Three Phase Single Stage Transformer Less Grid Connected PV System

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Abstract— **In this paper, a three-phase single-stage current source inverter-based photovoltaic system for grid connection is proposed. The system utilizes transformer-less single-stage conversion for tracking the maximum power point and interfacing the photovoltaic array to the grid. The maximum power point is maintained with a fuzzy logic controller. A proportional-resonant controller is used to control the current injected into the grid. To improve the power quality and system efficiency, a double-tuned parallel resonant circuit is proposed to attenuate the second- and fourth- order harmonics at the inverter dc side. A modified carrier based modulation technique for the current source inverter is proposed to magnetize the dc-link inductor by shorting one of the bridge converter legs after every active switching cycle. Simulation and practical results validate and confirm the dynamic performance and power quality of the proposed system.**

Keywords— **CSI – Current Source Inverter, MPPT – Maximum Power Point Tracking, PV-Photo Voltaic, PWM – Pulse Width Modulation.**

I. Introduction

In conventional method, two stage converter using for control to interfacing the PV system to grid. The two stage converter consists of two conversion stages. The first stage is dc-dc converter for boosting and conditioning the PV constant (MPPT) output and second stage is dc-ac inverter for interfacing the PV to the grid. In two stages the conversion efficiency is less and the number of components more. The two stage converter needs more components and high isolation for boosting the solar power with MPPT. These drawbacks can be overcome by using this proposed method. Under normal operating condition, output power of a PV cell not much reduced. But under rapidly changing conditions, temperature and insulation is changed due to environmental conditions and affects the solar power. By measuring the instantaneous voltage and current from the solar, and compares with the reference values and maintains the maximum possible output power. This is done by using Fuzzy controller to perform the working of MPPT. Resonant Filter reduces the harmonics from the solar output and it's integrated to the grid through three phase PWM Inverter.

A single-stage inverter topology for grid connected PV systems. The proposed configuration can not only boost the usually low photovoltaic (PV) array voltage, but can also convert the solar dc power into high quality ac power for feeding into the grid, while tracking the maximum power from the PV array. Total harmonic distortion of the current, fed into the grid, is restricted as per the IEEE-519 standard. The proposed topology has several desirable features such as better utilization of the PV array, higher efficiency, low cost and compact size. Further, due to the very nature of the proposed topology, the PV array appears as a floating source to the grid, thereby enhancing the overall safety of the system. A survey of the existing topologies, suitable for single-stage, grid connected PV applications, is carried out and a detailed comparison with the proposed topology is presented. A complete steady-state analysis, including the design procedure and expressions for peak device stresses, is included. Necessary condition on the modulation index for sinusoidal pulse width modulated control of the proposed inverter topology has also been derived for discontinuous conduction mode operation. All the analytical, simulation and experimental results are presented [1-3].

A single-stage topology with improved features has been proposed. Relevant analysis, including derivations of the expressions for peak voltage and current stresses across the switching devices, has been performed and a design procedure has been presented. The topology is simple, symmetrical and easy to control. The other desirable The proposed configuration, operating in DCM, along with the conventional hill climbing MPPT scheme, is highly robust. This is because the operating voltage of the PV array can be controlled by varying . Also, there is a one-to-one relationship between the average operating voltages of the PV array [4-7].

The modelling method and the proposed circuit model are useful for power electronics designers who need a simple, fast, accurate, and easy-to-use modelling method for using in simulations of PV systems. In the first pages, the reader will find a tutorial on PV devices and will understand the parameters that compose the single-diode PV model. The modeling method is then introduced and presented in details. The model is validated with experimental data of commercial PV array [8].

It has analyzed the development of a method for the mathematical modeling of PV arrays. The objective of the method is to fit the mathematical *I–V* equation to the experimental *remarkable points* of the *I–V* curve of the practical array. The method obtains the parameters of the *I–V* equation by using the following nominal information from the array datasheet: open circuit voltage, short-circuit current, maximum output power, voltage and current at the MPPT, and current/temperature and voltage/temperature coefficients. This paper has proposed an effective and straightforward method to fit the mathematical *I–V* curve to the three (*V*, *I*) *remarkable points* without the need to guess or to estimate any other parameters except the diode constant *a*. A closed solution for the problem of finding the parameters of the single-diode model equation of a practical PV array. Other authors have tried to propose single-diode models and methods for estimating the model parameters, but these methods always require visually fitting the mathematical curve to the *I–V* points and/or graphically extracting the slope of the *I–V* curve at a given point and/or successively solving and adjusting the model in a trial and error process. Some authors have proposed indirect methods to adjust the *I–V* curve through artificial intelligence and interpolation techniques. Although interesting, such methods are not very practical and are unnecessarily complicated and require more computational effort than it would be expected for this problem [9-11].

Moreover, frequently in these models *R*s and *R*p are neglected or treated as independent parameters, which is not true if one wishes to correctly adjust the model so that the maximum power of the model is equal to the maximum power of the practical array. An equation to express the dependence of the diode saturation current *I*0 on the temperature was proposed and used in the model. The results obtained in the modeling of two practical PV arrays have demonstrated that the equation is effective and permits to exactly adjust the *I–V* curve at the open-circuit voltages at temperatures different from the nominal [12-20]. The cooperative control strategy of micro sources and the energy storage system (ESS) during islanded operation is presented and evaluated by a simulation and experiment. The ESS handles the frequency and the voltage as a primary control. And then, the secondary control in micro grid management system returns the current power output of the ESS into zero. The test results show that the proposed cooperative control strategy can regulate the frequency and the voltage, and the secondary control action can contribute to improve the control capability. In this paper, the cooperative control strategy of the micro sources and the ESS during islanded operation has been proposed. During islanding, the power balance between supply and demand does not match at the moment. As a result, the frequency and voltage of the microgrid will fluctuate, and the system can experience a blackout unless there is an adequate power-balance matching process. The controller of inverter in the ESS responds in milliseconds. Otherwise, the diesel generator, gas engine, and fuel cell have a relatively slow response time. In islanded operation, by proper power-balancing action of the ESS, the frequency and the voltage of the microgrid can be regulated at the normal values. However, the control capability for balancing between generation and consumption of the ESS may be limited by its available system capacity. Therefore, the power output of the ESS should be brought back to zero as soon as possible by the secondary control in MMS in order to secure the maximum controlling reserve. Dynamic modeling and simulations of the microgrid under the proposed control strategy were carried out using PSCAD/EMTDC[21].

The block diagram of the proposed system is shown in Fig. 1.

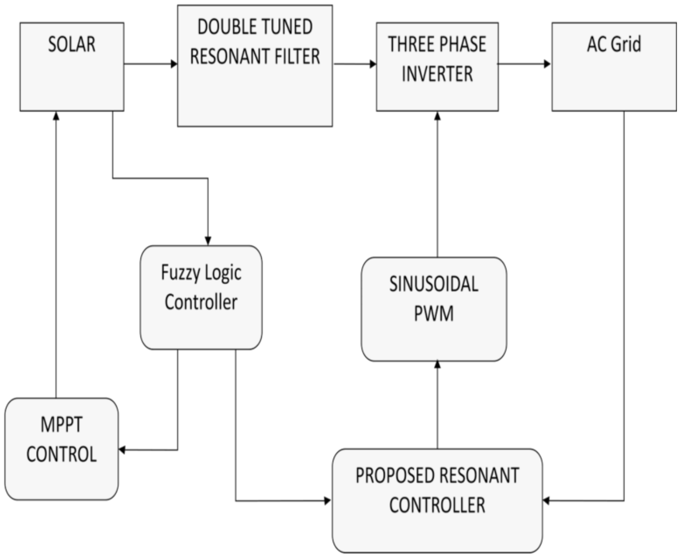

Fig. 1 Block diagram.

Solar produces electrical energy from light energy. It works on the principle of photo voltaic effect. Depending on climatic condition, solar power rapidly changes. Output power depends on amount of irradians and temperature present in the cell. As the solar power changes at every instant, it gives the poor efficiency of about 15 % only. Hence output is increased by increasing the size of the panel. But it needs more intial cost. Another way of getting the maximum power is to track the maximum possible power at every instant called “Maximum Power Point Tracking”. In this project Fuzzy Controller is used to track the maximum power from solar. Inverter converts smooth link DC current into AC. In order to reduce the harmonics adopt PWM technique called “Sinusoidal PWM” which compares reference signal with the carrier signal and produces the pulses to the inverter. A double-tuned parallel resonant circuit tuned at the second- and fourth-order harmonics and gives smooth DC link current.

II. DOUBLE TUNED RESONANT FILTER

The double tuned resonant filter is shown in Fig. 2

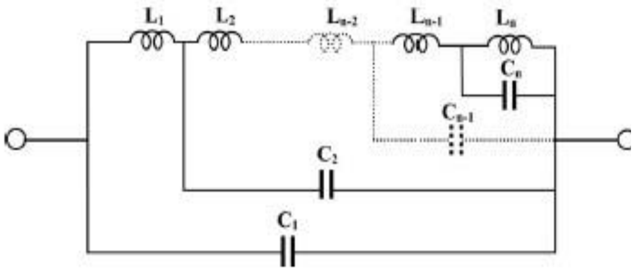

Fig. 2 Double Tuned Resonant Filter.

There are some networks that display both band pass and band stop characteristics.

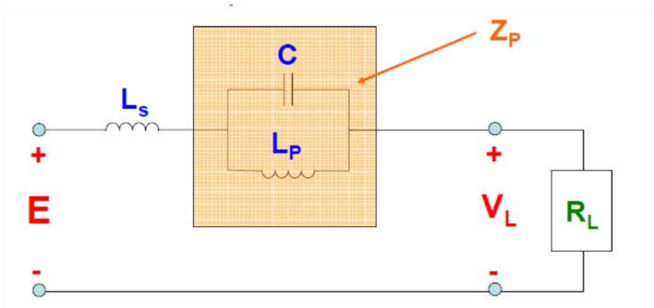

Fig. 3 Parallel Resonant Circuit.

The parallel resonance circuit represents a band stop filter having an impedance given by Equation (1).

$$Z_P = \frac{\left(\frac{1}{j\omega C}\right)\times(j\omega L_P)}{j\left(\omega L_P - \frac{1}{\omega C}\right)}$$

$$Z_P = \frac{\left(\frac{L_P}{C}\right)}{\left(\omega L_P - \frac{1}{\omega C}\right)}(-90°) \quad (1)$$

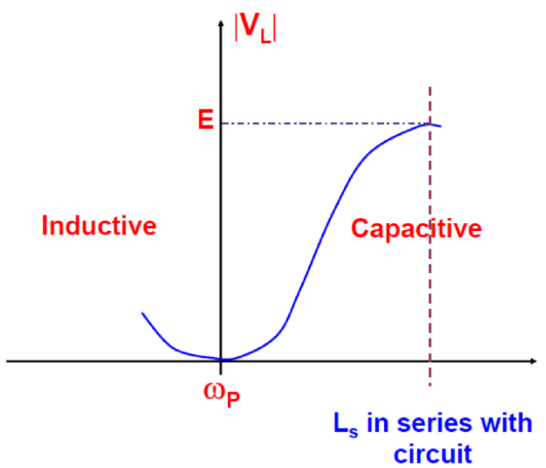

Fig. 4 Characteristics of Parallel resonance circuit.

Ls is designed to cancel the capacitance effect of the parallel resonance circuit such that |VL|=E (making a band pass filter at this frequency. If the frequency required to be accepted is below resonance, a condenser Cs is used. Actual coils will include resistances that must be taken in consideration when calculating the amplitudes at the accepted and rejected frequencies.

$$Z_P = \frac{R_P}{1+jQ\Omega} = R \pm jX \quad (2)$$

At resonance $\Omega = 0$

At $\omega < \omega_p$ $\quad \Omega = -ive, Z_P\ is\ inductive.$

At $\omega > \omega_p$ $\quad \Omega = +ive, Z_P\ is\ capacitive.$

The series resonance circuit is shown in Fig. 5.

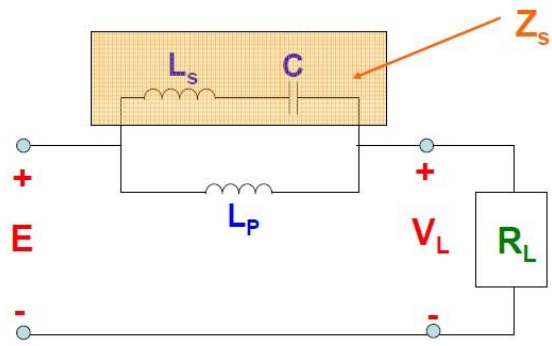

Fig. 5 Series resonance circuit.

The above circuit having an impedance given by Equation (3).

$$Z_S = j\left(\omega L_S - \frac{1}{\omega C}\right) = \left(\omega L_S - \frac{1}{\omega C}\right)(90°) \quad (3)$$

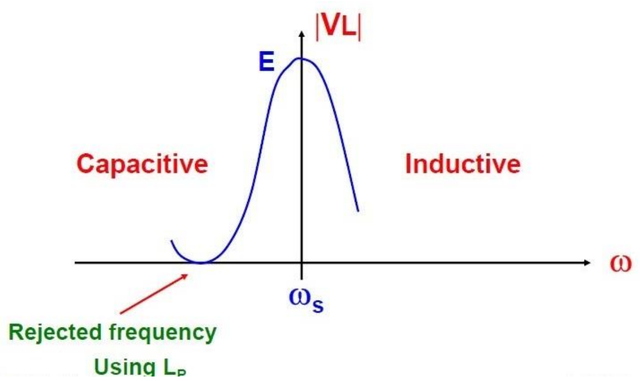

Fig. 6 Characteristics of Series resonance circuit.

To reject a frequency below ωs, use a coil LP to make parallel resonance (band stop filter) 2. To reject a frequency above ωs use a capacitor CP for the same purpose. Actual coils will include resistances that must be taken in consideration when calculating the amplitudes at the accepted and rejected frequencies.

III. PI CONTROLLER

A.PI controller

It is an algorithm that can be implemented without resorting to any heavy control theory. The aim of such an algorithm is to determine the plant input (in our case the stator voltage frequency) that will make the measured output (in our case the speed of the rotor) reach the reference (the speed the user wishes to have). PI stands for Proportional and Integral, two terms, which describe two distinct elements of the controller: - a proportional term, which is equal to the product of the error signal (the measured plant output subtracted to the reference) by a constant called the proportional gain. The proportional term mainly determines the short-term behavior of the controller since it determines how the controller strongly reacts to reference changes; - an integral term, which adds long-term precision to the controller. This term is the product of the sum of all the previous error signal values by a constant called the integral gain. This sum keeps all the previous error signal values in memory, and evolves as long as the error is not zero. It allows the controller to cancel the difference between the measured output and the reference, but it usually makes the closed loop system slower and decreases its stability, however. These two terms are sometimes added to a third one, proportional to the derivative of the error signal. The resulting regulator is then called a PID (Proportional, Integrator and Derivative). To control the speed of and induction motor by the V/f principle, this third term is not useful. It increases the speed of the closed loop, but it also derivates noises and it decreases the stability of the closed loop. So, the D term is tricky to adjust.

B. Technical Description

The proposed converter is designed to be a power conditioning unit for a fuel cell powered systems. It is characterized by low voltage and high current values, which normally results in high losses of the system. Thus, serious attention should be paid to loss reduction not only in conductors but also in the semiconductor switches of the inverter. Losses in IGBT switches can be significantly reduced by proper control methods. One of the benefits that the qZS topology offers is soft switching without additional components. The number of soft switching transients achievable depends mostly on the modulation method. In some cases both zero current switching (ZCS) and zero voltage switching (ZVS) are possible over full operation range Two basic shoot-through control techniques for the qZS-based dc/dc converter were recently proposed: pulse width modulation (PWM) and phase shift modulation (PSM). In both cases, shoot-through is generated during zero states. The zero and shoot-through states are spread over the switching period so that the number of higher harmonics in the transformer primary could be reduced. To reduce switching losses of the transistors, the number of shoot-through states per period is limited by two. Moreover, to decrease the conduction losses of the transistors, shoot-through current is evenly distributed between both inverter legs. According to both methods (PWM, PSM) are fairly identical in terms of conduction losses since the number of conduction states and their duration remain unchanged. However, due to an increased number of hard-switched commutations in the case of the PSM shoot-through control method, switching losses were increased by more than 20%. Moreover,

Taking all that into account, PWM control seems to be the best control method for the qZS-based dc/dc converter. The only problem with the PWM shoot-through control is that it imposes unequal operating frequencies of the transistors, which results in unequal switching losses. Today’s major trend in power electronics is to increase efficiency. It is only achievable by optimizing operation parameters and components of a converter. One should avoid over- or under-loaded components. That is the reason why in the current research focus is on equalizing switching losses in the qZS inverter.

C. Controlling Technique- PWM Control with Shifted Shoot-Through

This modulation technique was proposed by the authors an alternative to the conventional PWM control that was explained previously. To equalize transistor switching losses, the shoot-through states are shifted towards active states. As a result, there is one switching transient less for bottom side transistors, as indicated in Table I. The states are shown for one period of the isolation transformer. As it can be seen, bottom side transistors have now two times higher operating frequency compared to the top side transistors. However, shoot-through states remain inside zero states, which is the condition required to keep the transformer voltage unchanged.

TABLE I
SHOOT THROUGH STATES

Parameters	Value
Input voltage, U_{IN}	30 V
Desired DC Link voltage, U_{DC}	60 V
Load Resistance, R_{load}	300 ohm
Operating frequency of qZS-network, f_{qZS}	30 kHZ
Operating frequency of transformer, f_{Tr}	15 kHZ
Shoot through state, t_s	8.3 µs
Active state, t_A	33.3 µs
Zero State, t_Z	8.3 µs
Inductances *L1* and *L2*	50 µH
Capacitances C1 and *C2*	240 µF
Transformer turns ratio	1:5

IV. FUZZY LOGIC

Fuzzy logic control has found many applications in the past decade. This is so largely because fuzzy logic control has the capability to control nonlinear, uncertain system even in the case where no mathematical model is available for the control system. The advantage of fuzzy logic controller is to provide an effective means of handling the approximate and inexact nature of the real world. The fuzzy logic also has features such as the resemblance to human thinking and the usage of natural language. With these features the fuzzy logic is applied to the control field, and the fuzzy logic has become a field of intelligent control and one of the emerging parts of research.

A. Fuzzy control system design

Fuzzy control provides a formal methodology for representing, manipulating, and implementing a human's heuristic knowledge about how to control a system.

The fuzzy controller has four main components:

The "rule-base" holds the knowledge, in the form of a set of rules, of how best to control the system, The inference mechanism evaluates which control rules are relevant at the current time and then decides what the input to the plant should be, The fuzzification interface simply modifies the inputs so that they can be interpreted and compared to the rules in the rule-base and The defuzzification interface converts the conclusions reached by the inference mechanism into the inputs to the plant.

Mean of maxima in this project we are using fuzzy controller for get constant charging current. For obtaining fuzzy controller in MATLAB, some procedure is to do in fuzzy interface system in MATLAB. We can use five primary graphical user interface tools for building, editing, and observing FIS in the toolbox.

B. Fuzzy Inference System Editor

The FIS editor handles the high level issues for the system .Fuzzy tool box does not limit the number of inputs. The FIS editor displays information about fuzzy interference system.

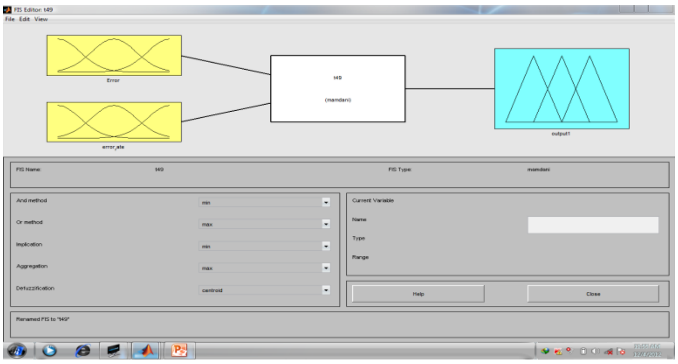

Fig. 7 FIS editor.

The diagram shows names of the each input variable at the left, and those output variables on the right. The sample membership functions shown in the boxes are just icons and do not depict the actual shapes of the system. The FIS editor handles the high level issues for the system.

C. Membership Function editor

The Membership Function editor is used to define to define the shapes of all the membership functions associated with each variable. Here error and error rate values is divided between -100 and 100 with seven variables. The name seven variables are Negative Small (NS), Negative Medium (NM) Negative Big (NB), Positive Small (PS), Positive Medium (PM), Positive Big (PB).Range can adjusted with suitable values.

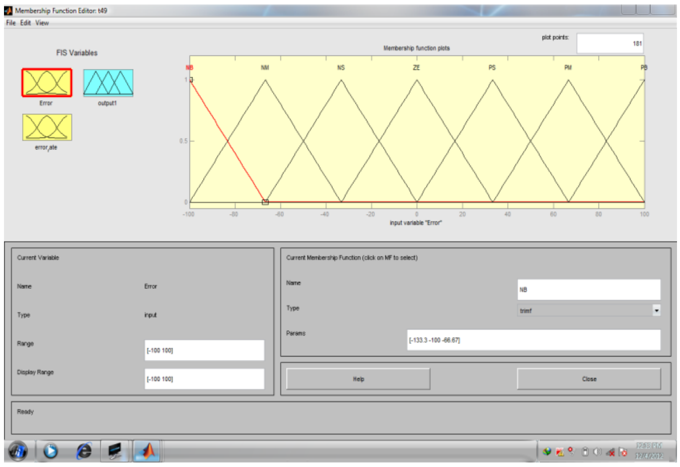

Fig. 8 Membership function Editor.

D. Rule Table

Basically a linguistic controller contains rules in the If-then format. Here used seven variables for one input, then totally 49 rules.

TABLE II
RULE TABLE

ERROR RATE / ERROR	NB	NM	NS	ZE	PS	PM	PB
NB	ZE	PS	PS	PM	PM	PB	PB
NM	NS	ZE	PS	PS	PM	PM	PB
NS	NS	NS	ZE	PS	PS	PM	PM
ZE	NM	NS	NS	ZE	PS	PS	PM
PS	NM	NM	NS	NS	ZE	PS	PS
PM	NB	NM	NM	NS	NS	ZE	PS
PB	NB	NB	NM	NM	NS	NS	ZE

E. Rule editor

The Rule Editor is for editing the list of rules that defines the behavior of the system. Rule base consist of If –then rules which tie the inputs with the outputs. Using if –then rules, stored in the rule base, convert fuzzy inputs to fuzzy output. Here we are using two parameters error and error rate, which is scaled Negative Small (NS),Negative Medium(NM) ,Negative Big(NB),Positive Small(PS),Positive Medium(PM),Positive Big(PB).Depending these variables we are creating or editing rule editor.

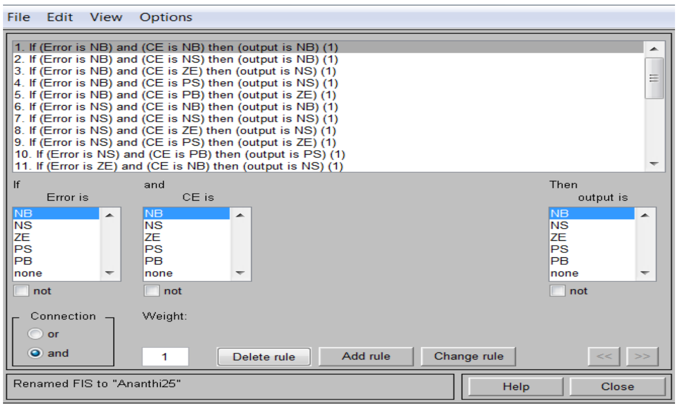

Fig. 9 Rule Editor.

V. SIMULATION

A. Solar design

The proposed solar design, MPPT design and the corresponding output is shown in Fig. 9, Fig. 10 and Fig. 11 respectively.

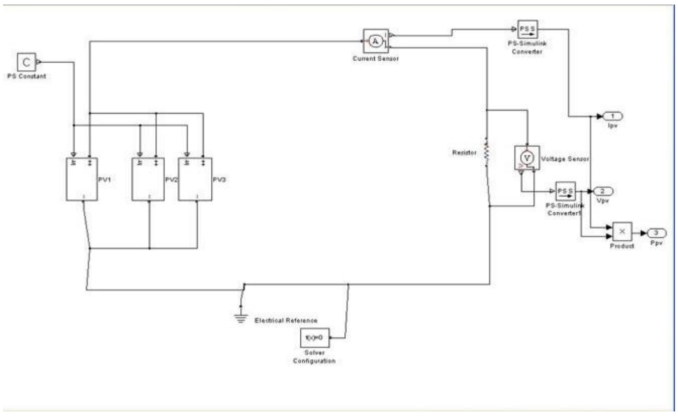

Fig. 10 Solar design.

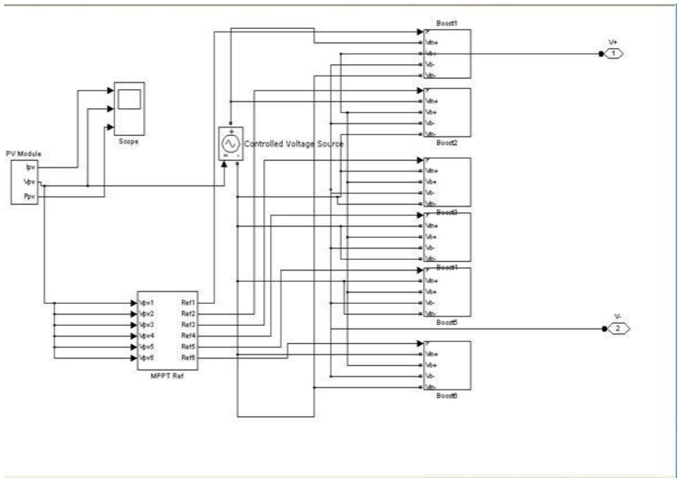

Fig. 11 MPPT Design.

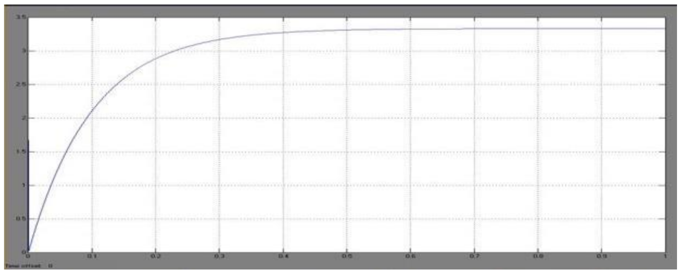

Fig. 12 Solar output.

The PWM output of above system is shown in Fig. 12

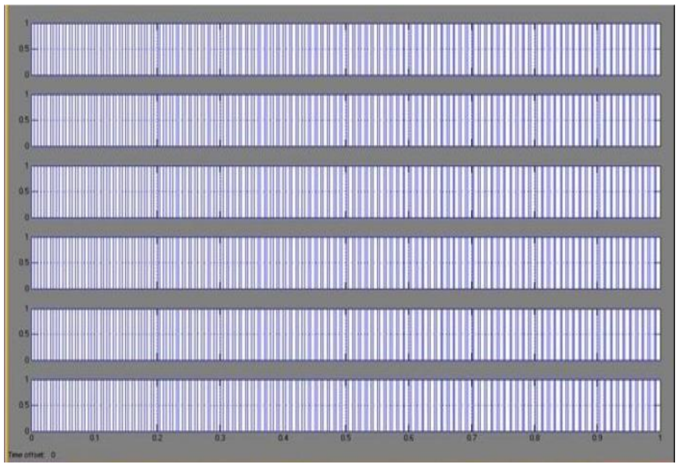

Fig. 13 PWM Output.

B. Design of proposed system

The MATLAB design and the Fuzzy based design is shown in Fig. 13 and Fig. 14 respectively.

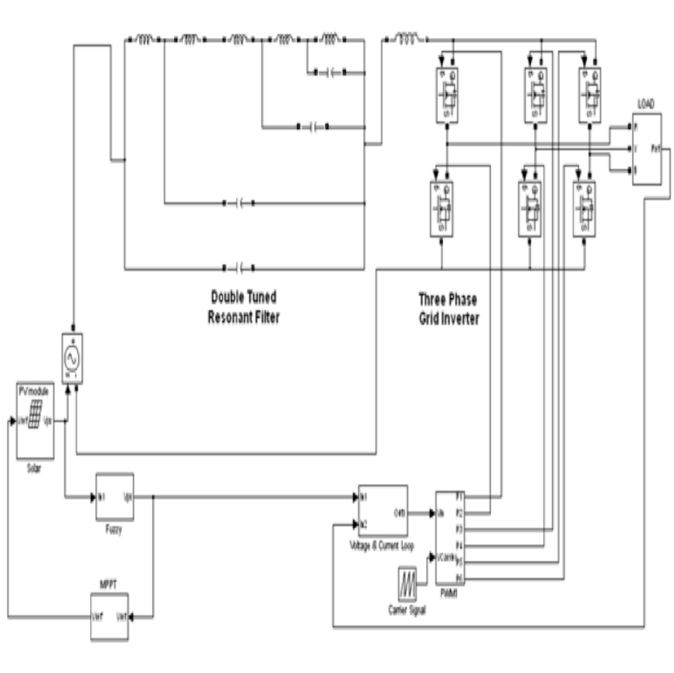

Fig. 14 MATLAB design of proposed system.

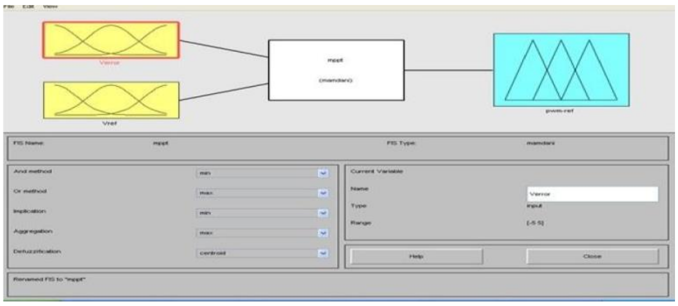

Fig. 15 Fuzzy based design.

The final output phase voltages of the proposed system is shown in Fig. 15.

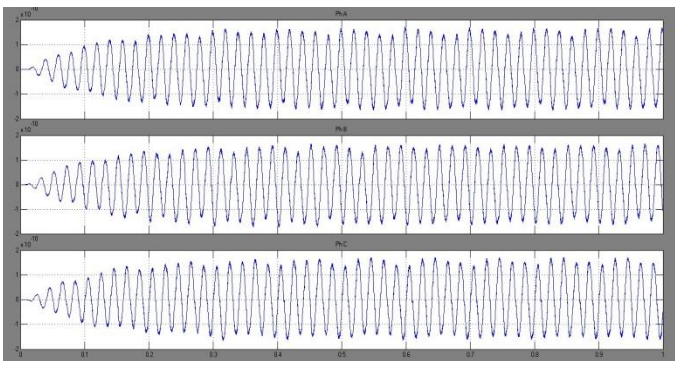

Fig. 16 Final output phase voltages.

VI. CONCLUSION

A single-stage single-phase grid-connected PV system using a CSI has been proposed that can meet the grid requirements without using a high dc voltage or a bulky transformer. The control structure of the proposed system consists of MPPT, a current loop, and a voltage loop to improve system performance during normal and varying weather conditions. Since the system consists of a single-stage, the PV power is delivered to the grid with high efficiency, low cost, and small footprint. A modified carrier-based modulation technique has been proposed to provide a short circuit current path on the dc side to magnetize the inductor after every conduction mode. Moreover, a double-tuned resonant filter has been proposed to suppress the second- and fourth-order harmonics on the dc side with relatively small inductance. The THD of the grid- injected current was 1.5% in the simulation and around 2% practically. The feasibility and effectiveness of the proposed system has been successfully evaluated with various simulation studies.

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