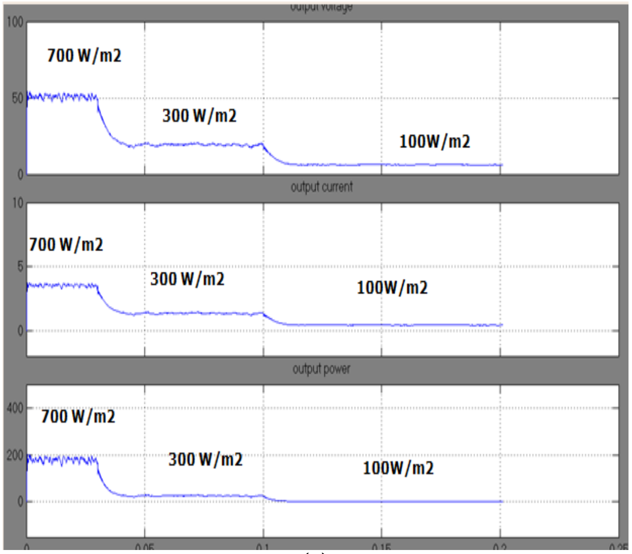


(b)

Fig.12. Output waveforms of PV Module with the proposed Converter under 400W/m^2 with P&O MPPT algorithm for (a) SPP 030201200 (b) MS24250 PV panel



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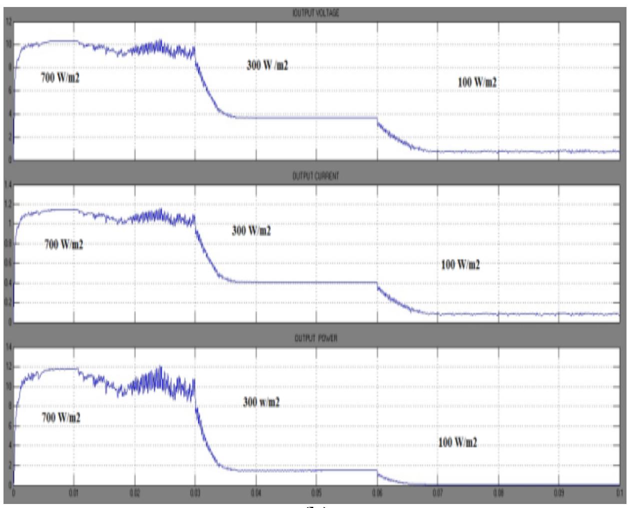


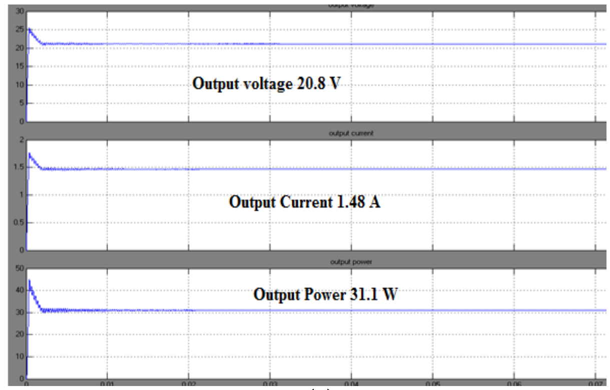
(b)

Fig.13. Output waveform of a PV Module with the proposed Converter under various insolation levels with P&O MPPT Algorithm for (a) SPP 030201200 panel (b) MS24250 panel

From the figures, it is found that, there are some steady state oscillations around MPP even though there is no overshoot. As a consequence, the system accuracy is low giving rise to wastage of some amount of available energy.

5.2. Analysis using proposed technique:

The same system has been simulated with Fuzzy Logic (FL) based direct duty cycle controller, in order to eliminate the disadvantage of P & O algorithm for the same condition using MATLAB and few selected results were presented for making comparison between fuzzy logic and conventional P&O MPPT controllers. The output power, voltage and current from two different PV modules are shown in Fig. 14, & 15 for random insolation values.



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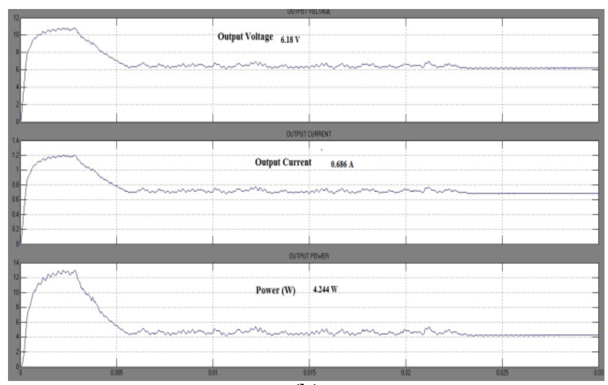

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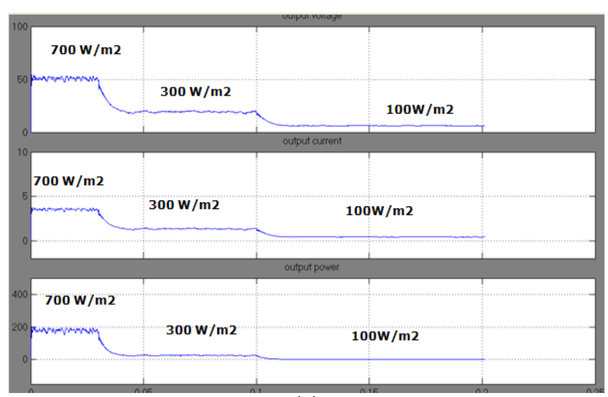
Fig.14. Output waveforms of PV Module with the proposed Converter under 400W/m2 with FL based DDC MPPT algorithm for (a) MS24250 (b) SPP 030201200 PV panel



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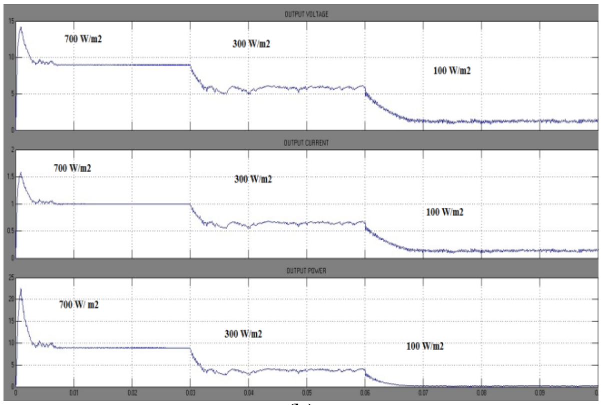


(b)

Fig.15. Output waveform of a PV Module with the proposed Converter under various insolation levels with FL based DDC MPPT algorithm for (a) MS24250 (b) SPP 030201200 PV panel

On comparing the results obtained from both techniques, the proposed FL based controller is found superior in terms of better performance over the conventional P & O one as shown in table 3.

Table 3: Comparison of SSPVS converter output with P&O and FUZZY MPPT

Sl. no	PV module	Insolation (W/m^2)	P & O			FUZZY		
			V_{out} (V)	I_{out} (A)	P_{out} (W)	V_{out} (V)	I_{out} (A)	P_{out} (W)
1.	MS 24250	700	48.56	3.372	163.8	49	3.403	166
2.		300	20.06	1.488	31.67	21.6	1.5	32.4
3.		100	7.1	0.493	3.5	7.136	0.497	3.55
4.	SPP 030201200	700	9.41	1.010	9.5041	9.694	1.01	9.589
5.		300	3.843	0.4595	1.766	6.012	0.612	3.897
6.		100	0.834	0.194	0.1618	1.657	0.197	0.326

6. EXPERIMENTAL ANALYSIS

Figure.16 clearly depicts the block diagram representation for implementation of the proposed system. In the hardware configuration 12V, 20W **SPP 030201200** solar PV panel module has been employed. This panel was installed on the rooftop of our department power electronics laboratory for the purpose of research analysis. To verify the functionality of the proposed system as shown in Fig. 17 (a - d), a prototype model of the positive output KY- SR buck boost converter with FL based control circuit including Arduino UNO microcontroller has been developed.

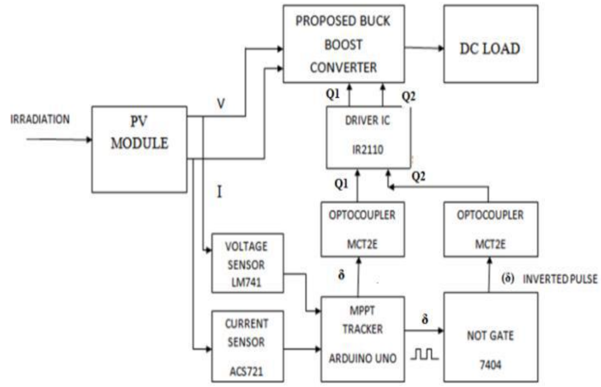


Fig.16. Block diagram representation for implementation of overall system

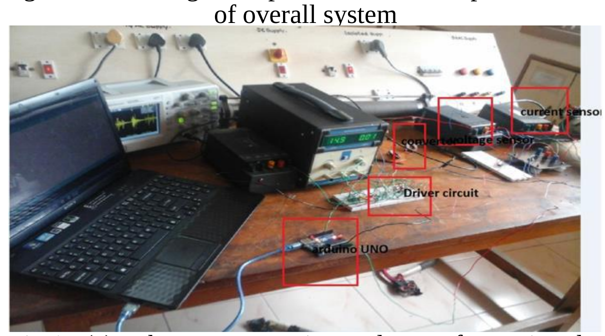


Fig 17 (a) Laboratory experimental setup for testing the FL MPPT controller using Arduino UNO with proposed KY – SR Buck Boost converter

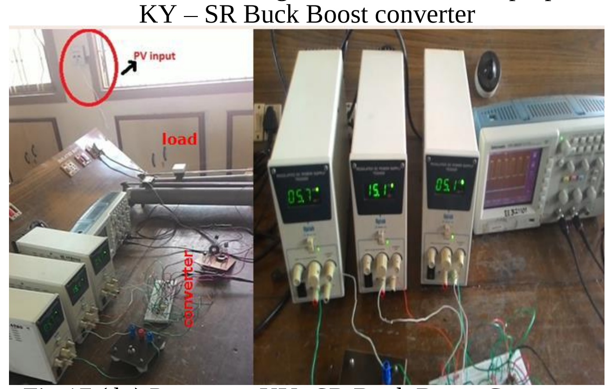


Fig.17 (b) Prototype KY- SR Buck Boost Converter circuit with PV Input implemented onBread board (another view of overall system)

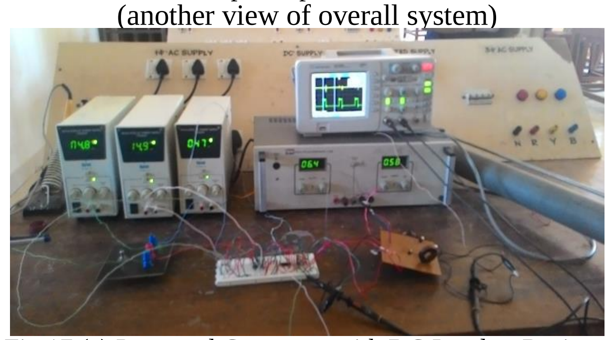


Fig.17 (c) Proposed Converter with DC Load as Resistor (another view of overall system)

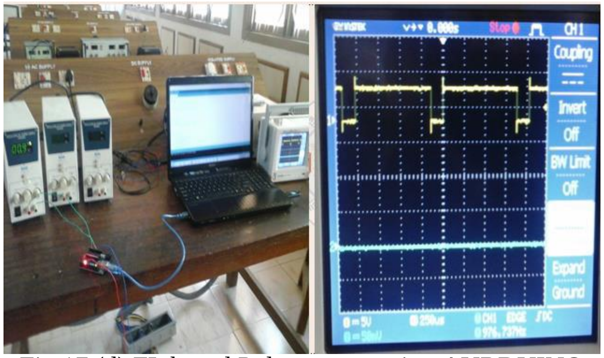


Fig.17 (d) FL based Pulse output using AURDUINO UNO

In this work, the voltage and current measurement is important to determine the environmental condition, which is necessary to make an accuracy of MPP tracking. In addition, this operating voltage and current of the PV module are fed as an input to the converter and controller simultaneously. Hence this PV array voltage and current were measured by using LM741voltage sensor and ACS721 Hall-effect current sensor.

In addition, Arduino UNO with Atmega328 microcontroller was used to provide the control signals for the proposed converter. The programming of the fuzzy logic controller based MPPT algorithm is coded with embedded C and PWM scheme is built, debugged, and run with the help of the microcontroller board.

The power circuit of the proposed system consists of a positive output KY-SR converter, gate driver circuit and the duty cycle control circuit. The switching frequency of the system was chosen to be 10 KHz, which is the required time for the proposed converter to reach the steady-state condition. The control signals are the analog voltage and current of the PV module which has to be converted into digital using an ADC in a microcontroller, and then compared with the preset values to decide the next step; accordingly it generates the PWM signal to the gate driver circuit and thereby controls the switching of MOSFET's. Figure 18 shows the experimental setup for pulse generation circuit and its output waveforms respectively.

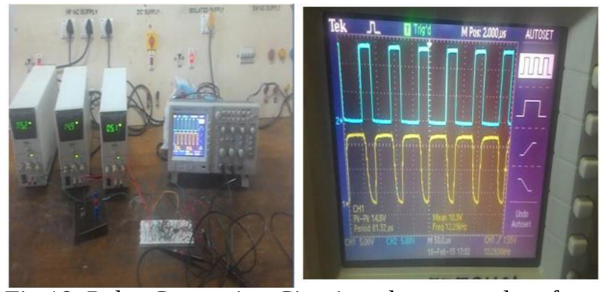
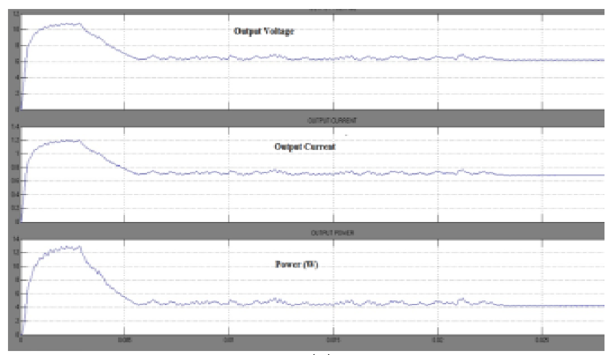
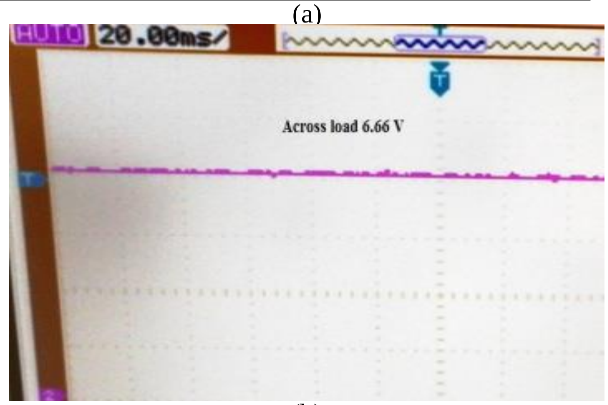


Fig.18. Pulse Generation Circuit and output pulses from IC IR2110 for two Switches

This whole hardware setup is tested in our laboratory and the result obtained is shown in Fig. 19 (b). The output voltage is shown for 250 C temperatures and 400 W/m2 irradiation condition. With 6.66 V across load and 0.611A current delivered to the 12 Ω load resistor, Fuzzy MPPT extracts 4.069W from the PV module. This is obviously nearby value of maximum power 4.45W to the corresponding test condition. The simulation result for this condition is also shown in Fig. 19 (a).



(a)



(b)

Fig. 19. (a) Simulation (b) Experimental output of proposed system with FL based MPPT controller when f=10 kHz, R=12Ω with 400 W/m2 input from 12V, 20 W SPP 030201200 panel.

In this, the experimental results validates the proposed system operates more efficient and it justifies the effectiveness of using controller concept in PV system operation so that the maximum PV output power can be obtained. Nevertheless, all results obtained reveals that the system operates with the best performance.

7. CONCLUSIONS

In this work, the performance of proposed Positive KY-SR buck boost converter was analysed with FL based direct duty cycle control technique powered from standalone solar PV energy system. The proposed system has been simulated using MATLAB and some of the results were presented for investigation. From the results acquired, the proposed FL based system shows the enhanced performance in terms of output voltage, output power and efficiency. In addition, the suggested control concept was provenusing the prototype set up and the results acquired under various solar insolation levels were found to be very close to the simulated output in terms of output voltage, output power and efficiency. It also demonstrates that the proposed control system is capable of tracking the maximum power and thus improves the efficiency of the PV system even though instantaneous variations has been occurred on the input side. Moreover, the proposed converter operates with reduced power loss using less number of switches and cost effective because of implementing the control strategy with fast detection and response time using low cost Arduino microcontroller. Thus, the main objectives of this flexible and well efficient system has been achieved by reducing the complexity of implementing the fuzzy technique in a simple way to control the duty cycle directly in a précised manner with more stability.

Further work will be pursued in incorporating more intelligent schemes in the controller which can also be used as a fundamental stage for a grid connected PV plant and also for industrial applications. It can also be extended by embedding various converters to enhance the performance of renewable energy sources. The proposed system can be used to power LED lighting system in airport, advertisement board, and batteries, static and dynamic DC loads.

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