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PV System using Maximum Power Point Tracking and Boost Converter

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Abstract— The requirement for renewable energy sources is very high in recent years due to the acute energy crisis. Photovoltaic power is regarded as a chief source of energy in several countries with high solar power density. The main obstruction for reach of solar PV systems is their low efficiency and high capital cost. Therefore, controlling Maximum Power Point Tracking (MPPT) for the solar array has become an essential aspect in a PV generation as Maximum Power Point (MPP) changes with the solar radiation and temperature. In this paper, Perturbation and Observation (P&O) lgorithm is used for maximum power point tracking as it has the potential to adjust the solar array reference voltage to attain maximum power point. P&O system has certain limitation which is overcome in this paper with the utilization of fuzzy based P&O. But, this produces oscillations in voltage conversion. To overcome this difficulty, a better converter should be used in voltage conversion. Cuk converter is one of the existing efficient converters in PV systems. One of main drawback in cuk converter is more duty cycles are required for better conversion and some oscillations will persist in voltage conversion. To overcome these drawbacks, Boost converter is used in this paper. In Boost converter, 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 Boost converter is increased. The system is simulated under different climatic conditions. The simulation model of controller is built in MATLAB / Simulink background, and the simulation result shows the reduction in oscillations and improvement in power conversion.

Keywords— Maximum Power Point Tracking, Perturb and Observe, Boost Mode Converter.

I. INTRODUCTION

The majority of the production of energy in this modern industrialized world is strongly based on very limited non-renewable resources such as petroleum. Moreover, the issues of the global energy shorting and environmental pollution due to energy have become a great concern. As a result, it is very vital to establish the clean, safe, reliable and sustainable new energy sources such as wind energy, water energy, solar energy, etc. Solar energy is the most competent, reliable and harmless form of energy source [1]. It can be produced by the utilization of photovoltaic (PV) array.

Photovoltaic have the capability to provide electricity in a clean, quiet and reliable way. Photovoltaic systems consist of photovoltaic cells, devices that alter light energy directly into electricity. As the source of light is generally the sun, they are usually known as solar cells. Thus, the photovoltaic process is generating electricity directly from sunlight [2].

PV cells transform sunlight directly into electricity without generating any air or water pollution. In order to raise their potential, 12 individual PV cells are interconnected collectively in a sealed, weatherproof pack up called a module. When two modules are wired collectively in series, their voltage is doubled while the current remains constant. When two modules are wired in parallel, their current is doubled while the voltage remains constant. In order to attain the desired voltage and current, modules are wired in series and parallel into a PV array. The flexibility of the modular PV system facilitates developers to generate solar power systems that can meet a wide variety of electrical requirements [2].

Tracking the Maximum Power Point (MPP) of a photovoltaic (PV) array is an important aspect of a PV system [3]. Maximum Power Point is the optimum operating point in the PV array to obtain the maximum power. There is only one optimum operating point on the power-voltage (or current) curve as an electric characteristic feature of the output power to the operating voltage or current has a convex characteristic feature [4]. Variation in lighting intensity causes these trackers to move

away from the MPP when lighting conditions alter, the tracker requires to response in a short time to the change to avoid energy loss. Thus, it is difficult to track the MPP of the PV cell quickly and effectively in the real application. In order to overcome this drawback, many MPPT algorithms [5] were suggested for tracking the MPP of solar module [6], [7], the most widely used approaches among them is a hill-climbing approach and Perturbation and Observation.

P&O technique is perturbation in operating voltage of the PV array. The Perturb and Observe (P&O) technique works by regularly perturbing (i.e. adding or subtracting) the array terminal voltage or current and evaluating the PV output power with that of the prior perturbation cycle. The Perturb and Observe algorithm has self-tuning ability which adjusts the array reference voltage and step size of the voltage to achieve maximum power point [12]. The main drawback in PV system is that PV module’s operating voltage is troubled every cycle so this paper uses fuzzy based P&O approach to overcome the above limitation. The fuzzy theory based on fuzzy sets and fuzzy approaches offers a wide-ranging technique of stating linguistic rules hence they may be processed rapidly by a computer.

II. METHODOLOGY

The fundamental structural unit of a solar module is the PV cells. A solar cell alters energy in the photons of sunlight into electricity through the photoelectric fact seen in certain types of semiconductor materials such as silicon and selenium. A single solar cell can only create a little amount of power. In order to enhance the output power of a system, solar cells are usually connected in series or parallel to form PV modules. PV module characteristic features [16] show an exponential and non-linear relation between output current and voltage of PV module. The main equation for output current of a module is [16]

$$I_o = n_p - I_{ph} - n_p I_{rs}\left[exp\left(k_o \frac{v}{n_s}\right) - 1\right] \text{-------------(1)}$$

where, *I*o represents the PV array output current, PV output voltage is denoted by , *Iph* represents the cell photocurrent that is proportional to solar irradiation, *Irs* denotes the cell reverse saturation current that primarily depends on the temperature, k_o represents a constant, ns denotes the number of PV cells connected in series and n_p denotes the number of such strings connected in parallel. In (1), cell photocurrent is computed from

$$I_{ph} = [I_{scr} + k_i(T - T_r)]\frac{S}{100} \text{-----------(2)}$$

I_{scr} represents the cell short-circuit current at reference temperature and radiation,
k_i is short circuit current temperature coefficient,
T_r is the cell reference temperature,
S is solar irradiation in mW/ cm^2.

and cell reverse saturation current is computed from

$$I_{rs} = I_{rr}\left[\frac{T}{T_r}\right]^3 exp\left(\frac{qE_G}{kA}\left[\frac{1}{T_r} - \frac{1}{T}\right]\right) \text{--------------(3)}$$

where,

T_r represents the cell reference temperature,
I_{rr} denotes the reverse saturation at T_r,
E_G denotes the band-gap energy of the semiconductor used in the cell.

The sample current vs voltage of a PV module is shown in Figure 1. The Fig. 1 shows four elevations of the current voltage curve of 215 W panel. Maximum Power Point is obtained for all the four curves. This *point* is connected to a voltage and current which are Vmpp and Impp respectively and is very much dependent on the solar irradiation and ambient temperature [17]. Vmpp is observed to be nearly 27 volts.

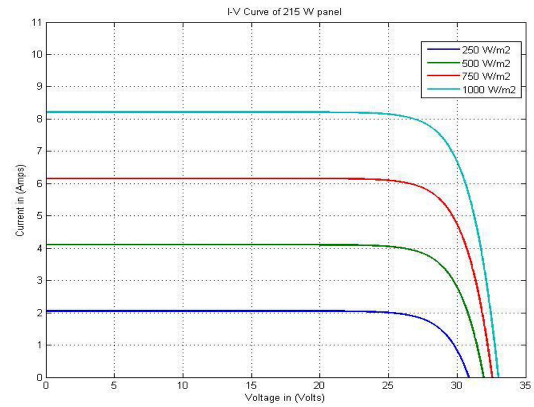


Fig. 1 Current Vs Voltage Curve of a PV Module

III. PERTURB AND OBSERVE MPPT

Perturb and Observe (P&O), as the name represent, the working is based on the inspection of the array output power and on the perturbation (adding or subtracting) of the power with respect to the change in array voltage or current. This method continuously adds or subtracts the reference current or voltage with respect to *the* earlier power sample. The P&O is the simplest algorithm which maintains the PV array voltage and the implementation cost is also much reduced. The P&O method defines that when the operating voltage of the PV panel is perturbed by a small addition and the resulting change in voltage ΔV is positive, then it means that the direction of MPP is followed and the system continues to perturbate in the same direction. If ΔV is negative, it means that the direction of *MPP* is deviating and the sign of perturbation needs to be changed.

The operation of the P&O MPPT is shown in Figure 2. The computation of actual state k and previous state k-1 of parameters V and I are considered. The actual and previous state of the parameters power, P and voltage, V are compared. According to the conditions as represented in Fig. 2, increment or decrement of perturbed voltage, ΔV will be applied to the PV module operating voltage.

Fig. 3 demonstrates the power-voltage characteristic feature of PV model which discusses the principle of MPP tracking [18]. There are four probable scenarios which will affect the direction of the tracking in P&O MPPT. Figure 3 shows four curves of PV for 250 W/m2, 500 W/m2, 750 W/m2 and 1000 W/m2.

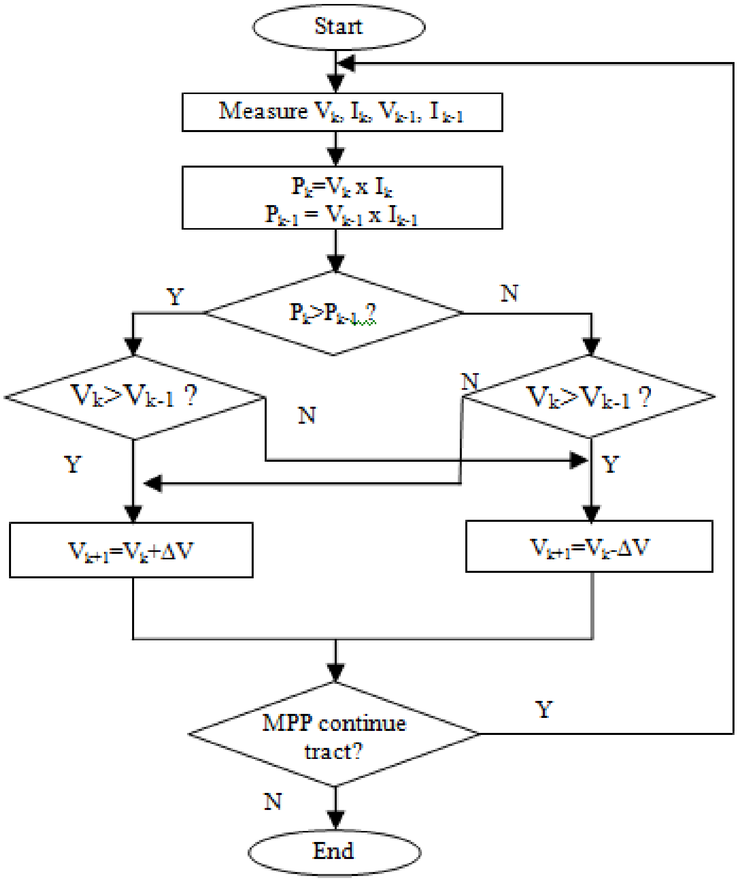


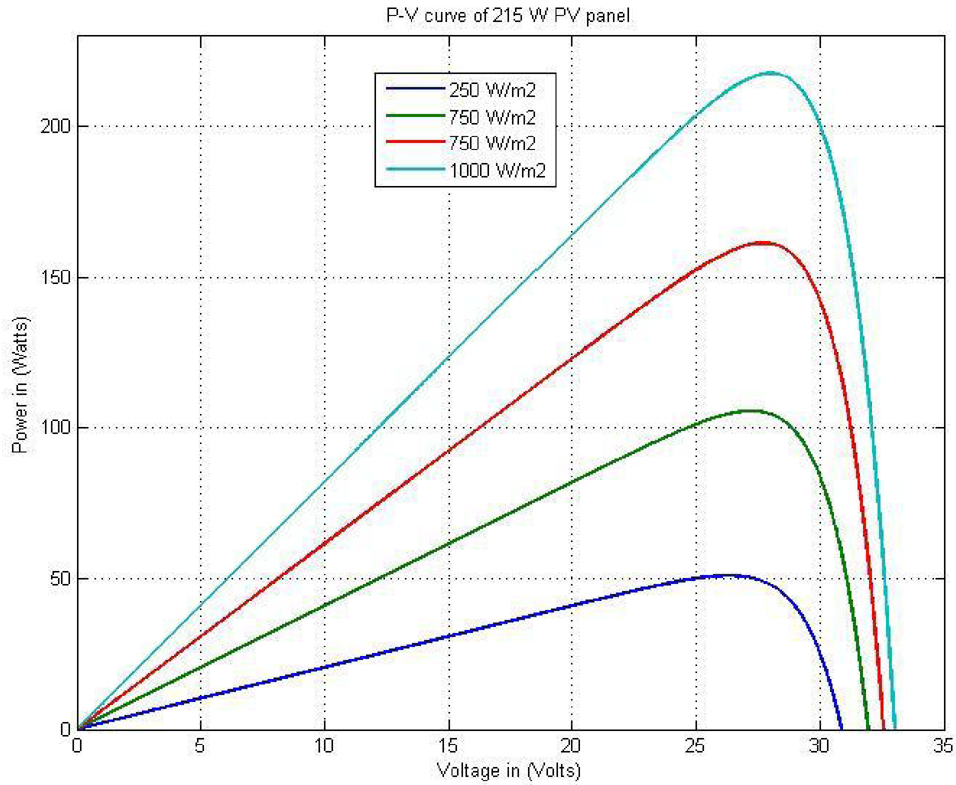
Fig. 2 Flowchart Shows the Operation of P&O MPPT

Case I where $Pk>Pk$-1 *and* $Vk>Vk$-1, it will be an increasing region of the curve in Figure 3. When the operating *voltage* is
increased, the PV power is increased also. Therefore, a small change of voltage ΔV need to be added to the present PV
operating voltage followed by monitoring of the PV power. The process is continued until the MPP is identified.

Case II where $Pk>Pk-1$ *and* $Vk<Vk-1$ referred to the decreasing region of the curve in Figure 3. It can be observed that when the operating voltage is reduced, the PV power is increased. To recognize the MPP operating *point*, reduction of ΔV should be made on the current PV operating voltage and the parameters Pk and Pk-1 are compared. If the condition $Pk>Pk-1$ is satisfied, the decrement of ΔV will be continued until the MPP is effectively spotted.

Case III where $Pk<Pk-1$ and $Vk>Vk-1$ can be illustrated as decreasing region of the curve in Figure 3. In this scenario, the PV power is diminishing as the increased of PV operating voltage. Hence, it should have a ΔV decline on the current PV operating voltage.

Case IV where $Pk<Pk-1$ and $Vk<Vk-1$ is illustrated as increasing region of the curve in Figure 3. The PV power is *reducing* as the decreasing of PV operating voltage. Thus the PV operating voltage should have an increment of ΔV to track the PV maximum power point.



The main limitation of P&O MPPT approach is the PV module's operating voltage is troubled every cycle [18]. The algorithm will always carry out an increment or decrement of ΔV to the PV operating voltage. The *process* of maximum power tracking will be executed on even the MPP has been effectively tracked. This is because of the output power of PV module for the next perturbed cycle is unpredictable.

The constant tracking of MPP is significant for maximum power gaining from PV module. But, it will lead to another problem. The increment and decrement of ΔV will result in oscillation of the PV operating *voltage* and hence cause the power fluctuation which result in the power loss in the PV system. Hence, fuzzy logic is employed in the P&O MPPT to decrease the oscillation of the PV operating voltage and thus decreasing the power loss in the PV system. This will increase the power conversion and efficiency of the proposed system.

IV. FUZZY LOGIC

Fuzzy logic is a tool with their heuristic nature connected with simplicity and efficiency for linear and non-linear systems. It is fairly simple to implement as fuzzy do not need correct mathematic model. Moreover, fuzzy is competent to function correctly even with the vague inputs. Moreover, fuzzy is more forceful *compared* to the conventional non-linear controller [19]. The process of fuzzy logic control can be categorized into four fundamental elements such as fuzzification, rule base, inference engine and defuzzification.

The operation of fuzzy logic control is shown in Fig. 4. The rule base used in fuzzy logic controller is presented in Table 1.

The fuzzification is the method of changing the system actual signal λ and δ into linguistic fuzzy sets using fuzzy membership function. The membership function is the curvature that presents each point of membership value. *Fuzzy* rule base is a set of if-then rules which all the data is available for the controlled parameters. The fuzzy rule base is set based on professional experience and the process of the system control. Fuzzy inference engine has the function of formulating a logical decision depending on the fuzzy rule setting. It will then change the fuzzy rule base into fuzzy linguistic output. Defuzzifier is to convert the linguistic fuzzy sets back into actual value *γ*.

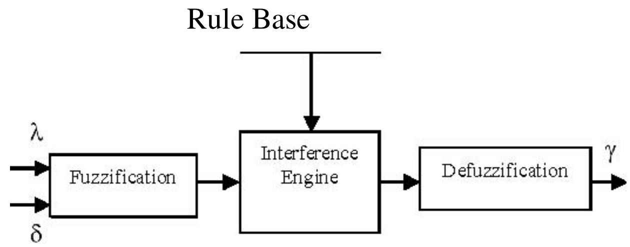
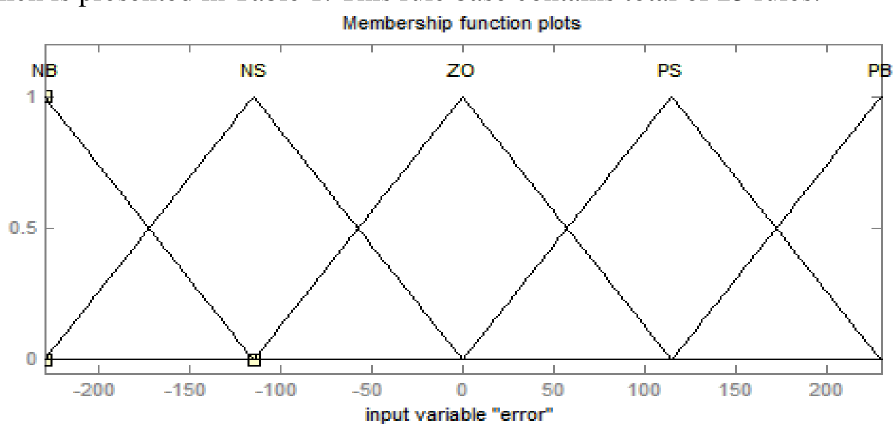
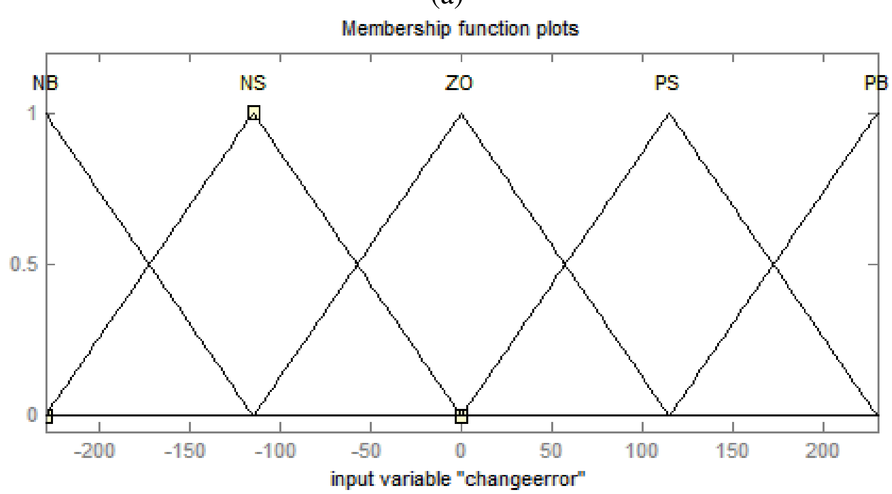


Fig. 4 Four Basic Elements in Fuzzy Logic Controller

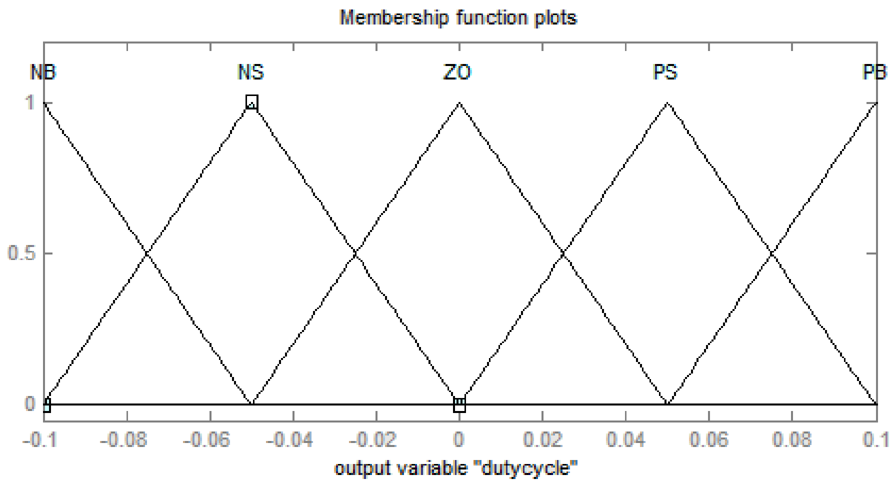
In fuzzification process, the numerical input variables are changed to linguistic variables in accordance with the membership functions which are presented in Figure 5. Five fuzzy levels are utilized for all the inputs and outputs variables: NB (negative big), NS (negative small), ZO (zero), PS (positive small), and PB (positive big). These five fuzzy levels are utilized to enhance the control surface and to permit a soft *conversion* from transient to steady condition. The user holds the capability of selecting values of numerical variables for the inputs. After E and CE are computed, they are transformed into linguistic variables and then the output, D is obtained with the help of rule base table which is presented in Table 1. This rule base contains total of 25 rules.



(a)



(b)



(c)

Fig. 5 Membership Function for Fuzzy (a) Input of Error, E (b) Input of Change in Error, CE (c) Output of Duty Cycle, D

TABLE I: RULE BASE FOR FUZZY LOGIC CONTROLLER

E\CE	NB	NS	ZO	PS	PB
NB	NB	NB	NB	NS	ZO
NS	NB	NB	NS	ZO	PS
ZO	NB	NS	ZO	PS	PB
PS	NS	ZO	PS	PB	PB
PB	ZO	PS	PB	PB	PB

The fuzzy logic controller tracks the MPP with the help of P&O Algorithm. Generally, weights are added to the rules to enhance the reasoning accuracy and to decrease the objectionable results. The centroid technique is the mostly used defuzzification technique as it has better averaging properties and it yields better outcome. While performing defuzzification, fuzzy logic controller output is converted back to a numerical variable. Therefore, this offers an analog signal to control the power converter.

V. BOOST CONVERTER

When proposing a maximum power point tracker, the main task is to select and devise a high efficient converter which is supposed to work as the main constituent of the MPPT. Efficiency of switch mode DC-DC converters is extensively discussed in [20]. Most Switching Mode Power Supplies (SMPS) are well intended to function with high efficiency.

Among all the existing topologies, both cuk and buckboost converters offer the chance to have either higher or lower output voltage compare with input voltage. Though buck- boost configuration is cheaper than cuk, some limitations such as discontinuous input current, high peak currents in power components and poor transient response makes it less efficient. Alternatively, cuk converter has low switching losses and maximum competence among non-isolated DC-DC converters. It also can offer a better output current character because of the inductor on the output leg. Hence, cuk configuration is an appropriate converter to be employed in designing the MPPT.

The circuit diagram of Cuk converter is shown in Fig. 6. There are two modes of operation in Cuk converter. First mode of operation is when the switch is *closed* (ON) and it is conducting as a short circuit. In this mode, capacitor releases C1 energy to the output. On the second operating mode when the switch is open (OFF), diode is forward biased and conducting energy to the output. Capacitor C1 is charging from input. Relations between output and input currents and voltagesfor using cuk converter are given by,

$$V_o = -\left(\frac{D}{1-D}\right)V_{in} \quad \text{-------- (4)}$$

$$I_o = -\left(\frac{1-D}{D}\right)I_{in} \quad \text{--------- (5)}$$

But, Cuk cannot *offer* a steep step-down, respectively step-up of the line voltage, as needed by several sophisticated applications. To offer a high voltage-conversion ratio, the fundamental converters would have to operate with a great value of the duty cycle, smaller than 0.1 in voltage-step-down converters, higher than 0.9 in voltage-step-up converters. An extreme duty cycle impairs the competence and enforces obstacles for the transient response [21]. Moreover, in order to create such an extreme duty cycle, the control circuit must include a very fast, expensive comparator.

The extreme duty cycle may even result in failures at high switching frequency because of the very short conduction time of the diode (self-driven transistor) in step-up converters, or of the active transistor in step-down converters. In order to overcome this, simple switching dual structures for step up is proposed in this paper, formed by a *capacitor* and diode. The *step* up structure is inserted in classical Cuk converter to offer new power supplies with a steep voltage conversion ratio. After the conversion of Cuk converter to Boost boost mode Cuk converter, the resulting circuit is shown in Fig. 7.

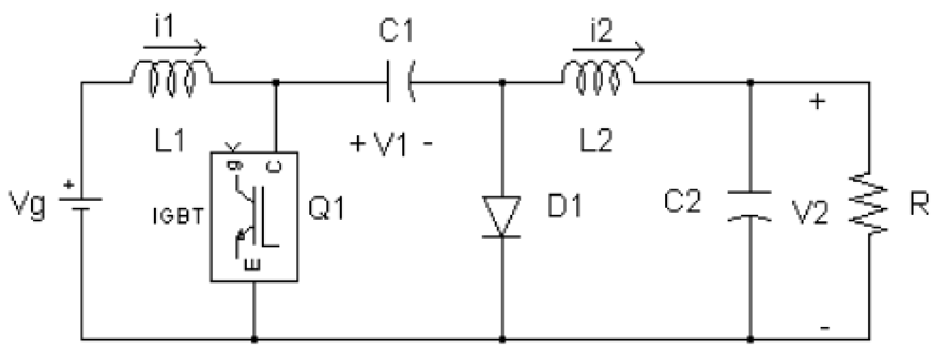


Fig. 6 Circuit diagram of Cuk Converter

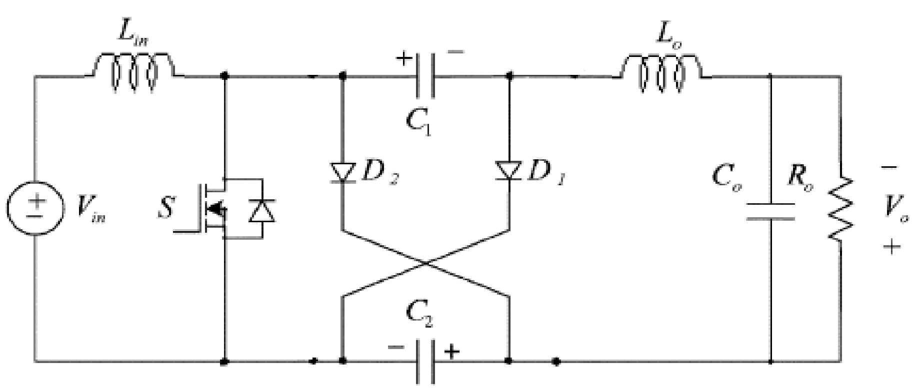


Fig. 7 Circuit diagram of Boost Boost Mode Cuk Converter

The voltage balances for Boost boost mode cuk converter is given by

$$V_{in}D + (V_{in} - V_C)(1 - D) = 0 \text{ ---------- } (6)$$

$$(V_o - 2V_C)D + (V_o - V_C)(1 - D) = 0 \text{ ------}(7)$$

Therefore, the output voltage is given as,

$$V_o = \frac{1 + D}{1 - D} V_{in} \text{ --------- } (8)$$

VI. SIMULATION RESULTS

The performance of the controller is investigated at variable changes of solar irradiance but only at constant temperature of 25°C. In this paper, controllers are examined with variable changes of solar irradiance and moreover with the changes of cell temperature which is also influencing the PV maximum power gaining. Fig. 8 shows the schematic block diagram of proposed power conversion. The circuit parameters used to test the proposed Boost Boost Mode Cuk Converter system is as follows.

- Lin = Lo = 44mH
- C1 = C2 = 0.004µF
- Co = 270µF
- Ro = 30Ω
- D = 0.5

The proposed fuzzy based P&O system is tested and is compared with the P&O system by evaluating the output power and efficiency at various solar irradiations (200 watts/ m2,400 watts/m2, 600 watts/m2, 800 watts/m2 and 1000 watts/m2).

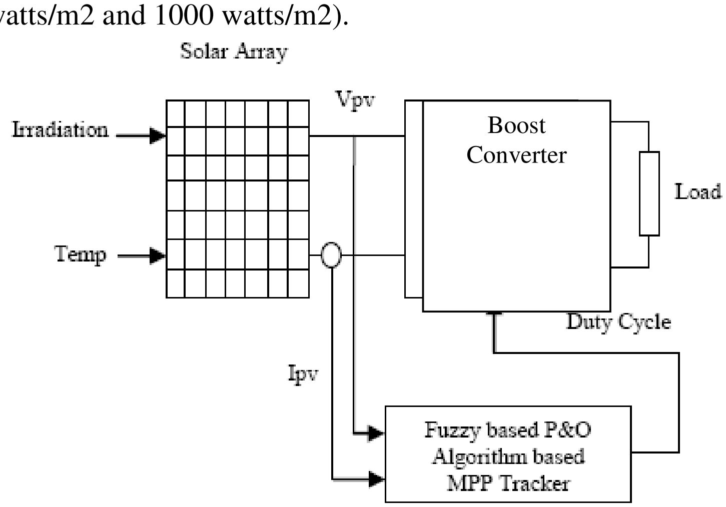


Fig. 8 Schematic Block Diagram of Proposed Power Conversion

The resulting PV output power at various solar irradiations of 200 watts/m2, 400 watts/m2, 600 watts/m2, 800 watts/m2 and 1000 watts/m2 are shown in Fig. 11, Fig. 12, Fig. 13, Fig. 14 and Fig. 15, respectively. It is observed from the figures that proposed Boost boost mode Cuk Converter based P&O system is very effective and provides better output when compared with the Cuk converter based P&O system.

From the figures, it can be observed that the usage of Boost boost mode cuk converter resulted in the improvement of PV power output. Particularly, it can be noted that the oscillation are very much suppressed in using Boost boost mode cuk converter when to the usage of classical cuk converter.

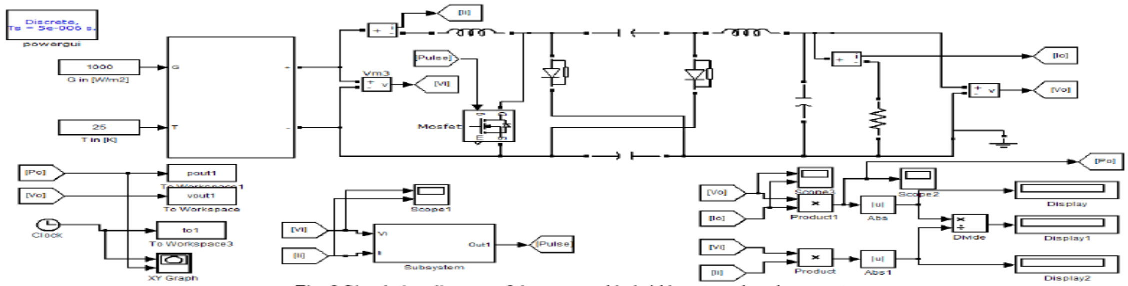


Fig. 9 Simulation diagram of the proposed hybrid boost mode cuk converter

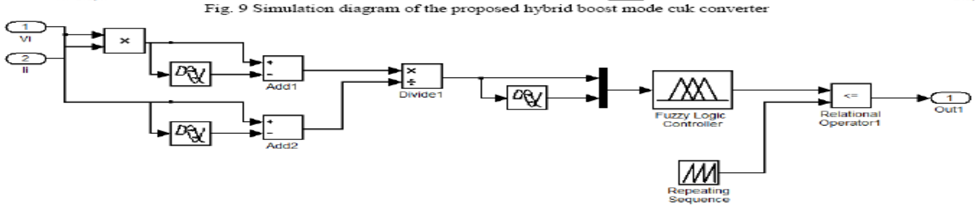


Fig. 10: Fuzzy logic based P & O algorithm in simulink

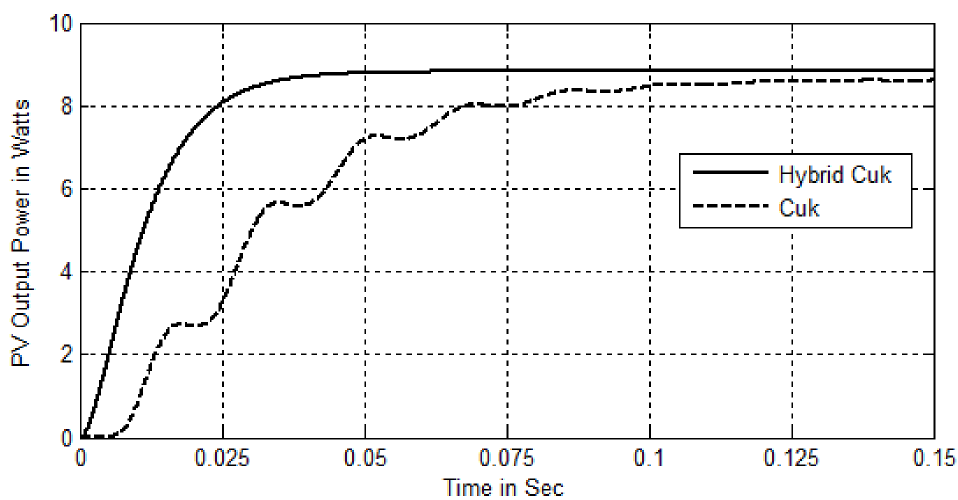


FIG. 11 PV OUTPUT POWER AT SOLAR IRRADIATION OF 200 WATTS/M^2

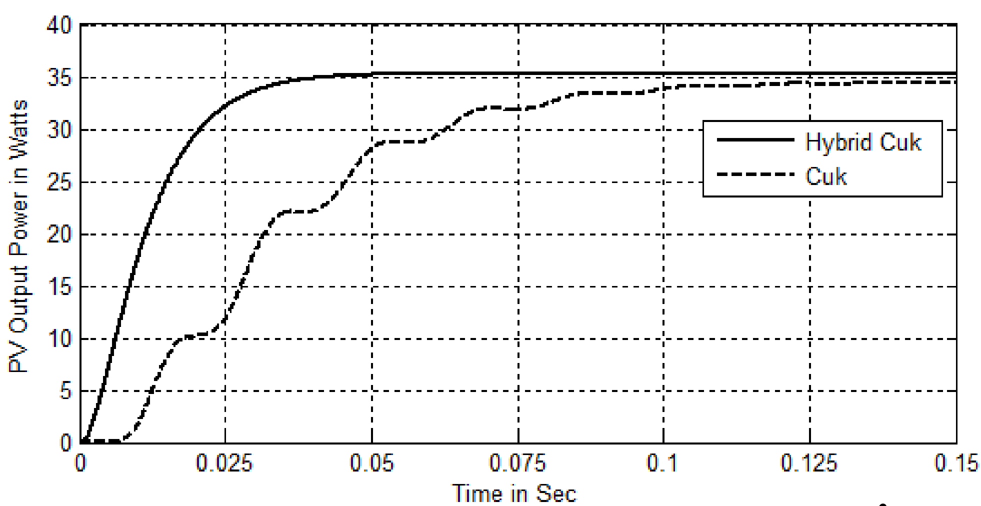


Fig. 12 PV Output Power at Solar Irradiation of 400 watts/m^2

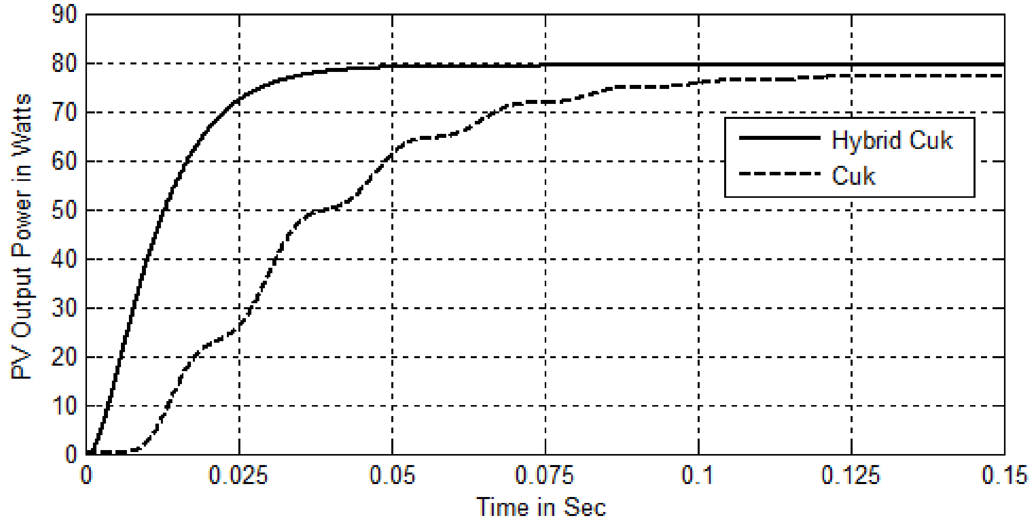


Fig 13 PV Output Power at Solar Irradiation of 600 watts/m^2

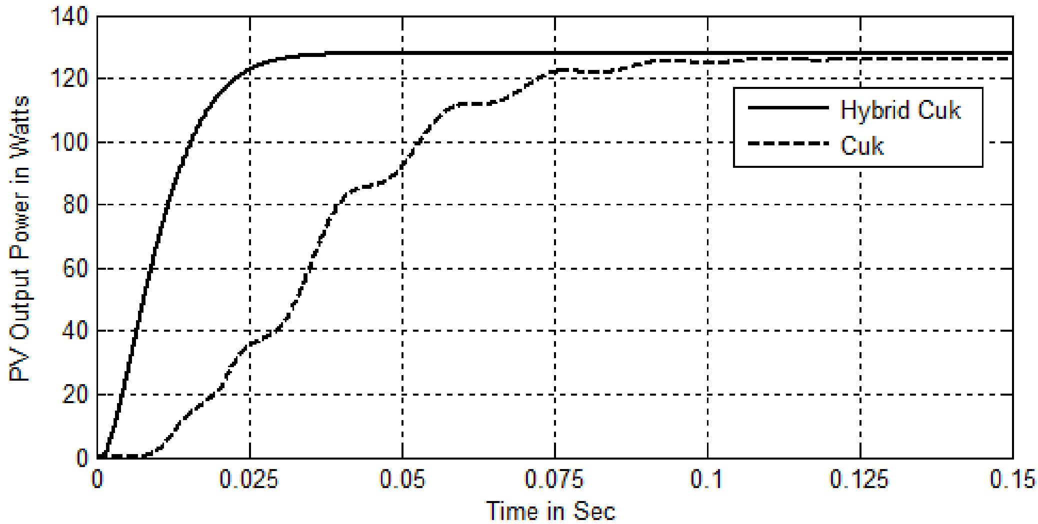


Fig. 14 PV Output Power at Solar Irradiation of 800 watts/m^2

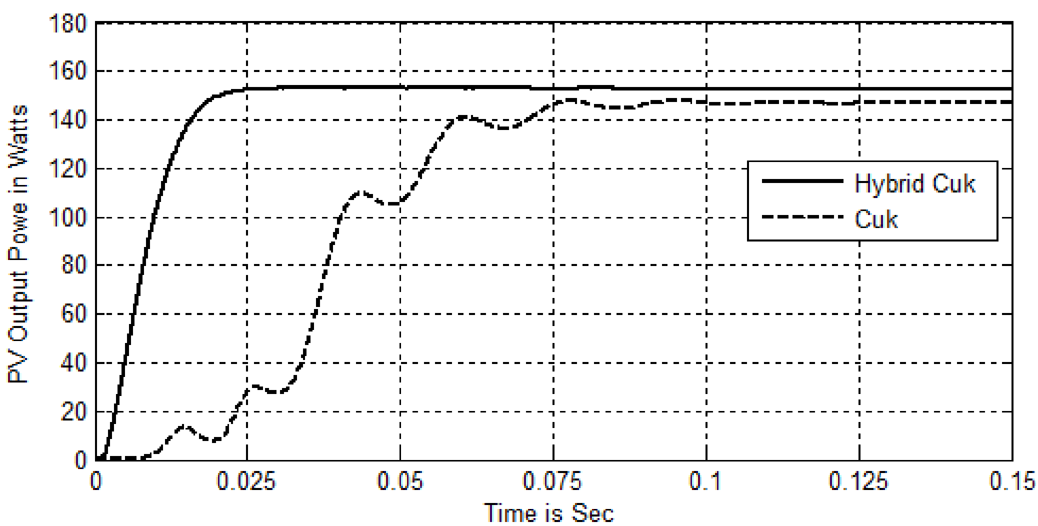


Fig. 15 PV Output Power at Solar Irradiation of 1000 watts/m^2

Table 2 shows the performance of the proposed Boost boost mode cuk converter with the conventional Cuk Converter. The parameters considered for the performance evaluations are power, voltage, current and efficiency. It is observed from the Table 2 that the output power obtained by the Cuk converter is 147.63 watts where as for the Boost boost mode Cuk converter, it is 152.64 watts. In the same case, the voltage produced by the Cuk Converter is 57 volts where as it is 61.8 volts in the case of Boost boost mode Cuk converter. Output current for the Cuk converter is 2.59 amps but it is just 2.47 amps for the proposed approach. Thus, the output efficiency of using Boost boost mode cuk converter and classical cuk converter of 1000 watts/m2 irradiation level is shown in Table 2. From the Table 2, it can be observed that the output efficiency for using Boost boost mode cuk converter is better i.e., 95.4 % when compared to the usage of classical cuk converter i.e., 92.26 %.

Table Ii: Comparison Results Of Pv Generated Power In Cuk And Boost Boost Mode Cuk Converter

Solar Irradiation / Electrical Parameters	1000 Watts / m^2			
	Cuk Converter		Hybrid Boost mode Cuk Converter	
	Input	Output	Input	Output
Power in Watts	160	147.63	160	152.64
Voltage in Volts	23.39	57	23.47	61.8
Current in Amps	6.84	2.59	6.82	2.47
Efficiency	92.26%		95.4%	

VII. CONCLUSION

Photovoltaic (PV) generation is playing a vital role as a renewable source as it provides many benefits such as it requires no fuel costs, nonpolluting, needs little maintenance, and emitting no noise when compared to others. PV modules still have fairly low conversion efficiency; so, controlling Maximum Power Point Tracking (MPPT) for the solar array is very vital in a PV system. This paper proposes an efficient fuzzy based approach to track Maximum Power Point in PV system. The proposed system uses fuzzy based Perturb and Observe approach and the converter used is Boost boost mode cuk converter which is better compared to conventional cuk converter. The simulation results show that the proposed Boost Boost mode Cuk Converter system provides better efficiency for PV generation and the oscillations are very much reduced when compared with the traditional Cuk converter.

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