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Photovoltaic Micro-Inverter System Using Repetitive Current Control

M.Ananthi[1], C.Vennila[2]

[1]PG Scholar,Department of Electrical and Electronics Engineering , Alagappa Chettiar College of Engineering & Technology, Karaikudi – 630004.India

[2] Department of Electrical and Electronics Engineering , Alagappa Chettiar College of Engineering & Technology, Karaikudi – 630004.India

Abstract—**This paper presents a Photovoltaic Micro inverter System with Repetitive Current Control Technique. The Boost Converter is also used to step up the input voltage magnitude without the use of transformer. A MPPT technique ramps up the PV voltage reference accordingly. Fuzzy logic control is used for this proposed method. A MATLAB simulation was carried out to verify the performance of the system.**

Index Terms- **MPPT – Maximum Power Point Tracking, PV – Photo Voltaic.**

INTRODUCTION

The concept of micro inverter has become a future trend for single-phase grid-connected photovoltaic (PV) power systems for its removal of energy yield mismatches among PV modules, possibility of individual PV-module-oriented optimal design, independent maximum power point tracking (MPPT),and “plug and play” concept . In general, a PV micro inverter system is often supplied by a low-voltage solar panel, which requires a high-voltage step-up ratio to produce desired output ac voltage. Hence, a dc–dc converter cascaded by an inverter is the most popular topology, in which a HF transformer is often implemented within the dc–dc conversion stage.

In terms of the pulse width modulation techniques employed by the PV micro inverter system, two major categories are attracting most of the attentions. In the first, PWM control is applied to both the dc–dc converter and inverter In addition, a constant voltage dc link decouples the power flow in the two stages such that the dc input is not affected by the double-line-frequency power ripple appearing at the ac side .By contrast, the second configuration utilizes a quasi-sinusoidal PWM method to control the dc–dc converter in order to generate a rectified sinusoidal current at the inverter dc link. Accordingly, a line-frequency-commutated inverter unfolds the dc-link current to obtain the sinusoidal form synchronized with the grid. Although the latter the advantage of higher conversion efficiency due to the elimination of HF switching losses at the inverter, the double line-frequency power ripple must be all absorbed by the dc input capacitor, making the MPPT efficiency compromised unless a very large capacitance is used. Moreover, the dc–dc conversion stage requires more challenging control techniques to meet the grid current regulation requirement. Therefore, in terms of the MPPT performance and output current quality, the first category of PV micro inverter is more appropriate and will be adopted. The proposed current control scheme consists of a conventional PI and a plug-in repetitive controller. On the basis of the mathematical model of the three-phase pulse width-modulated (PWM) boost rectifier under the generalized supply voltage conditions, the control task is divided into: 1) dc-link voltage harmonics control and 2) line-side current harmonics control. In the voltage harmonics control scheme, a reference current calculation algorithm has been derived accordingly to ensure that the dc link voltage is maintained constant at the demanded value and the supply-side power factor is kept close to unity. In the line-side current harmonics control scheme, a plug in Repetitive controller is designed to achieve low total harmonic distortion (THD) line-side currents of the three-phase PWM boost rectifier[1-2].

A novel control strategy for grid-connected voltage source inverters (VSI) with an LCL-filter is proposed. By splitting the capacitor of LCL-filter into two parts proportionally, a new current Feedback control is introduced. In this way, the inverter control system can be degraded from third-order to first-order, the open loop gain and the bandwidth can be increased, and the close-loop control system can easily optimized for minimum steady-state error and current harmonic distortion. Compared with the traditional strategies, the new control strategy has the superiority of simple, low cost and size, high efficiency, and its adaptability to single-phase r three-phase inverters. Thus, the new current control strategy is more attractive to grid-connected PV, fuel cell, and wind generation systems [3].

PV energy is one of the favourable renewable energy resources for the mankind and MIC has been proved to be one of the important enabling technologies in PV utilization. A variety of topologies which have been proposed in the recent publications for the MICs with ratings up to 500 W are reviewed in the paper. Different MIC topologies are categorized into three arrangements based on the dc link configurations. Finally, the important advantages and disadvantages of the individual MIC arrangements are also discussed in detail [5]. A two-layer current control structure has been proposed. The outer layer uses a repetitive control algorithm to give good tracking of periodic signals such as harmonic currents. This layer works out the current reference for the inner current-control loop. The latter achieves practically-decoupled control of - and -axis filter currents in order to fulfil the outer loop goals. All the controllers have been digitally implemented [6].

A novel flyback-type utility interactive inverter circuit topology suitable for ac module systems when its lifetime under high atmospheric temperature is taken into account. A Most distinctive feature of the proposed system is that the decoupling of power pulsation is executed by an additional circuit that enables employment of film capacitors with small capacitance not only for the dc input line but also for the decoupling circuit, and hence the additional circuit is expected to extend the lifetime of the inverter. The proposed inverter circuit also enables realization of small volume, light weight, and stable ac current injection into the utility line. A control method suitable for the proposed inverter is also proposed [7].

A novel repetitive controller that can be directly combined with an SPWM inverter is proposed. The system is simple in structure because there is no instantaneous feedback inner loop. High-resonant peak of the open-loop inverter is compensated with a zero-phase shift notchfilter, which enables larger tolerance to parameter variations than the inverse transfer function of the inverter; and makes the harmonic rejection capability less affected when compared with a conventional second-order filter. Fast error convergence is achieved with appropriate time-advance compensation of the delay within the system .The proposed controller design method enables robust stability by restricting the cancellation within medium-and-low-frequency range while heavily attenuating the high-frequency gains.[8]

A novel technique using a SEPIC or Cuk converter to efficiently track the MPP of a solar panel has been presented. The technique is simple and elegant and does not require complicated mathematical computation, hardware implementation, microprocessor, or digital signal processor. The tracking capability of the proposed technique has been verified experimentally with a 10-W solar panel at different radiation levels[9].

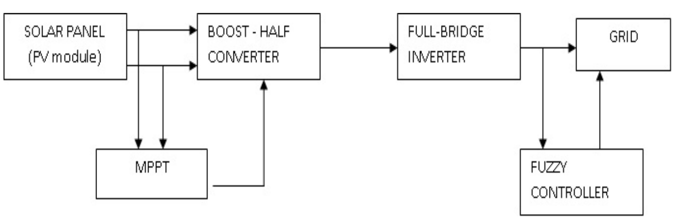


Fig. 1 Block diagram.

The paper has been organized as follows: Chapter II gives an overview of PV cell. Chapter III describes the proposed method of Repetitive control, Chapter IV describes the boost half bridge converter and full bridge inverter. Chapter V explains the fuzzy controller. Chapter VI explains the MATLAB simulation and its results. Finally, summarization of this work is presented in Chapter VII.

I. PV CELL

The simplest model of PV cell is shown as an equivalent circuit below that consists of an ideal current source in parallel with an ideal diode. The current source represents the current generated by photons (often denoted as Iph or I_L), and its output is constant under constant temperature and constant incident radiation of light. There are two key parameters frequently used to characterize a PV cell. Shorting together the terminals of the cell, the photon generated current will follow out of the cell as a short-circuit current (I_{sc}).Thus, $I_{ph} = I_{sc}$. When there is no connection to the PV cell (open-circuit), the photon generated current is shunted internally by the intrinsic p-n junction diode. This gives the open circuit voltage (V_{oc}). The PV module or cell manufacturers usually provide the values of these parameters in their datasheets

$$I = I_{lg} - I_{os} * \left[e^{\{q*(V+I*R_s)/AkT\}} - 1\right] - (V + I * R_s)/R_{sh} \quad (1)$$

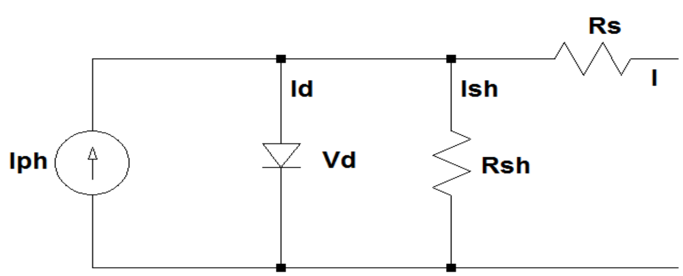
Where,

$$I_{os} = I_{or} * \frac{T}{T_r}^3 * \left[e^{\left\{q*E_{go}*(\frac{1}{T_r}-\frac{1}{T})/A*k\right\}}\right] \quad (2)$$

$$I_{lg} = \{I_{scr} + Ki * (T - 25)\} * \lambda \quad (3)$$

Fig. 2 Single Diode model of solar Cell.

I & V : Cell Output Current and Voltage
Ios : Cell reverse saturation current;
T : Cell temperature in Celsius;
K : Boltzmann's constant, $1.38 * 10^{-19}$ J/K;
Q : Electron charge, $1.6*10^{-23}$ C;
Ki : Short circuit current temperature coefficient.
λ : Solar irradiation in W/m^2;
Iscr : Short circuit current at 25 degree Celsius;
Ilg : Light-generated current;
Ego : Band gap for silicon;
A : Ideality factor
Tr : Reference temperature;
Ior : Cell saturation current at Tr;
Rsh : Shunt resistance;
Rs : Series resistance;



The characteristic equation of a solar module is dependent on the number of cells in parallel and number of cells in series. It is observed from experimental results that the current variation is less dependent on the shunt resistance and is more dependent on the series resistance.

Fig. 2 Single Diode model of solar Cell.

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II. REPTITIVE CONTROL

Repetitive control is useful if periodic disturbances act on a control system. Perfect (asymptotic) disturbance rejection is achieved if the period-time is exactly known. For those cases where the period-time changes and cannot be measured directly by an auxiliary signal, a robust repetitive controller structure is proposed. It uses multiple memory-loops in a certain feedback con3guration, such that small changes in period-time do not diminish the disturbance rejection properties.

The internal model principle states that for asymptotically tracking a reference command by the output of a closed-loop system, a realization (model) of the disturbance=reference generating system should be included in the feedback loop. As a well-known example, signals with a DC (! = 0) content can be modelled using an integrator, and inclusion of integral action in the feedback controller prevents steady-state errors for constant references and disturbances. A discrete time integrator is a positive feedback over one delay, implying that one memory location is used to store the integral value. With zero input the integral value updates itself bythe positive feedback loop.

III . BOOST CONVERTER

Boost converter steps up the input voltage magnitude to a required output voltage magnitude without the use of a transformer. The main components of a boost converter are an inductor, a diode and a high frequency switch. These are in a co-ordinated manner supply power to the load at a voltage greater than the input voltage magnitude. The control strategy lies in the manipulation of the duty cycle of the switch which causes the voltage change.

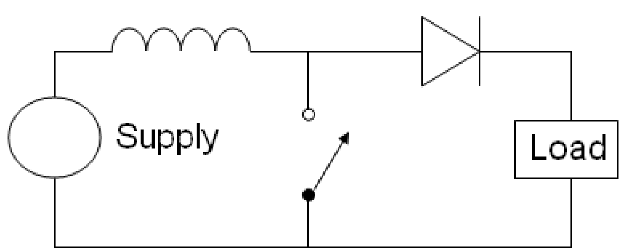


Fig. 3 Boost converter.

A. Modes Of Operation

There are two modes of operation of a boost converter. Those are based on the closing and opening of the switch. The first mode is when the switch is closed; this is known as the charging mode of operation. The second mode is when the switch is open; this is known as the discharging mode of operation.

In the charging mode, the switch is closed and the inductor is charged by the source through the switch. The charging current is exponential in nature but for simplicity is assumed to be linearly varying. The diode restricts the flow of current from the source to the load and the demand of the load is met by the discharging of the capacitor.

In the discharging mode, the switch is open and the diode is forward biased. The inductor now discharges and together with the source charges the capacitor and meets the load demands. The load current variation is very small and in many cases is assumed constant throughout the operation.

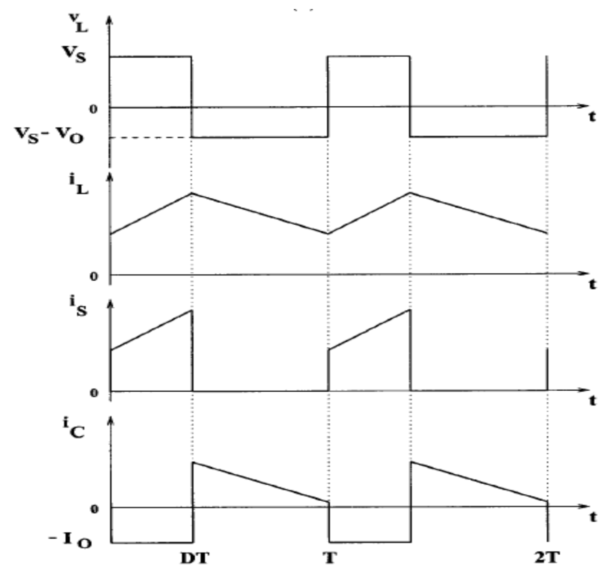


Fig. 4 Waveforms.

B. Maximum Power Point Tracking

The efficiency of a solar cell is very low. In order to increase the efficiency, methods are to be undertaken to match the source and load properly. One such method is the Maximum Power Point Tracking (MPPT). This is a technique used to obtain the maximum possible power from a varying source. In photovoltaic systems the I-V curve is non-linear, thereby making it difficult to be used to power a certain load. This is done by utilizing a boost converter whose duty cycle is varied by using an mppt algorithm. A boost converter is used on the load side and a solar panel is used to power this converter.

IV. FUZZY CONTROLLER

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.

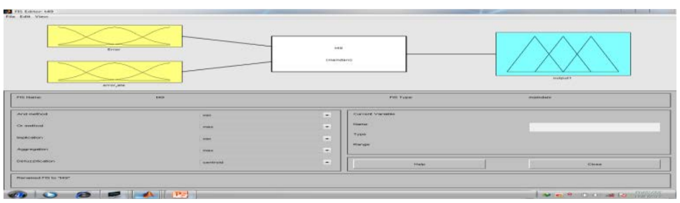


Fig. 5 FIS editor.

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.

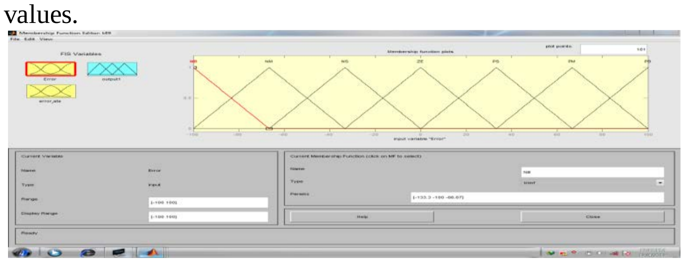


Fig. 6 Membership function Editor.

D. Rule Table

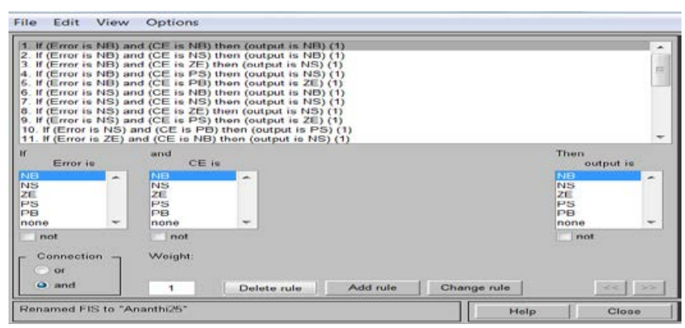
Basically a linguistic controller contains rules in the If-then format. Here used seven variables for one input, then totally 49 rules.

TABLE I
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. 7 Rule Editor.

V. SIMULATION AND RESULTS

A. Simulation diagrams

The Table – II shows the specifications for the solar cell.

PARAMETER	SPEICIFICATION
Short-circuit current	5.45A
Open-circuit voltage	22.2V
Current at Pmax	4.95A
Voltage at Pmax	17.2V
Maximum Power	85.14W

TABLE – II
SPECIFICATION OF SOLAR CELL

The simulation diagrams for the solar photovoltaic system, PI controller, sliding mode controller, Boost half bridge converter, repetitive current control, grid side inverter, fuzzy controller are shown from Fig. 8 to Fig.14 respectively.

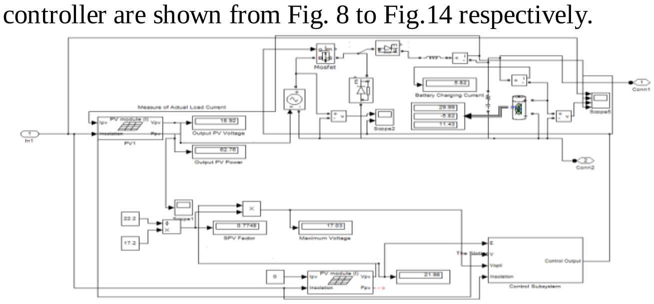


Fig. 8 Simulation of Solar Photovoltaic System.

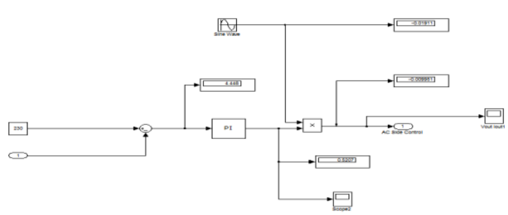


Fig. 9 Simulation of PI controller.

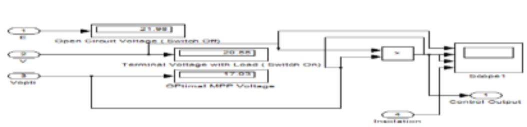


Fig. 10 Simulation of SMC Method.

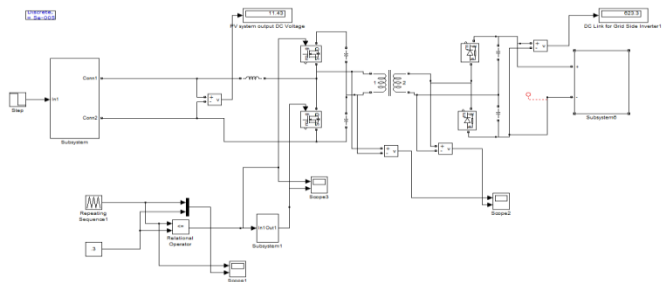


Fig. 11 Simulation Diagram of Boost-Half Bridge Converter.

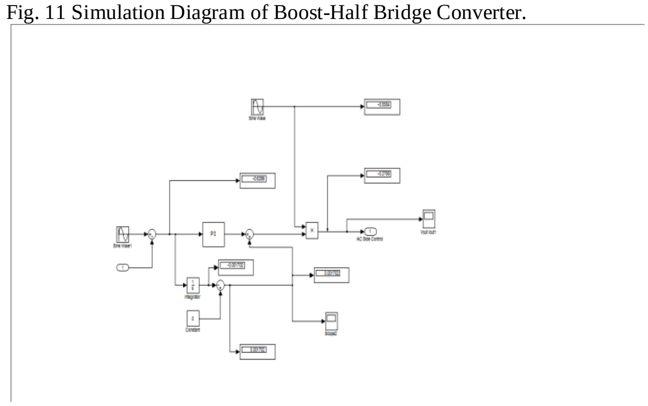


Fig.12 Simulation diagram of RCC method.

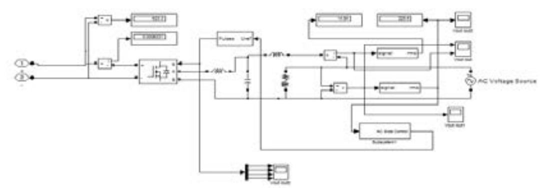


Fig. 13 Grid side inverter.

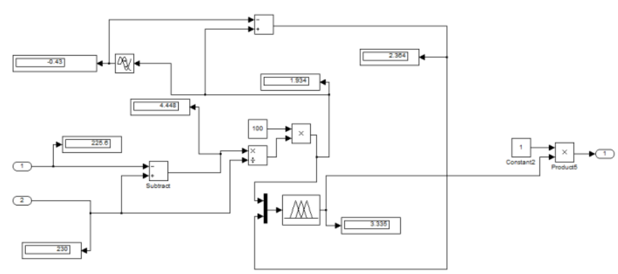


Fig. 14 Simulation of fuzzy controller.

B. Simulation results

The simulation results of PV cell, gating signals for the converter, full bridge inverter with PI controller is shown from Fig. 15 to Fig. 17 respectively.

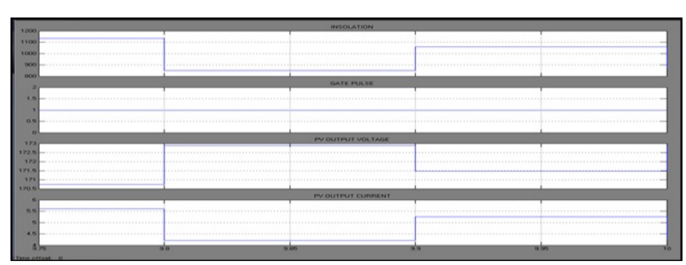


Fig. 15 Simulation Result of Solar Photovoltaic System using PI Controller.

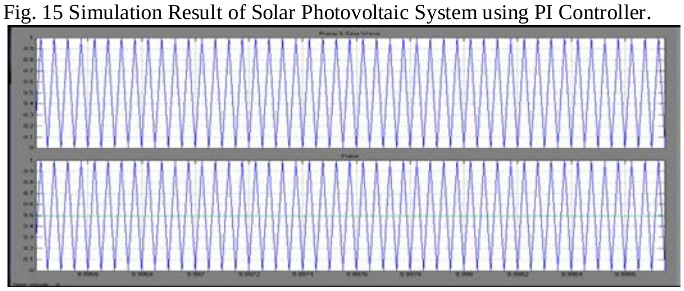


Fig. 16 Simulation for boost half bridge converter Gating Signal.

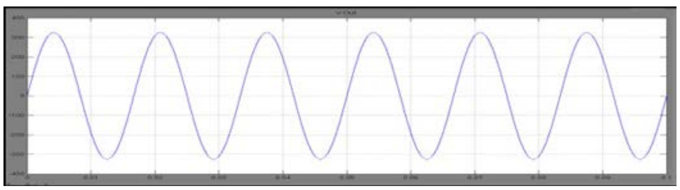


Fig.17 Simulation Result of grid side inverter.

The simulation results of PV cell, gating signals for the converter, full bridge inverter with Fuzzy controller is shown from Fig. 18 to Fig. 20 respectively.

Fig. 18 Simulation result of PV system.

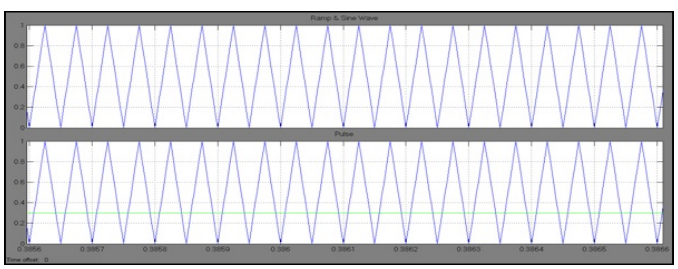


Fig. 19 Simulation result of Boost converter.

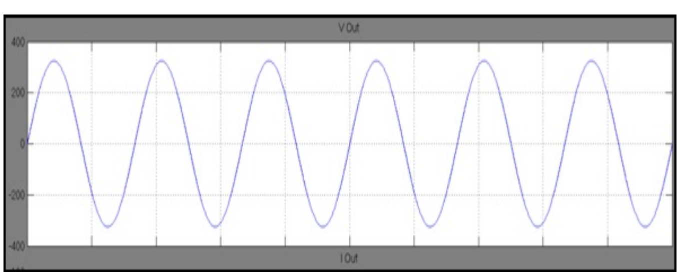


Fig. 20 Simulation result of grid side inverter.

VI. CONCLUSION

In this project, a novel boost-half-bridge micro inverter for grid-connected PV systems has been presented. High power factor and very low total harmonic distortions are guaranteed under both heavy load and light load conditions. Dynamic stiffness is achieved when load or solar irradiance is changing rapidly. Finally, the customized MPPT method that generates a ramp-changed reference for the PV voltage regulation guarantees a correct and reliable operation of the PV micro inverter system.

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