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Integration of Maximum Power Point Tracking Algorithms with Sepic Converter for Solar Power System

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Abstract

This paper proposes the concept of MPPT and implements the two different MPPT algorithms combined in to a ARM controller. Modeling of the converter and the solar cell are carried out in Simulink and interfacing both with the MPPT algorithm to obtain the maximum power point operation is of the prime importance of this paper. Experimental setup of a 10W solar panel with a MPPT controller analyzed this paper and proves the importance of proposed controller.
Keywords: MPPT, fuzzy-logic, SEPIC converter.

Introduction

Solar energy is the most readily available source of energy and it is free. Moreover, solar energy is the best among all the renewable energy sources since, it is non-polluting[1]. Energy supplied by the sun in one hour is equal to the amount of energy required by the human in one year. Photo voltaic arrays are used in many applications such as water pumping, street lighting in rural town, battery charging and grid connected PV systems. Solar energy is abundantly available that has made it possible to harvest it and utilize it properly[2].

The power conversion mechanisms have been greatly reduced in size in the past few years. The development in power electronics and material science has helped engineers to come up very small but powerful systems to withstand the high power demand. But the disadvantage of these systems is the increased power density.

The use of the newest power control mechanisms called the Maximum Power Point Tracking (MPPT) algorithms has led to the increase in the efficiency of operation of the solar modules and thus is effective in the field of utilization of renewable sources of energy.[3] One of the major concerns in the power sector is the day-to-day increasing power demand. so efficiency of system should be increase.

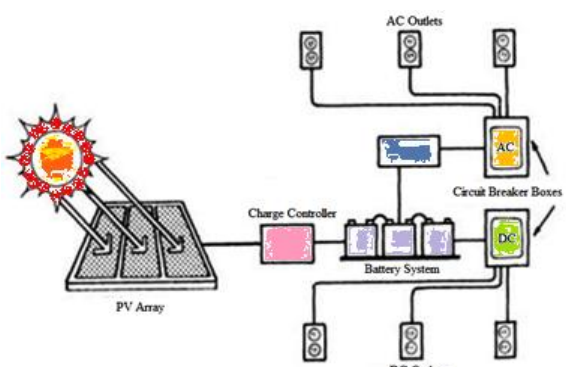

Figure 1: General setup of solar powered system

A single-stage inverter, used conventional PI controllers along with the MPPT scheme. The limitations of the PI controller are well known because it is sensitive to parameter variations, weather conditions, and other uncertainties. Therefore, there is need to apply a more efficient controller that can handle the uncertainties, such as unpredictable weather, for the PV system. The sliding-mode controller [4] is famous for its large signal stability, robustness, and simple implementation. Effectively, the sliding-mode controller operates at infinite, varying, and self-oscillating switching frequency; hence, the control variables follow a specific reference path to accomplish the wanted steady-state process. However, the advantage of an intelligent controller is that its design does not require an accurate system mathematical model, and it can handle the nonlinearity of arbitrary complexity[5].

General setup of solar PV cell based power system shown in figure1. Due to its output gain flexibility, the single-ended primary inductor converter (SEPIC)introduced and acts as a buck–boost dc–dc converter, where it changes its output voltage according to its duty cycle[6]. The selection of a proper dc–dc converter plays an important role for maximum power point tracking (MPPT) operation. The criteria for photovoltaic (PV) converter selection depend on many factors, such as cost, efficiency, flexibility, and energy flow. There is no general agreement in the literature on which one of the two converters is better, i.e., the SEPIC or the Cuk The MPPT algorithm represents optimal load for PV array, producing opportune voltage for the load. The PV panel yields exponential curves for current and voltage, where the maximum power occurs at the curve's mutual knee. The applied MPPT uses a type of control and logic to look for the knee, which in turn allows the SEPIC converter to extract the maximum power from the PV array. The tracking method used, i.e., perturb and observe (P&O), provides a new reference signal for the controller and extracts the maximum power from the PV array[7].

This paper presents an FLC-based MPPT operation of the SEPIC converter for PV inverter applications. As the proposed method always transfers maximum power from PV arrays to the inverter side, it optimizes the number of PV modules. The proposed scheme is implemented in real time using ARM7 microprocessor. The fuzzy controller for the SEPIC MPPT scheme shows high precision in current transition and keeps the voltage without any changes, in the variable-load case, represented in small steady-state error and small overshoot. As the inverter is used in a PV system, FLC is employed for more accurate output sine wave, higher dynamic performance under rapidly varying atmospheric milieu exploiting maximum power effectively, and improved THD, as compared to conventional PI-controlled converters.

Principle of Operation SEPIC Converter MPPT and FUZZY logic

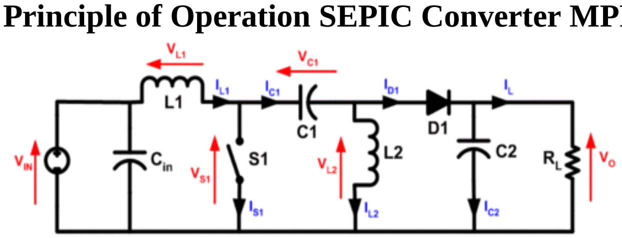

Figure 2: Schematic diagram of a SEPIC

Single-ended primary-inductor converter (SEPIC) is a type of DC-DC converter allowing the electrical potential (voltage) at its output to be greater than, less than, or equal to that at its input; the output of the SEPIC is controlled by the duty cycle of the control transistor.

A SEPIC is essentially a boost converter followed by a buck-boost converter, therefore it is similar to a traditional buck-boost converter, but has advantages of having non-inverted output (the output has the same voltage polarity as the input), using a series capacitor to couple energy from the input to the output (and thus can respond more gracefully to a short-circuit output), and being capable of true shutdown: when the switch is turned off, its output drops to 0 V, following a fairly hefty transient dump of charge.

SEPICs are useful in applications in which a battery voltage can be above and below that of the regulator's intended output. For example, a single lithium ion battery typically discharges from 4.2 volts to 3 volts; if other components require 3.3 volts, then the SEPIC would be effective.

Fig 2 shows the schematic diagram of a SEPIC converter, as with other switched mode power supplies (specifically DC-to-DC converters), the SEPIC exchanges energy between the capacitors and inductors in order to convert from one voltage to another. The amount of energy exchanged is controlled by switch S1, which is typically a transistor such as a MOSFET; MOSFETs offer much higher input impedance and lower voltage drop than bipolar junction transistors (BJTs), and do not require biasing resistors as MOSFET switching is controlled by differences in voltage rather than a current, as with BJTs).number of switches.

MPPT Algorithms

Hill-Climbing Techniques

Both P&O and INC algorithms are based on the "hill-climbing" principle, which consists of moving the operation point of the PV array in the direction in which power increases .Hill-climbing techniques are the most popular MPPT methods due to their ease of implementation and good performance when the irradiation is constant . The advantages of both methods are the simplicity and low computational power they need. The shortcomings are also well-known: oscillations around the MPP and they can get lost and track the MPP in the wrong direction during rapidly changing atmospheric conditions. These drawbacks will be explained later.

Among these techniques, the P&O and the INC algorithms are the most common. These techniques have the advantage of an easy implementation but they also have drawbacks, as will be shown later. Other techniques based on different principles are fuzzy control, neural circuit, fractional open circuit voltage or short circuit current, current sweep, etc. Most of these methods yield a local maximum and some, like the fractional open circuit voltage or short circuit current, give an approximated MPP, not the exact one. In normal conditions the V-P curve has only one maximum, so it is not a problem. While, if the PV array is partially shaded, there are multiple maxima in these curves. According to order to relieve this problem, some algorithms have been implemented. These techniques differ in many aspects such as required sensors, cost, complexity, convergence speed range of effectiveness, correct tracking when irradiation and/or change in temperature, hardware needed for the implementation or popularity.

Perturb and Observe

The P&O algorithm is also called "hill-climbing", while both names refer to the same algorithm depending on how it is implemented. Hill-climbing consist of a perturbation on the duty cycle of the power converter and P&O a perturbation in the operating voltage of the DC link between the PV array and the power converter. In the case of the Hill-climbing, perturb the duty cycle of the power converter implies modifying the voltage of the DC link between the PV array and the power converter, so both name refer to the same technique

In this method, the sign of the last perturbation and the sign of the last increment in the power are used to decide what the next perturbation should be.on the left of the MPP incrementing the voltage increases the power whereas on the right, decrementing the voltage increases the power. If there is an increment in the power, the perturbation should be kept in the same direction and if the power decreases, then the next perturbation should be in the opposite direction. Based on these facts, the algorithm is implemented . The process is repeated until the MPP is reached. Then the operating point oscillates around theMPP. This problem is common also to the INC method, as was mention earlier. A scheme of the algorithm is shown in Figure 3

The incremental conductance algorithm is based on the fact that the slope of the curve power vs. voltage (current) of the PV module is zero at the MPP, positive (negative) on the left of it and negative (positive) on the right

V P=0 (IP=0) at the MPP V (1)

P>0 (IP<0) on the left V (2)

P< 0 (IP>0) on the right (3)

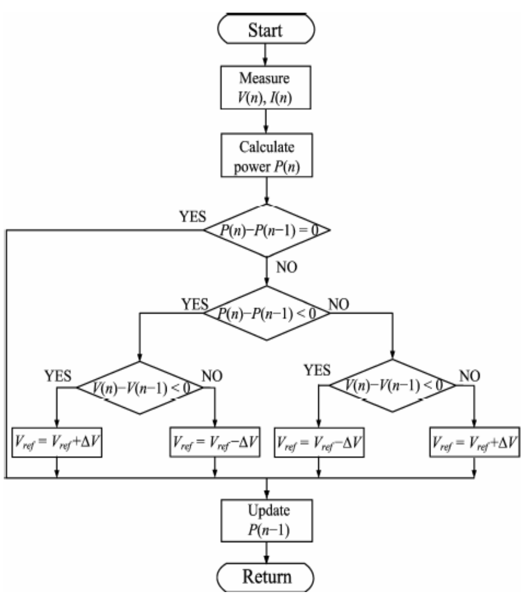

Figure 3: Flowchart for P & O Algorithm

By comparing the increment of the power vs. the increment of the voltage (current) between two consecutives samples, the change in the MPP voltage can be determined.

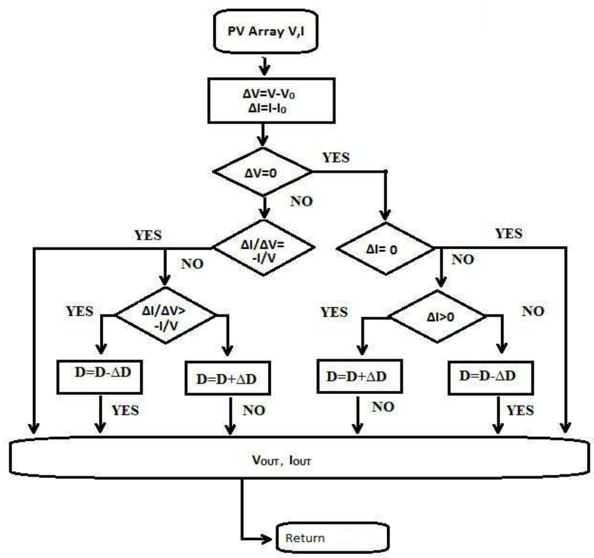

Figure 1.10: Incremental Conductance algorithm

Fuzzy logic

Fuzzy logic control generally consists of three stages: fuzzification, rule base lookup table and defuzzification. During fuzzification, numerical input variables are converted into linguistic variables based on a membership function. The inputs to a MPPT fuzzy logic controller are usually an error *E* and a change in error *E*. The user has the flexibility of choosing how to compute *E* and *E*. In the defuzzification stage, the fuzzy logic controller output is converted from a linguistic variable to a numerical variable still using a membership function .This will provide analog signal that will control the power converter to the MPP.

$(k) = (k) - P(k-1) \div V(k) - V(k-1)$ (4)

$(k) = (k) - E(k-1)$ (5)

Fuzzy logic controllers have the advantages of working with imprecise inputs, not needing an accurate mathematical model, and handling nonlinearity but the basic drawback is high cost of implementation.

Fractional open circuit voltage

This method uses the approximately linear relationship between the MPP voltage (V_{MPP}) and the open circuit voltage (V_{OC}), which varies with the irradiance and temperature :

$V_{MPP} = K_1 V_{OC}$

Where $k1$ is a constant depending on the characteristics of the PV array and it has to be determined beforehand by determining the *VMPP* and *VOC* for different levels of irradiation and different temperatures. The constant $k1$ has been reported to be between 0.71 and 0.78.Once the constant of proportionality, $k1$, is known, the MPP voltage V_{MPP} can be determined periodically by measuring V_{OC}. To measure V_{OC} the power converter has to be shut down momentarily so in each measurement a loss of power occurs. Another problem of this method is that it is incapable of tracking the MPP under irradiation slopes, because the determination of V_{MPP} is not continuous. One more disadvantage is that the MPP reached is not the real one because the relationship is only an approximation.

To overcome these drawbacks, some solutions have been proposed. For example, pilot cells can be used to obtain V_{OC}. They are solar cells that represent the PV array's cells and which are not used to produce electricity but to obtain characteristics parameters such as V_{OC} without interfering with the power converters. These pilot cells have to be carefully chosen and placed to represent the PV array characteristics and the irradiation conditions. One drawback of using these pilot cells is that the cost of the system is increased. Depending on the application, this technique can be used because it is very easy to implement and it is cheap - it does not require DSP or microcontroller control and just one voltage sensor is used. However, according to this method is not valid under partial shading of the PV array because then the constant $k1$ changes. To update voltage sweep is proposed though this increases the complexity of the system, the cost increases and there are more power losses during the sweep.

Fractional short circuit current

Just like in the fractional open circuit voltage method, there is a relationship, under varying atmospheric conditions, between the short circuit current I_{SC} and the MPP current, I_{MPP}, as is shown by: $I_{MPP=}K_2 I_{SC}$ .The coefficient of proportionality k_2 has to be determined according to each PV array, as in the previous method happened with k_1. According to the constant k_2 has been reported to be between 0.78 and 0.92.
Measuring the short circuit current while the system is operating is a problem. It usually requires adding an additional switch to the power converter to periodically short the PV array and measure I_{SC}. In I_{SC} is measured by shorting the PV array with an additional field-effect transistor added between the PV array and the DC link capacitor.

One other option is shown in a boost converter is used and the switch of the converter is used to short the PV array. Short circuiting the PV array also leads to a loss of power. One last handicap is that the real MPP is not reached because the proportional relationship is an approximation. Furthermore, k_2 changes if the PV array is partially shaded, which happens due to shades or surface contamination. To overcome this problem, proposes an online tuning of k_2 and a periodical sweep of the PV voltage from open circuit to short circuit to update k_2 and guarantee that the real MPP is reached in the presence of multiple maxima which obviously increases the complexity of the system. Most of the literature using this MPPT technique uses a DSP as controller.

Proposed System

The change of voltage level fed to the inverter is the main function of the dc–dc converter. In this paper, the voltage level increases or decreases depending on the maximum power. Furthermore, the controller changes the voltage level by changing the duty cycle of the pulse width-modulated (PWM) signal, which tracks the reference signal. A sinusoidal reference signal is compared with the output signal to produce a supposedly zero error signal. Another reference signal is used to compare the SEPIC's output, to achieve the maximum power. This reference signal is adaptive, changing its shape according to weather conditions.

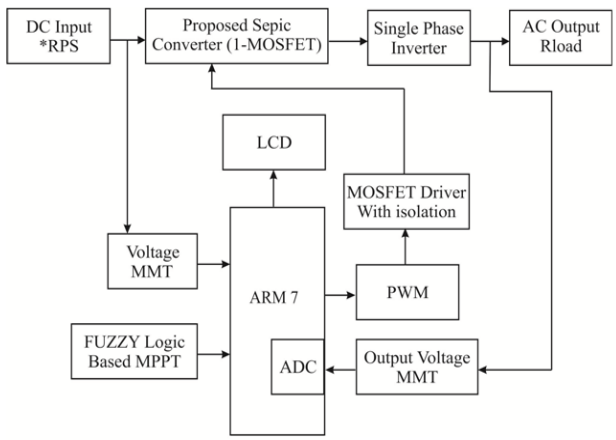

Figure 3: block diagram of proposed system

The SEPIC's v output signal is, thus, compared with the adaptive reference signal, to feed the inverter with the most suitable power. The inverter's input signal should be as smooth as possible, but the SEPICMPPT generates a nonsmooth signal, owing to its tracking of maximum power. This problem is not as big, since the no smooth signal can be enhanced by the inverter's fuzzy controller and the low-pass filter connected to the inverter. Hence, although the input signal is not smooth, the exploitation of the maximum power is possible, as well as the creation of a smooth output signal.

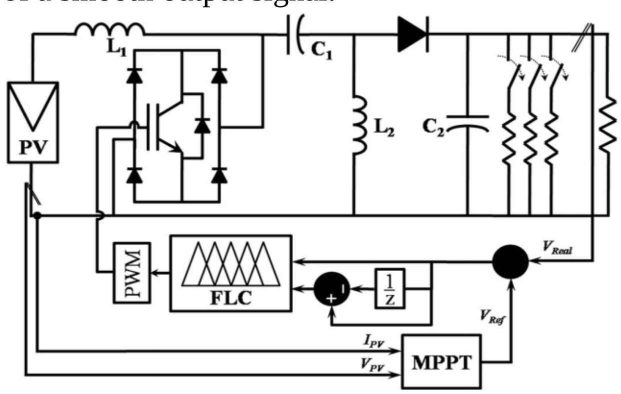

Figure 4: proposed Circuit diagram of the SEPIC converter for the FLC-based MPPT scheme

Fig. 4 is the circuit diagram of the SEPIC dc–dc converter together with the MPPT and the fuzzy controller. The design of the fuzzy controller was done using Mamdani's method for both the converter and the single-phase inverter. The selection of the membership functions will be discussed in the next section. The PWM changes its duty cycle according to the control signal, configuring a feedback from the output signal represented in voltage, current, and power to get the reference signal, which is unpredictable and adapts itself depending on the maximum power achieved by the duty cycle's changes. The maximum power point can be achieved in case of a grid-connected system, a full-load condition, or using battery charging in case of a standalone system. However, if the load need is lower than PV capacity, the PV voltage will move right in the PV curve, achieving the opportune power. This case happens even if the batteries of the standalone system are full and the load is lower than PV power. In grid-connected systems, the load is always there due to the huge number of clients. Therefore, the maximum power point can always be achieved subject to the load need.

In Fig. 5, the SEPIC converter can use single switch. However, for PV applications, the dc–dc converter can be used to supply the inverter, as well as to charge the batteries in standalone systems, hence using bidirectional switch.

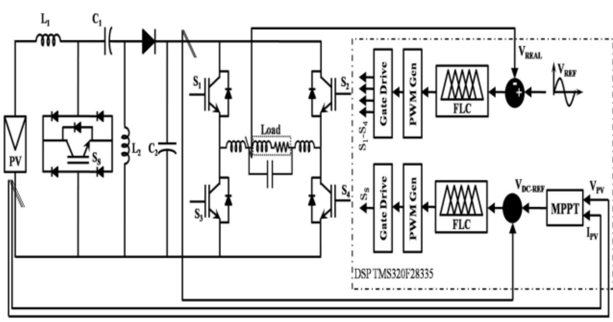

Figure 5: Overall control scheme for proposed FLC-based MPPT scheme for the SEPIC converter.

1FLC ALGORITHM

The overall control scheme of the proposed system is shown in Fig. 5. In FLC design, one should identify the main control variables and determine the sets that describe the values of each linguistic variable. The specific structure of the FLC is shown in table1.

The input variables of the FLC are the output voltage error $e(n)$ and the change of this error $e\_(n)$. The output of the FLC is the duty cycle of $d(n)$ of the PWM signal, which regulates the output voltage. Figs. 4 and 5 show the membership functions of the inputs and the outputs of the SEPIC-side FLCs. The triangular membership functions are used for the FLC for easier computation. A five-term fuzzy set, i.e., negative big (N-II), negative small (N-I), zero (Z), positive small (P-I), and positive big (P-II), is defined to describe each linguistic variable. The fuzzy rules of the proposed PV SEPIC dc–dc converter can be represented in a symmetric form, as shown in Table I. Moreover

The design of the focused membership function values depends on the nature of the signal.

e' \ e	N-II	N-I	Z	P-I	P-II
N-II	N4	N4	N4	N3	Z
N-I	N4	N2	N1	Z	P3
Z	N4	N1	Z	P1	P4
P-I	N3	Z	P1	P2	P4
P-II	Z	P3	P4	P4	P4

Table 1: fuzzy rule-based matrix

The control signal value is confined between −1 and 1, owing to the PWM carrier wave. The input signal values are between −100 and 100 because of the error signal, which is resultant from the difference between the output signal and the desired reference signal. In addition, most of error values are centered from −20 to 20. The sharpness of the control signal is very essential for minimizing the error signal to zero in short time; wherefore, the pulse membership function is used to configure the control signal fuzzy sets.

Proposed MPPT-BASED SEPIC Converter

The fuzzy controller is applied to the SEPIC converter to mimic the new reference signal coming from the MPPT. The new duty cycle $\delta(k)$ of the SEPIC converter switch was adjusted either by adding or by subtracting the previous duty cycle $\delta(k-1)$ with the duty cycle's perturbation step size. Equation (1) presents the relation between the present and previous duty cycles, i.e.,

$\delta(k) = \delta(k-1) \bullet \} \Delta\delta$ (6)

where $\Delta\delta$ is the change in duty cycle, resulting from the change of reference signal. The MPPT control technique is applied to achieve a new reference voltage for the fuzzy controller, which changes the duty cycle of the PWM signal for the SEPIC converter. The P&O algorithm has a simple structure and requires few parameters (i.e., power and voltage); that is why it is extensively used in many MPPT systems .In addition, it can be easily applied to any PV panel, regardless of the PV module's characteristics for the MPPT process. The P&O method perturbs the duty cycle and compares instantaneous power with past power. Based on this comparison, the PV voltage determines the direction of the next perturbation. P&O shows that, if the power slope increases and the voltage slope increases also, the reference voltage will increase; otherwise, it will decrease.

The drawback of most of the fuzzy-based MPPT algorithms is that the tracking point is located away from the maximum power point when the weather conditions change. However, a drawback of P&O technique is that, at steady state, the operating point oscillates around the maximum power point giving rise to the waste of available energy, particularly in cases of constant or slowly varying atmospheric conditions. This can be solved by decreasing the step size of perturbation. The step size of the P&O method affects two parameters: accuracy and speed. Accuracy increases when the step size decreases. However, accuracy leads to slow response when the environmental conditions change rapidly. Larger step size means higher speed for the MPPT operation, but this will lead to inaccuracy and larger intrinsic oscillations around the maximum power point in steady state. Step sizes should, thus, be chosen well to achieve high speed and accuracy. The step-size rate for the voltage reference signal in this paper is 0.5 V/ms.

Experiment Implementation

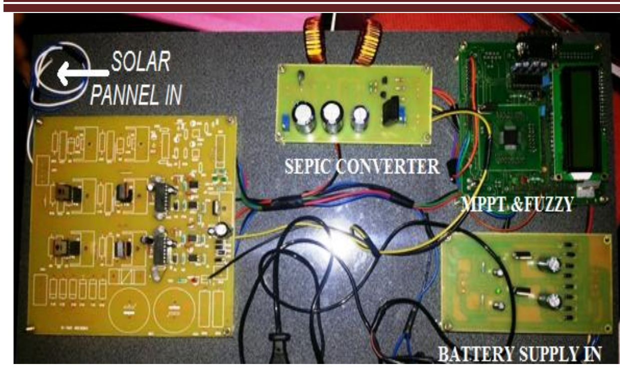

Figure 6: Real time implementation of proposed system

The change of voltage level fed to the inverter is the main function of the dc–dc converter. In this paper, the voltage level increases or decreases depending on the maximum power. Furthermore, the controller changes the voltage level by changing the duty cycle of the pulse width-modulated (PWM) signal, which tracks the reference signal. A sinusoidal reference signal is compared with the output signal to produce a supposedly zero error signal. Another reference signal is used to compare the SEPIC's output, to achieve the maximum power. This reference signal is adaptive, changing its shape according to weather conditions. The SEPIC's output signal is, thus, compared with the adaptive reference signal, to feed the inverter with the most suitable power. The inverter's input signal should be as smooth as possible, but the SEPICMPPT generates a no smooth signal, owing to its tracking of maximum power. This problem is not as big, since the non smooth signal can be enhanced by the inverter's fuzzy controller and the low-pass filter connected to the inverter. Hence, although the input signal is not smooth, the exploitation of the maximum power is possible, as well as the creation of a smooth output signal.

SIMULATION

The MPPT algorithm was built via (.m) file and linked with Simulink. The SEPIC circuit was built via SimPower toolbox shown in figure 6.

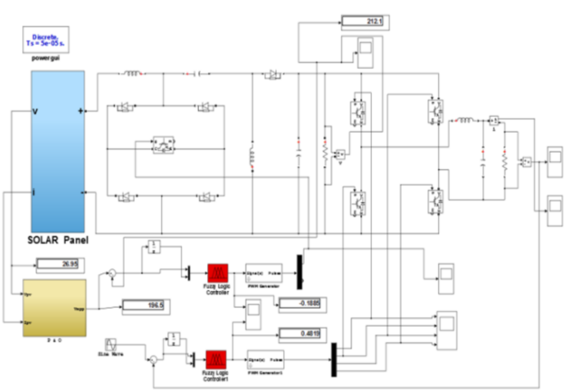

Figure5.1: proposed system model using SimPower toolbox.

PWM switching pulses are produced from comparison among sin waves and carrier. These pulses are shown in Fig. 5.2 figure 5.3 shows the waveform of load voltage and the output voltage is230 v. corresponding current of load is shown in figure 5.4. In figure 5.6show the 3 phase inverter output. Line to line voltage shown in figure. This can be seen the voltage is constant in all phases

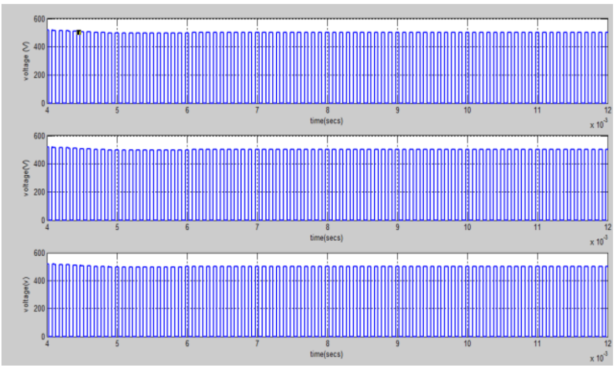

Figure 5.2: inverter turn ON pulses(3phase)

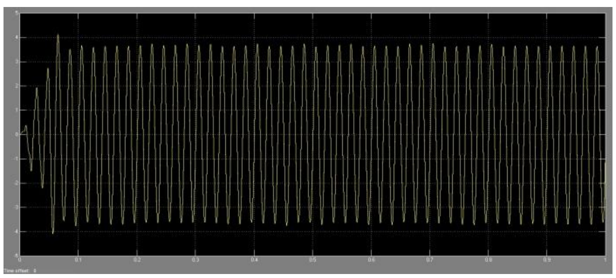

Figure 5.3: system output voltage per phase

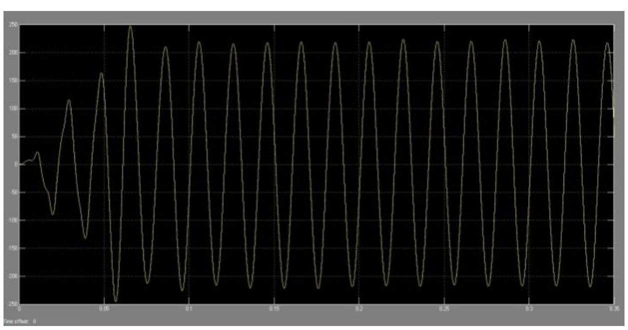

Figure 5.4: system output current per phase

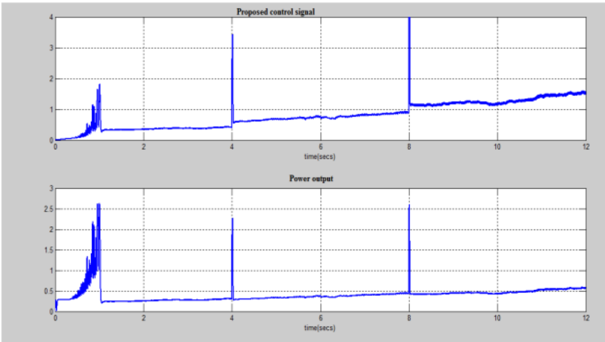

Fig 5. 5; system output corresponding control signal

For this experiment, we simulated proposed system and the inverter power corresponding input signal shown. Fig5.5 .. It can be seen how in proposed system produce maximum output .

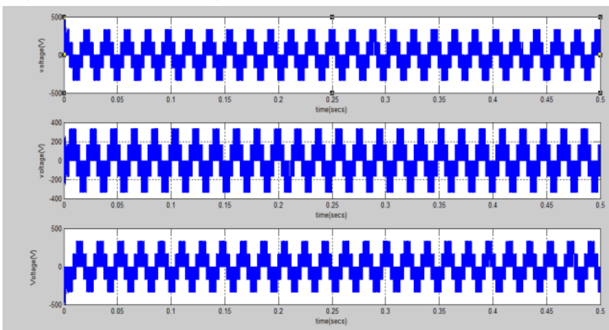

Fig 5.5 system output (3 phase)

Conclusion

An FLC-based MPPT scheme for the SEPIC converter and inverter system for PV power applications has been presented in this paper. A prototype SEPIC converter-based PV inverter System has also been built in the laboratory. ARM 7 LPC2142 Microcontroller is used for real-time implementation of the Proposed FLC and MPPT control algorithms. The performance Of the proposed controller has been found better than that of the Conventional PI-based converters. Thus, it reduces the cost of the Inverter and the associated complexity in control algorithms. Therefore, the proposed FLC-based MPPT scheme for the SEPIC converter could be a potential candidate for real-time PV inverter applications under variable load conditions

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