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A Modular Fuzzy Logic Controller Based Cuk Converter Design with Reduced Switching Losses for Photovoltaic Energy System

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ABSTRACT

To overcome the conduction and switching losses generated by earlier converter designs, we propose a new modular fuzzy logic controller based Cuk converter design which increases the performance of photovoltaic system. The objective is to produce high-efficiency, voltage and current of a PV system with help of Fuzzy Logic Controller. The requirement of continuous and controlled flow of voltage has met with the support of fuzzy logic controller and the capacitors present with the schematic design helps this requirement to be met in an efficient way. The MOSFET controls the voltage in bi-direction and the capacitors help to supply the voltage in a steady flow. The capacitors get charged both in serial and parallel execution of the circuit and the MOSFET controls the flow of voltage. The conduction losses are reduced by using fuzzy logic controller in closed loop condition which reduces the switching losses and increases the output energy. The proposed modular Cuk fuzzy logic controller based converter is implemented in MATLAB simulation platform and the output performance is analyzed.

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INTRODUCTION

The growing nature of electric scarcity, induced researchers to innovate many advanced systems to reuse the electric power generated from various resources like bio-energy, wind energy, solar energy. The photovoltaic system is an electricity producer based on solar energy and which is capable of store and reuses the electric power at later stage. A photovoltaic array (also called a solar array) consists of multiple photovoltaic modules, casually referred to as solar panels, to convert solar radiation (sunlight) into usable direct current (DC) electricity. A photovoltaic system for residential, commercial, or industrial energy supply normally contains an array of photovoltaic (PV) modules, one or more DC to alternating current (AC) power converters (also known as an inverter), a tracking system that supports the solar modules, electrical wiring and interconnections, and mounting for other components. A small PV system is capable of providing enough AC electricity to power a single home, or even an isolated device in the form of AC or DC electric

The Canonical Cell forms the basis of analyzing switching circuits, but the energy transport mechanism forms the foundation of the building blocks of such converters. The Buck converter may consequently be seen as a Voltage to Current converter, the Boost as a Current to Voltage converter, the Buck-Boost as a Voltage-Current-Voltage and the CUK as a Current-Voltage-Current converter. All other switching converter MUST fall into one of these configurations if it does not increase the switching stages further for example into a V-I-V-I converter which is difficult to realize through a single controlled switch. It does not require an explanation that a current source must be made to deliver its energy into a voltage sink and viceversa. A voltage source cannot discharge into a voltage sink and neither can a current source discharge into a current sink. The first would cause current stresses while the latter results in voltage surges. This rule is analogous to the energy exchange between a source of Potential Energy (Voltage of a Capacitor) and a sink of Kinetic Energy (Current in an Inductor) and viceversa. Both can however discharge into a dissipative load, without causing any voltage or current amplification. The resonant converters also have to agree to some of these basic rules.

Unlike bipolar transistors that are basically current-driven devices, MOSFETs are voltage-controlled power devices. If no positive voltage is applied between gate and source the MOSFET is always non-conducting. If we apply a positive voltage UGS to the gate an electrostatic field will set up between it and the rest of the transistor. The positive gate voltage will push away the 'holes' inside the p-type substrate and attracts the moveable

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electrons in the n-type regions under the source and drain electrodes. This produces a layer just under the gate's insulator through which electrons can get into and move along from source to drain. The positive gate voltage therefore 'creates' a channel in the top layer of material between oxide and p-Si. Increasing the value of the positive gate voltage pushes the p-type holes further away and enlarges the thickness of the created channel. As a result we find that the size of the channel we've made increases with the size of the gate voltage and enhances or increases the amount of current which can go from source to drain- this is why this kind of transistor is called an enhancement mode device.

Unlike classical control strategy, which is a point-to-point control, fuzzy logic control is a range-to-point or range-to-range control. The output of a fuzzy controller derived from fuzzifications of both inputs and outputs using the associated membership functions. A crisp input converted to the different members of the associated membership functions based on its value. From this point of view, the output of a fuzzy logic controller based on its memberships of the different membership functions, which considered as a range of inputs.

A Photovoltaic system (informally, PV system) is an arrangement of components designed to supply usable electric power for a variety of purposes, using the Sunor other light sources as the power source. PV systems may be built in various configurations like Off-grid without battery (Array-direct), Off-grid with battery storage for DC-only appliances, Off-grid with battery storage for AC & DC appliances, Grid-tie without battery or Grid-tie with battery storage.

Related works:

Numerous related research works are already existed in literature which based on DC-DC converter PV system. Some of them are reviewed here.

A Cuk converter design to interface a pulsed load to a fuel cell (Using, A., 2002) is designed, which provides constant current drain on the fuel cell with little current ripple while supplying the pulsed load. Because of the high operating frequency of the pulsed load, the DC-DC converter output capacitor supplies the pulsed current requirement of the load. As a result, the Cuk converter is operated in the capacitor charging mode. A simple control circuit is used to maintain load voltage.

Modularized buck-boost with Cuk converter for high voltage series connected battery cells (Xi Lu, 2012)], has been presented. It nicely combines the buck-boost converter and the Cuk converter together and only requires n switches. It achieves almost half of the switch count reduction, without losing the advantage of modularization or sacrificing the device voltage stress, unlike many other existing one-switch-per-cell topologies. Meanwhile, it still maintains the buck-boost battery charge equalizer's best characteristic - simple pulse width modulation (PWM) - 50% duty cycle. Moreover, it offers a solution to bypass the open-circuit faulty cells, and prolong the life time of the whole battery string.

In Multi-Input Inverter for Grid-Connected Hybrid PV/Wind Power System (Wies *et al*., 2005), a PV panel was incorporated with a diesel electric power system to analyze the reduction in the fuel consumed. It was seen that the incorporation of an additional renewable source can further reduce the fuel consumption. When a source is unavailable or insufficient in meeting the load demands, the other energy source can compensate for the difference.

Several hybrid wind/PV power systems with Maximum Power Point Tracking (MPPT) control have been proposed earlier (Chen *et al*., 2007). They used a separate DC/DC buck and buck boost converter connected in fusion in the rectifier stage to perform the MPPT control for each of the renewable energy power sources. These systems have a problem that, due to the environmental factors influencing the wind turbine generator, high frequency current harmonics are injected into it. Buck and buck-boost converters do not have the capability to eliminate these harmonics. So the system requires passive input filters to remove it, making the system more bulky and expensive (Chen *et al*., 2007).

Voltage Controlled PFC Cuk Converter Based PMBLDCM Drive for Air-Conditioners (Singh, S., 2010), is proposed to regulate the voltage for the Air-Conditioners. A three-phase voltage source inverter is used as an electronic commutator to operate the PMBLDCM driving an air conditioner compressor. The speed of the compressor is controlled to achieve optimum air-conditioning using a concept of the voltage control at DC link proportional to the desired speed of the PMBLDCM. The proposed PMBLDCM drive with the voltage control is designed, modeled and its performance is evaluated in MATLAB Simulink environment. The obtained results are presented to demonstrate an improved power quality (PQ) at AC mains of the PMBLDCM drive system in wide range of the speed and the input AC voltage.

Maximum power point tracking in PV system using intelligence based P&O technique and hybrid Cuk converter (Sankarganesh, R., 2012), presented a design to reduce duty cycles for better conversion and voltage conversion. A hybrid boost mode Cuk converter is used in this and, step up structure is used which will result in better conversion ratio and better damping of oscillations. The main advantage of this proposed system is that the efficiency of the hybrid boost mode Cuk converter is increased. The system is simulated under different climatic conditions.

A high step up dc-dc converter with PV cell for distributed generation system (Mrudula,Y., 2012), is proposed a high gain and high efficiency using PV cell for a distributed system. By using the PV cell in series and discharged in a series to the DC-DC converter to achieve high step-up voltage gain and high efficiency. The steady-state analyses of voltage gain and boundary operating condition are discussed in detail. Prototype circuit of the proposed converter is built in the laboratory. Experimental results confirm that high efficiency and high step-up voltage gain can be achieved.

The earlier methods we reviewed are DC-DC converter designs for photovoltaic energy systems which is applied for many applications. All the above mentioned methods convert direct current to direct current but with different voltage level. The model stores the energy in capacitors and designed to release them in later stage where there is a low level voltage in the circuit. What happens when storing energy in some capacitors and releasing at later stage, some voltage loss and switching loss occurs. To overcome the identified problems with the earlier design we have designed a modular Cuk converter based PV system to improve the performance of PV system and converter performance. To overcome the problem of switching losses we propose a new modular fuzzy logic controller based Cuk converter design for photovoltaic energy system.

Proposed Design:

The proposed design has adapted fuzzy logic controller and MOSFET into generic Cuk converter. The MOSFET has connected in parallel with the dc source which controls the flow of voltage in bi-direction where as fuzzy logic controller attached with the design controls the closed loop operations.Fuzzy logic is a paradigm foran alternative design methodologythat can be applied in developingboth linear and nonlinearsystems for embedded control. The fuzzy rule set contains various rules according to the range of voltages and combination of values. The fuzzy logic controller could control the flow of voltage according to the rules specified in the rule set. The fuzzy logic controller avoids the switching loss generated by the MOSFET using the pulse generator with closed loop conditions. The subsystem of a pulse generator consists of logical operator and gate which is connected in serial to reduce switching loss. The dc source applied from a 12 V and gets the output of 12.1 V with running conditions.

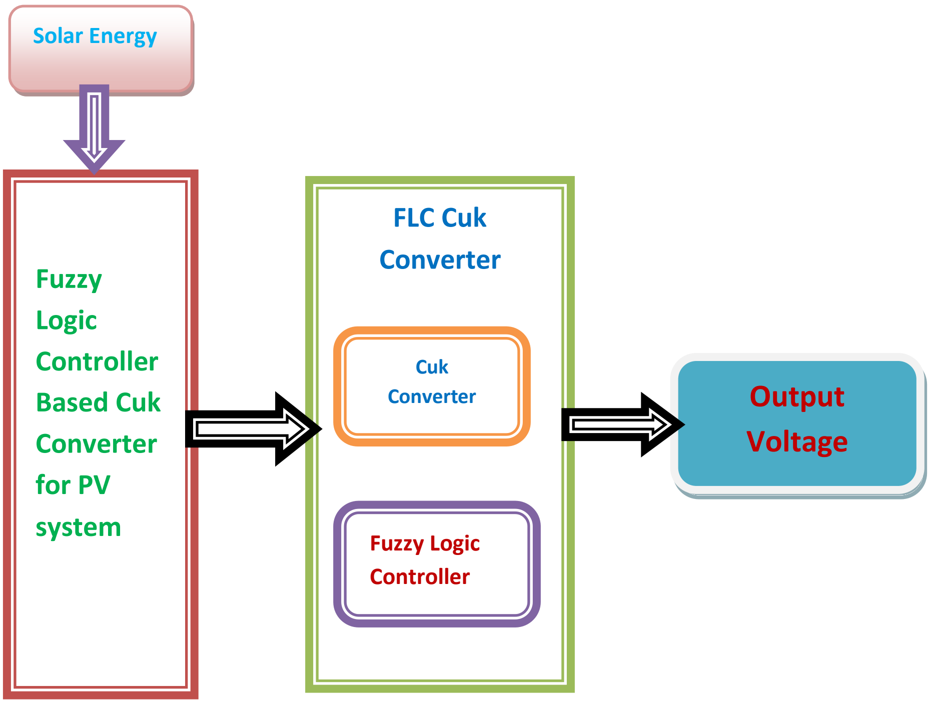

Fig. 1: Proposed System Architecture

Fuzzy Soft Switching:

The fuzzy logic controller is containing four subsystems. The subsystems are Fuzzifier, Fuzzy rule base, Fuzzy inference system and Defuzzifier. The fuzzifier converts the input voltage Vi into range of voltage values V_r and the fuzzy rule base consists of generated rules. The fuzzy inference system executes the matching function with the range of voltage values V_r and identifies the matching rule from the rule set $R_{s.}$ The defuzzifier converts the fuzzy values into real values as voltage and executes the matched rule from the rule set $R_{s.}$

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Psuedocode:

Step1: Read rule set $R_{s.}$
Step2: Generate fuzzy membership function from the output and input into fuzzy subsets.
Step3: Read input voltage V_i and generate range of values V_r.
$V_r = ø\{V_i\}$
V_r – subset of range of voltage values
Step4: For each rule R_x from rule set R_s
Compute closeness cl = $\{Rx(v_{1..n})-R_i(v_{1..n})\}$
Add cl to closeness list Cls.
End
Step5: Select closest matching rule R_i from Cls.
$R_i = \$(Cls(R_s))$.
Step6: Convert fuzzy values into real values RV.
Step7: Execute the rule identified with the real values.
Step8: Stop.

Schematic:

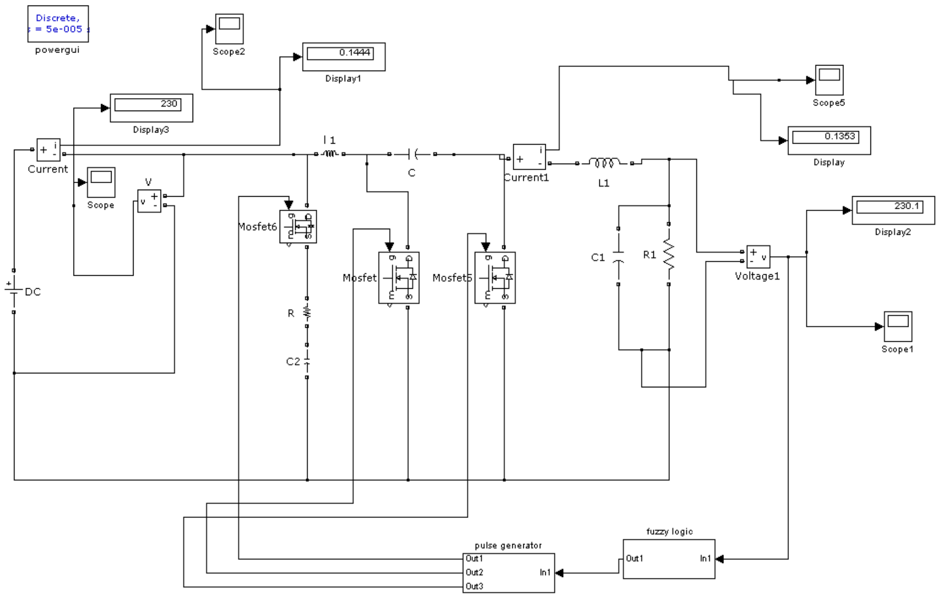

Fig. 2: Schematic of proposed design

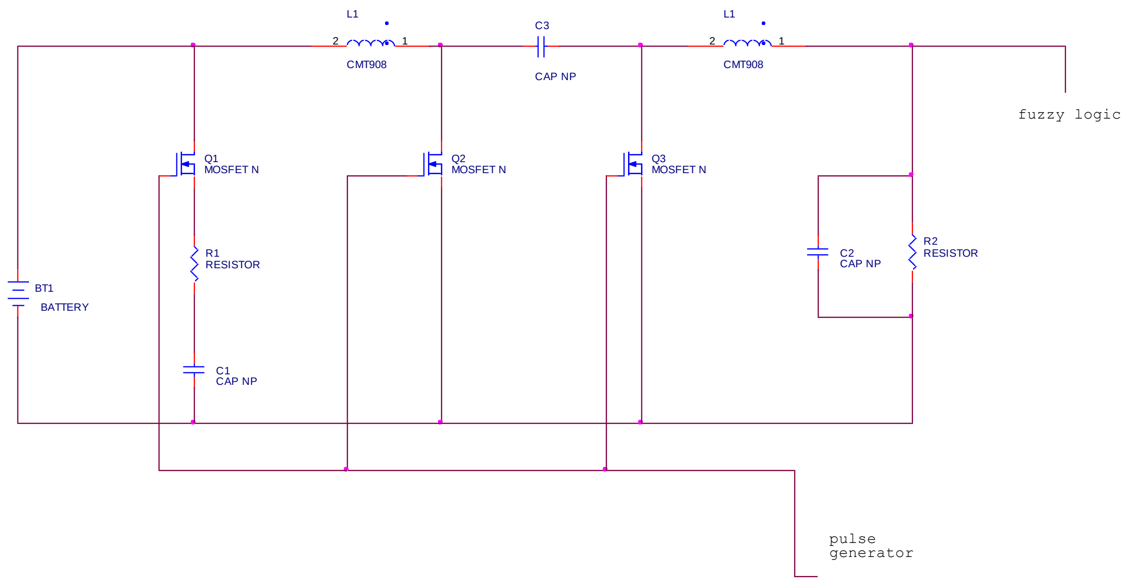

Fig. 3: Circuit diagram of proposed modular Cuk converter.

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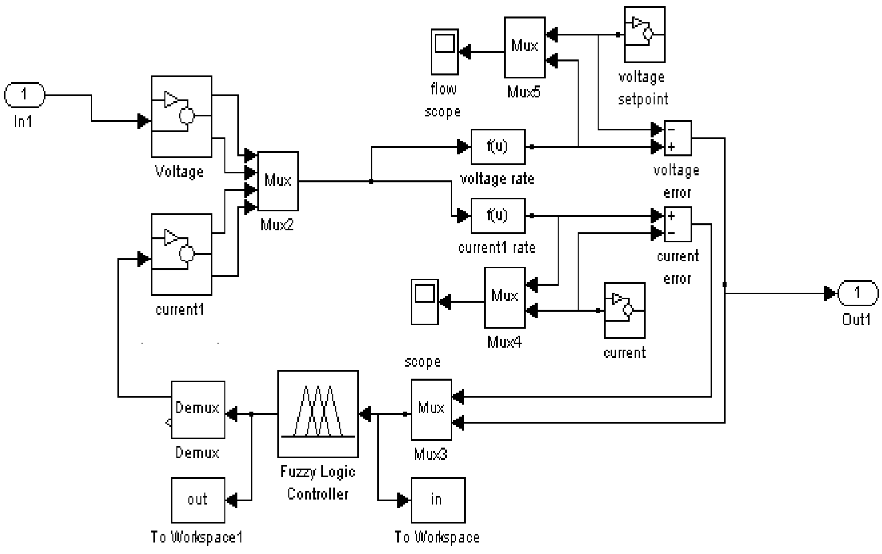

Fig. 4: Simulink structure of modular converter with fuzzy logic controller

The figure 3 shows the circuit diagram of the proposed modular Cuk converter where the figures 2 and 4 shows the schematic design and structure of modular converter implemented in Simulink.

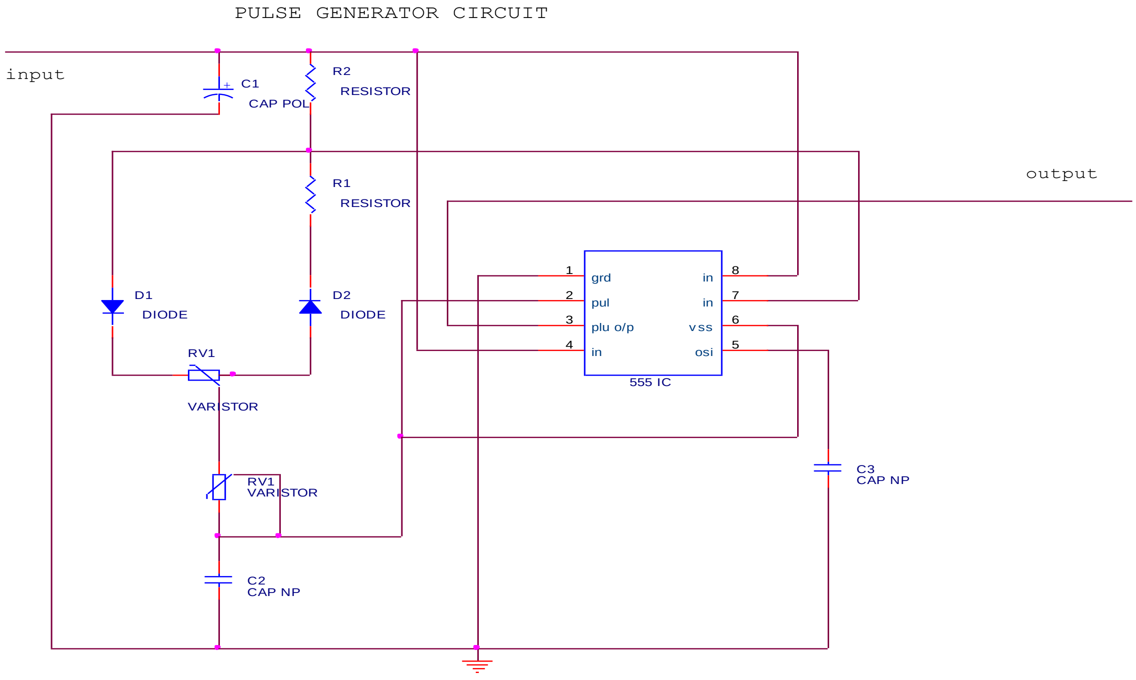

Fig. 5: Circuit diagram of pulse generator.

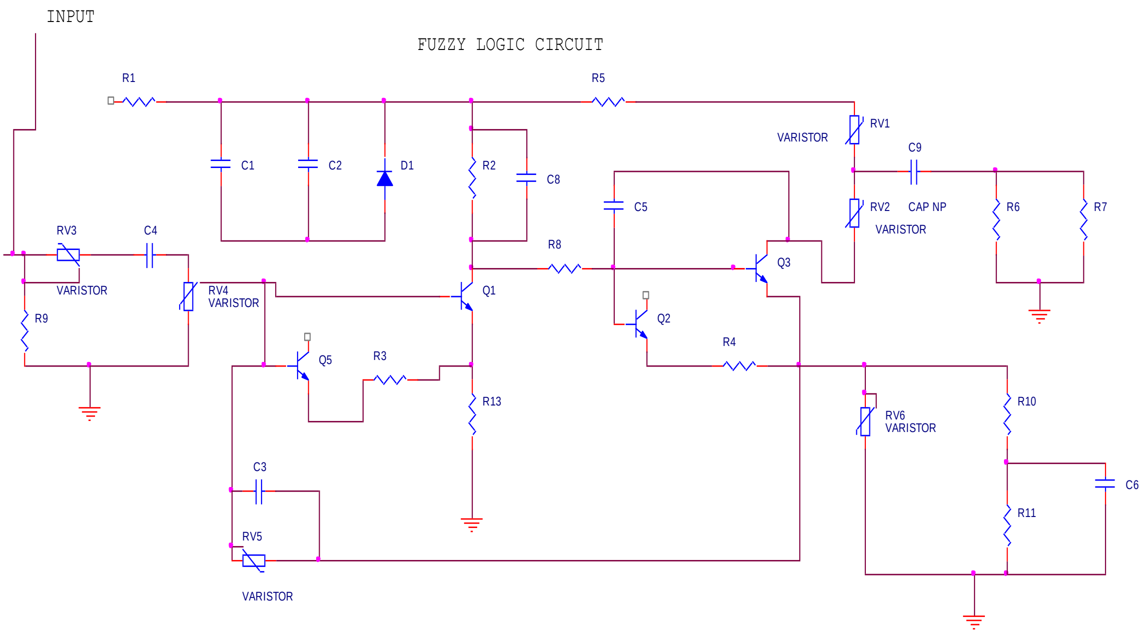

Fig. 6: Circuit diagram of fuzzy logic.

Simulation Results:

The proposed modular Cuk converter with fuzzy logic controller has been designed and simulated with MATLAB Simulink. The efficiency of the proposed model has been evaluated as follows.

The energy stored in the inductor is given by

$$E = 1/2\times(L \times I2) \quad (1)$$

The current passes through the inductor related to the voltage across the inductor shown as

$$VL = L\times(di/dt) \quad (2)$$

Inductor L1 connected in series with supply Vi and capacitor C and inductor L2 connected to the output capacitor.

$$V(L1) = Vi-Vc \quad (3)$$

$$V(L2) = Vo \quad (4)$$

The inductor L 1 is also connected to the input source and inductor L 2 is also connected to the capacitor and load.

$$V(L1) = Vi \quad (5)$$

$$V(L2) = Vc + Vo \quad (6)$$

The average current pass through inductor L1 and L2is given by

$$(1 - D) * Vc) \quad (7)$$

$$V (L2) = D (Vc + Vo) +((1 - D) *Vo) = (Vo + D * Vc) \quad (8)$$

$$Vc = Vo/ D \quad (9)$$

Voltage available across the inductor L1

$$V(L1) = (Vi +((1 - D) * Vo/ D)) = 0 \quad (10)$$

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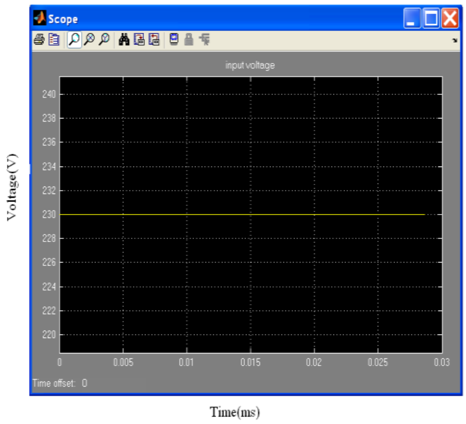
$V_{out}/ V_{in} = - D/(1 – D)$ (11)

Where D = Duty cycle.
V_{out} = output voltage. V_{in}= input voltage.
VL = inductance voltage. VC = capacitance voltage.

The ratio of an output voltage to the input voltage will be equal to negative ratio of duty cycle to the 1-D (Duty cycle).



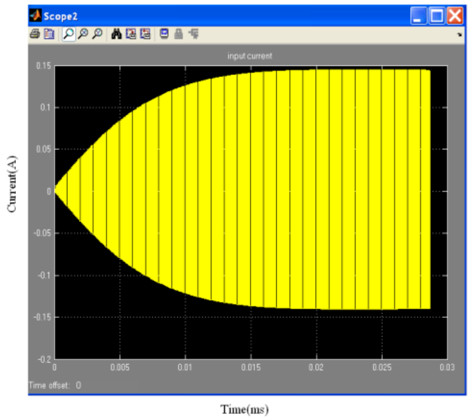
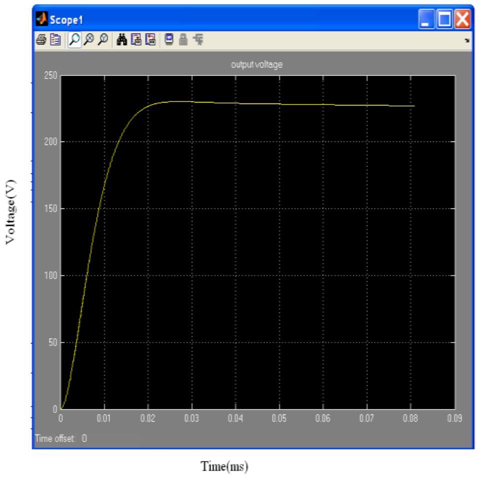


Fig. 7a: Input voltage **7b.** Input Current

The graph 7a shows the waveform generated using the MATLAB simulation for input voltage, and it shows clearly that the input voltage has constant value. The graph has been generated by connecting the supply voltage with the inductor, where the supply voltage is calculated directly. The graph 7b shows the wave form of input current.



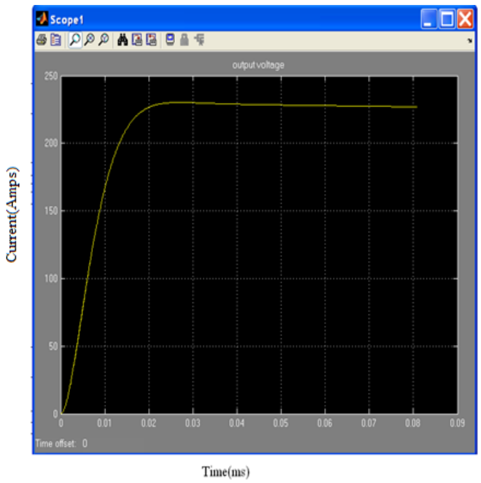


Fig. 8a: Output voltage **8b:** Output Current

The graph 8a shows the wave form of output voltage, which shows the efficiency of the proposed model. The graph has been generated by connecting output inductor with the capacitor. Also it looks clear that the output voltage will be slowly raised with 230v. The graph 8b shows the wave form of output current, generated by connecting the capacitance and inductance. The MOSFET are serially connected to the circuit so that input current does not vary. At the same time resistance and capacitance are connected parallel to the circuit which provides efficient output with increased voltage.

Table 1: Efficiency of the proposed model

Input current (Amps)	Input voltage (volts)	Input power (watts)	Output current (Amps)	Output voltage (volts)	Output power (watts)	Loss (watts)	Efficiency
230	0.15	34.5	230	0.14	32.2	2.3	93.33 %

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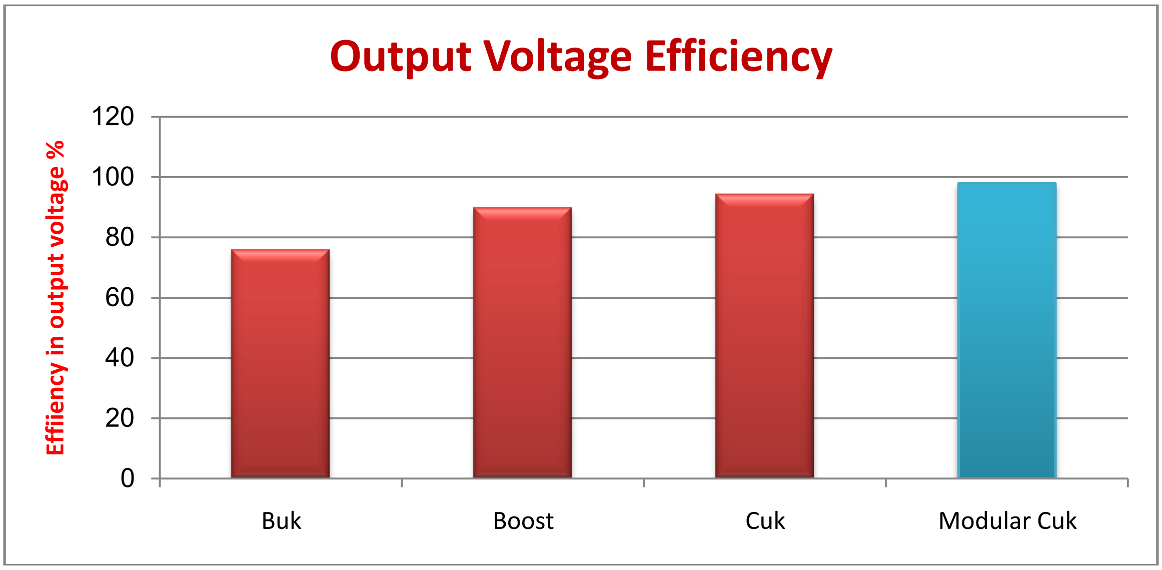
Table 2: Performance Comparisons

Converters	Buck		Boost		Cuk		Modular Cuk	
Efficiency	Input	Output	Input	Output	Input	Output	Input	Output
Power in Watts	56	42.49	63	56.56	118	111.1	148.5	144.4
Voltage in Volts	8	42.06	9	56	20	58.5	22.5	51.94
Current in Amps	7	1.01	7	1.01	5.9	1.9	6.6	2.78
Efficiency	75.87 %		89.77 %		94.15 %		97.29 %	

Hardware Kit of The Proposed Model:

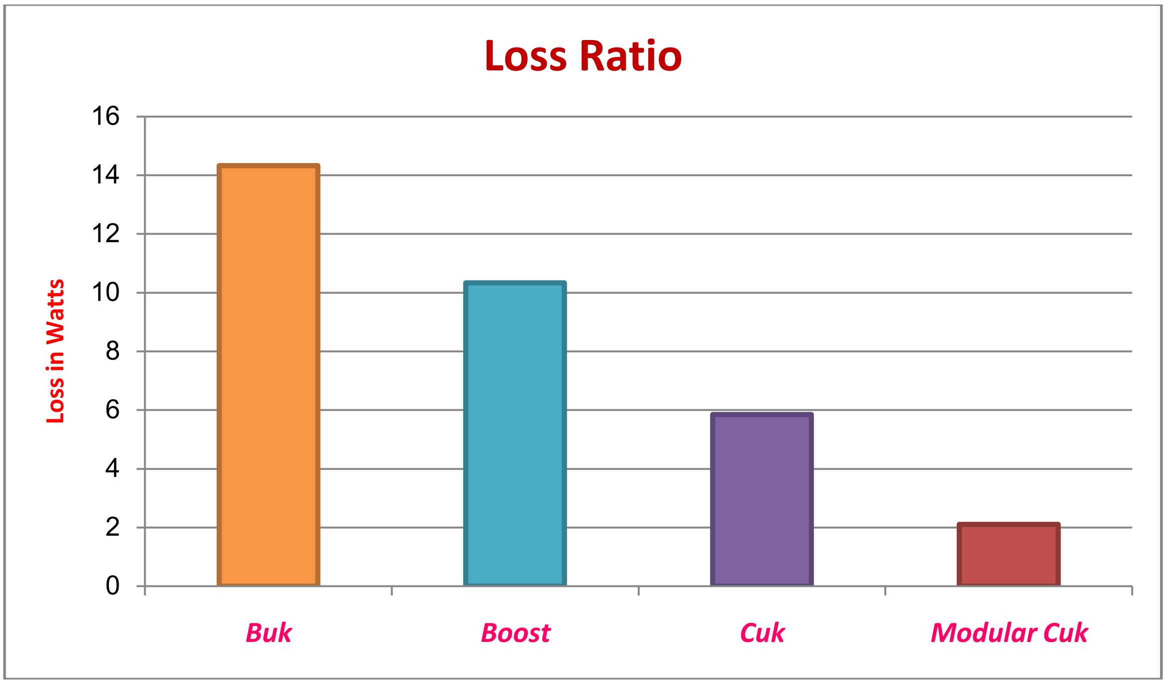
Fig. 9: Hardware kit of the proposed model

The modular Cuk converter based fuzzy logic controller kit has been designed and implemented with the PCB board. The two designed circuit applied to the PCB Board. In the first circuit, the voltage passes through the open loop condition and another circuit connected with the closed loop conditions. So the closed loop condition the output voltage varied by fuzzy logic controller.



Graph. 1: Output voltage efficiency of the converters.

From graph1, it is clear that the proposed modular Cuk converter has more efficiency than the others proposed earlier.



Graph. 2: Loss ratio of different algorithms.

The graph2 shows that the proposed method has less voltage loss compare to other methodologies for the same input current. The graph has been plotted for the input current of 230 amps.

Conclusion:

The proposed modular fuzzy logic controller based Cuk converter for photovoltaic system was simulated with MATLAB / SIMULINK software.In the proposed model the switching losses are reduced with the help of fuzzy logic controller and conduction losses are reduced by adapting the MOSFET as auxiliary circuit. The proposed schematic is hard wired to evaluate the performance and has produced efficient results.The proposed design has produced very good results and the output voltage and current produced are high. The efficiency produced by the modular design has been evaluated as 93.33 % which is a successful output.

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