JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

SINGLE STAGE SINGLE PHASE PHOTOVOLTAIC SYSTEM TO THE GRID

[1]K.Revathi Ramana Kumar, [2] K. Padma

[1]Master of Technology, [2]Professor, Master of Engineering,Ph.D
[1]Department of Electrical Engineering,
[1]Andhra University College of Engineering, Visakhapatnam, India

Abstract:
In this paper the issue of control strategies for single-stage photovoltaic (PV) Grid connected inverter is addressed. Two different current controllers have been implemented and an experimental comparison between them has been made. A complete control structure for the single-phase PV system is also presented. The main elements of the PV control structure are: - a maximum power point tracker (MPPT) algorithm using the incremental conductance method; - a synchronization method using the phase-locked-loop (PLL), based on delay; - the input power control using the dc voltage controller and power feed-forward; - and the grid current controller implemented in two different ways, using the classical proportional integral (PI) and the novel proportional resonant (PR) controllers.

Keywords :Photovoltaic, MPPT algorithm, Boost converter, H- Bridge Inverter, PLL Structure, PR controller, PI controller, lcl filters.

1. Introduction

The market for PV power applications continues to develop at a high rate. Between 2000 and till now the total installed capacity in the International Energy Agency (IEA) Photovoltaic Power Systems (PVPS) countries grew by 36 %, reaching MW of solar power now a days. Moreover, the price level of the PV modules and the system costs (inverter included) has decreased significantly. The use to PV systems connected in parallel with the mains was simplified and is often supported by incentives from utilities and/or governmental bodies. Before connecting a PV system to the power network, the dc voltage of the solar modules must be converted into an ac voltage. Some protection systems are required to prevent damage in the PV system caused by the utility network and vice versa. The PV systems require standards addressing the use and the performance of grid-connected PV inverters, thus ensuring the safety and quality of the manufacture.

The purpose of the power electronics in PVPS is to convert the dc current from the PV panels into ac current to the grid, with the highest possible efficiency, the lowest cost and to keep a superior performance. The basic interfacing is shown in Fig. 1.

A controversial issue for PV inverters is the harmonics level. The IEEE 929 standard permits a limit of 5% for the current total harmonic distortion (THD) factor with individual limits of 4% for each odd harmonic from 3rdto 9th and 2% for 1lth to 15th while a recent draft of European IEC61727 suggests almost the same thing as previously mentioned. These levels are far more stringent than other domestic appliance.

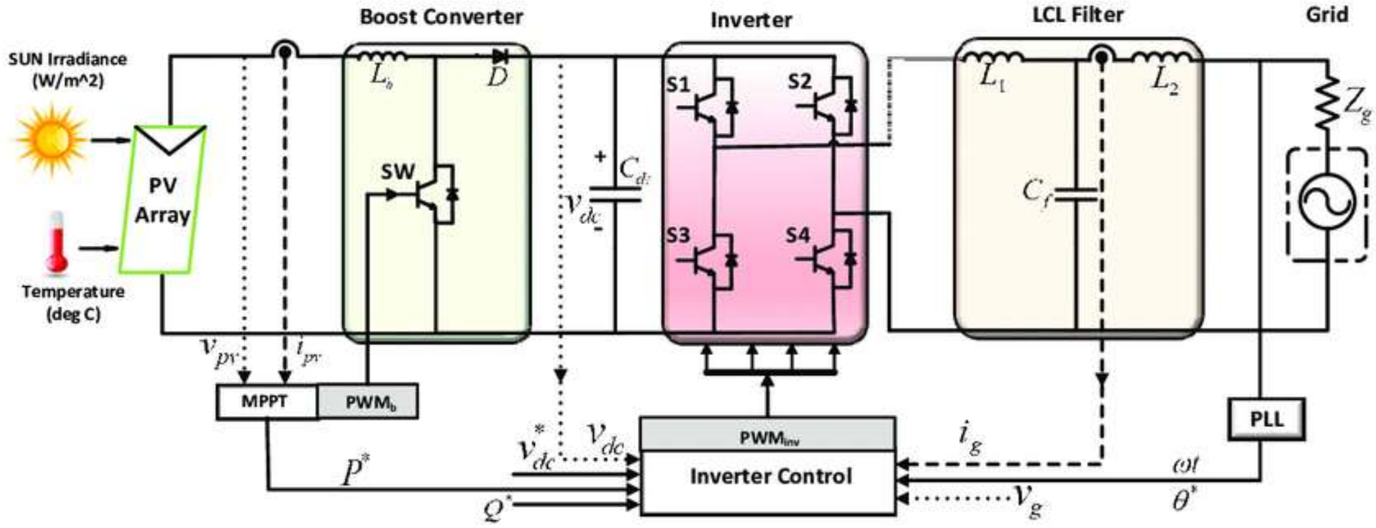


Figure 1. Grid integration with Photo Voltaic (PV) with LCL filter.

PV system and battery storage system operate parallel at DC link. PV system operates with fuzzy logic MPPT [5] method using boost converter. The PV panel supplies power to DC grid. The bidirectional converter operates in two modes; in the presence of DC grid, the battery is being charged, and in the absence of the DC grid, the battery supplies power to the grid. A single phase voltage source inverter is used to convert DC – AC using proportional integral and proportional resonant controller. The details of the control architecture and converters implementation are discussed in Section II to IV. The simulation results are presented and explained considering the output waveforms as shown in Section V.

2. Calculation of Boost converter Parameters:

To calculate the parameters of boost converter consider the parameters of PV module.

Power at maximum point(P_{mp})	2000W
Open circuit voltage(V_{oc})	44.86V
Voltage at maximum point (V_{mp})	37.73V
Short circuit current(I_{sc})	5.5A
Current at maximum point(I_{mp})	5.04A
Irradiance	1000
Operating temperature	25^0C

Table 1: Parameters of PV module.

In conventional converter the input voltage is fixed or constant as the ripple voltage and ripple currents are normally given or known. So parameters of a conventional boost converter can be calculated using below equations. In a normal condition, i.e. when the solar irradiance on the entire PV array is uniform, the power-voltage (P-V) and current-voltage (I-V) curves exhibits a single global MPP . To simulate the fast changing solar irradiance, two different levels of irradiance were selected, 1) highest (Point A, G=1000W/m2) and lowest (Point B, G= 300W/m2). It can be seen that, the maximum power point (MPP) has changed from point A to B when the irradiance (G) level decreases from 1000W/m2 to 300W/m2 .

For current-controlled PV inverters in most of the cases we make use of PI controller with grid voltage feed-forward (VFF), but this solution exhibits two well known drawbacks (due to the poor performance of the integral action): inability of the PI controller to track a sinusoidal reference without steady-state error and poor disturbance rejection capability. An alternative solution in order to alleviate the PI's drawbacks is presented in, where a second order generalized integrator (GI) can be used. The GI is a double integrator that achieves an "infinite" gain at a certain frequency (resonance frequency), and almost no attenuation exists outside this frequency. Thus, it can be used as a notch filter in order to compensate the harmonics in a very selective way. Another approach reported in where a new type of stationary-frame regulators called Proportional Resonant (PR) is introduced. In this approach the classical PI dc-compensator is transformed into an equivalent ac-compensator having the same frequency response characteristics in the bandwidth of concern.
This paper is aimed at presenting a single-stage converter for single-phase grid connected PV systems. Two different current controllers have been implemented and an experimental comparison between them has been made. A complete control structure for the single-phase PV system is also presented. An incremental conductance method has been used in order to track the MPPT of the PV characteristic. In order to get a clean sinusoidal current reference (synchronized with the grid voltage) it is used a PLL, a based on delay structure. The conclusions are presented in the final part of the paper.

3. System description of Grid Connection

Generally the power converter interface from the dc source to the load and/or to the grid consists of a two stage converter: the dc-dc converter and the dc-ac converter.[8] An interesting alternative solution could be the use of a single-stage converter where the dc-dc converter is avoided and in order to ensure the necessary dc voltage level the PV array can be a string of PV panels or a multitude of parallel strings of PV panels. In the classical solution with two-stage converter, the dc-dc converter requires several additional devices producing a large amount of conduction losses, sluggish transient response and high cost while the advantages of the single-stage converters are: efficient, a lower price and easier implementation. The disadvantages of the single-stage converter are the fact that the PV panels are in series and if the shading occurs on one or several PV panels then the efficiency of the whole system is reduced.

As shown in Fig. 2, the PV inverter system consists of a solar panel string and a dc link capacitor Cd, on the dc side with an output ac filter (LCL), insulation transformer and grid connection on the ac side. The number of panels in the string has to ensure a dc voltage higher than the ac voltage peak at all time. The energy conversion from dc to ac side is made by a single-phase voltage source inverter.

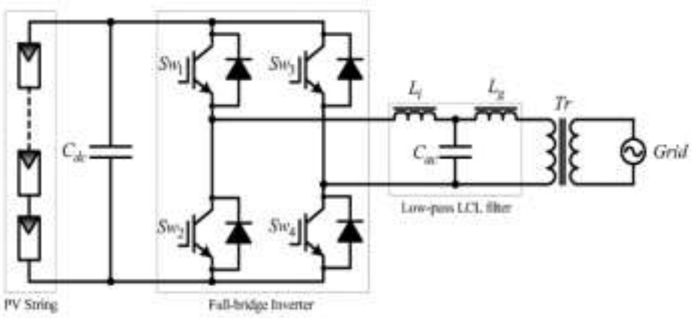


Figure 2. The voltage source PV inverter connected to the grid through an LCL filter.

3.1 Control of PV to Grid strategy:

For the grid-connected PV inverters in the power range of 1-2 kW, the most common control structure for the dc-ac grid converter is a current-controlled H-bridge PWM inverter having a low-pass output filter. Typically L filters are used but the new trend is to use LCL filters that have a higher order (3rd) which leads to more compact design. The drawback is its resonance frequency which can produce stability problems and special control design is required .Here we using boost converter for single phase single stage grid connected pv inverter , For require voltage level increasing the input (step up voltage).

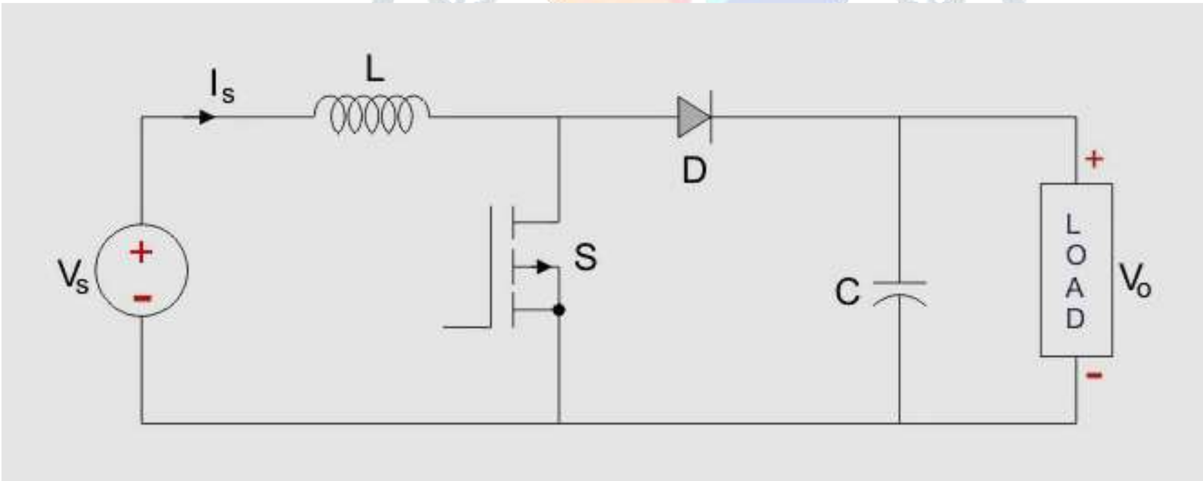


FIGURE 3 BOOST CONVERTER DIAGRAM

For the above operation with capacitor to maintain voltage levels but we required Voltage higher and less harmonics of less current, So we have to put boost converter instead of capacitor. The main elements of the control structure are the synchronization algorithm based on PLL, the MPPT, the input power control and the grid current controller.

The input voltage source is connected to an inductor. The solid-state device which operates as a switch is connected across the source. The second switch used is a diode. The diode is connected to a capacitor, and the load and the two are connected in parallel as shown in the figure above.

The inductor connected to input source leads to a constant input current, and thus the Boost converter is seen as the constant current input source. And the load can be seen as a constant voltage source. The controlled switch is turned on and off by using Pulse Width Modulation(PWM). PWM can be time-based or frequency based. Frequency-based modulation has disadvantages like a wide range of frequencies to achieve the desired control of the switch which in turn will give the desired output voltage. Time-based Modulation is mostly used for DC-DC converters. It is simple to construct and use.

The boost converter is used to "step-up" an input voltage to some higher level, required by a load. This unique capability is achieved by storing energy in an inductor and releasing it to the load at a higher voltage.

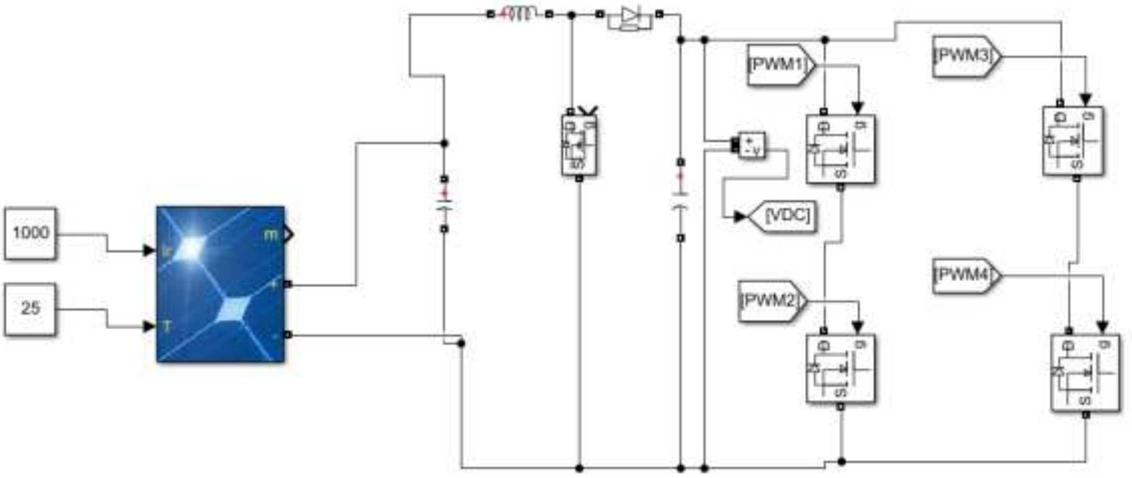


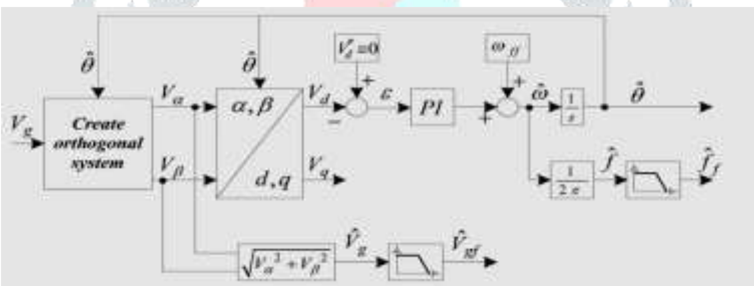
FIGURE 4 MATLAB SIMULATION OF BOOST CONVERTER

3.2 Phase Locked Loop(PLL) Structure:

The PLL is used to provide a unity power factor operation which involves synchronization of the inverter output current with the grid voltage and to give a clean sinusoidal current reference. The PI controller parameters of the PLL structure are calculated in such a way that we can set directly the settling time and the damping factor of this PLL structure. The PLL structure is also used for grid voltage monitoring in order to get the amplitude and the frequency values of the grid voltage. The general form of the PLL structure is presented in Fig. 4.

Current control scheme for single-phase inverter:

PLL STRUCTURE



This section describes a control method for single-phase inverter system which can provide low harmonics content in the output current waveform. The PR controller reduces the computational burden and control efforts while attaining frequency response characterized similarly to PI controller. Moreover, with PR controller selective harmonics compensation technique can be implemented without any excessive requirements particularly for non-linear load Figure 6 illustrates a block diagram of single-phase

3.3 MPPT algorithm :

The task of the MPPT in a PV energy conversion system is to tune continuously the system so that it draws maximum power from the solar array regardless of weather or load conditions. Since the solar array has non ideal voltage-current characteristics and the conditions such as irradiance, ambient temperature, and wind that affect the output of the solar array are unpredictable, the tracker should deal with a nonlinear and time-varying system. The conventional MPPT algorithms are using dP/dV = 0 to obtain the maximum power point output. Several algorithms can be used in order to implement the MPPT as follows [10]: perturb and observe, incremental conductance, parasitic capacitance and constant voltage, but only the first two are the most frequently used.

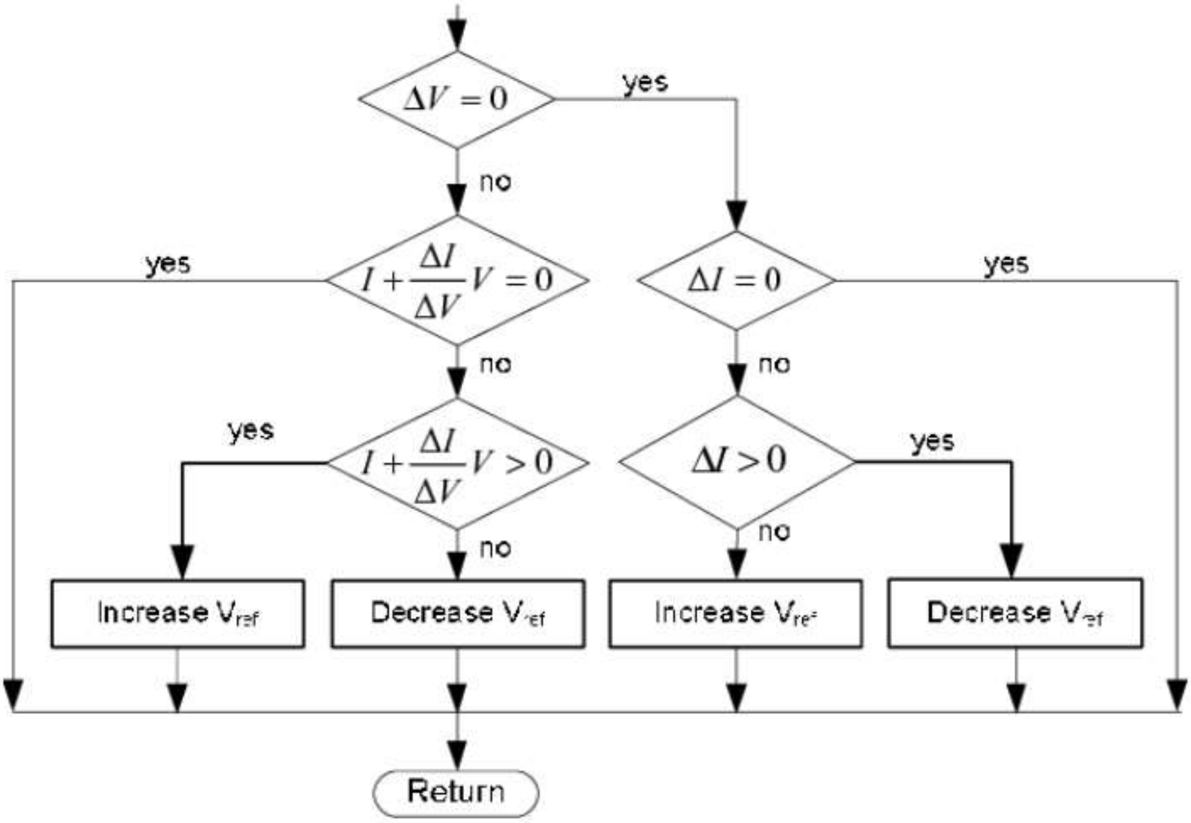


Fig 5: . Flowchart of the incremental conductance algorithm

3.4 Grid Current Controller :

Classical PI control[15] with grid voltage feed-forward (Ug) as depicted in Fig. 7a, is commonly used for current-controlled PV inverters.

Fig 6 : The current loop of PV inverter: a) with PI controller; b) with PR controller.

The PI current controller GpI(s) is defined as[15]:

$$GPI(s) = Kp + \frac{K_i}{s} \quad (1)$$

The filter transfer function G1(s) is expressed in (8).

$$Gf(s) = \frac{i_i(s)}{u_i(s)} = \frac{1}{L_i s}\frac{(s^2+Z_{LC}^2)}{(s^2+\omega_{res}^2)} \quad (8)$$

Calculation of Kp value:

a. Voltage Controller :
Controller time constants = 200µS
Filter Capacitance = 6.23µF

$$\text{Value of Kp} = \frac{\text{capacitance}}{\text{time constant}} = 0.03115 \quad (2)$$

b. Current controller :
Controller time constants = 150µS
Filter Inductance = 4.06mH
Inductor Series Resistance = 0.001

$$\text{Value of Kp} = \frac{\text{Inductance}}{\text{time constants}} = 27.066 \quad (3)$$

$$Gn = \frac{K_r \omega_n}{\omega_n^2 - \omega^2} \qquad \because \omega n = \frac{1}{\sqrt{LC}} \quad \because \omega = 2*pi*50 \quad (4)$$

Gn = 0.1

3.4.2 Calculation of Kr value :

Kr value of voltage controller = 100

$\frac{\omega^2}{K_r} = \frac{(2*pi*50)^2}{100}$ = 986.83 (5)

Kr value of voltage controller = 400

$\frac{\omega^2}{K_r} = \frac{(2*pi*50)^2}{400}$ = 246.7

Proportional resonant (PR) controller :

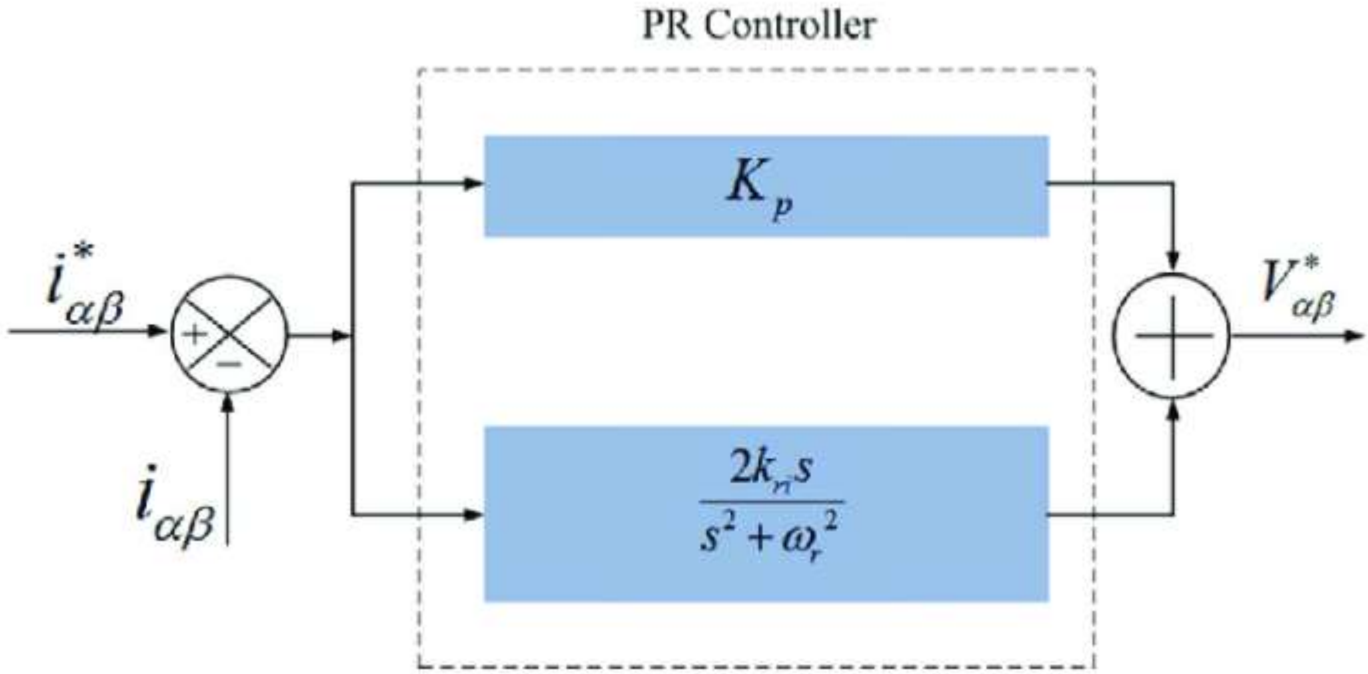


Fig 7 : PR CONTROLLER DIAGRAM

The ideal PR controller of S- domain is :

G PR (S) = Kp + 2Ki/(S2+w02) (6)

where, Kp is the proportional gain, Ki is the integral gain and (Zo =2∧fo) is the resonant frequency. Equation (1) shows an ideal PR controller suffers a stability problem with an infinite gain and sudden phase-shift at the resonant frequency, as shown in Figure 2(a). In order to mitigate the stability problems at the fundamental frequency, a non-ideal PR controller represented by Equation (2) can be used where the frequency response is shown in Figure 2(b) [12

$G\ PR\ (S) = Kp + 2\ KiW_c\ S/(S2+2WcS+w_0^2)$ (7)

where, Wc is the cut-off frequency of the controller. Proper gain tuning is required to regulate the dynamics of the system in terms of the bandwidth, phase, and gain margins. These can be checked through frequency response analysis. The harmonics can be reduced further by incorporating the PR controller with a selective harmonic compensation, especially for low-order harmonics. Usually, a harmonic compensator (HC) is designed to compensate for the low order harmonics such as 3rd, 5th and 7th harmonics. For low power system, the total harmonic distortion (THD) limit of the load current is 5% as per IEEE 519.

Standard Compensating high-order (e.g. the 11th and 13th) harmonics are also possible but at the expense of higher computational burden. The transfer function of the harmonic compensator to compensate the 3rd, 5th and 7th harmonics, for instance, is given by,

$$G_{h\ (S)} = \sum_{h = 3,5,7} K = S/\ S^2 + (hw_0)^2 \qquad (8)$$

where, Z0 is the fundamental frequency, h is the harmonics order and Kih is the specific resonant gain, which must be tuned to a comparatively high value for reducing the steadystate error.

PI CONTROLLER:

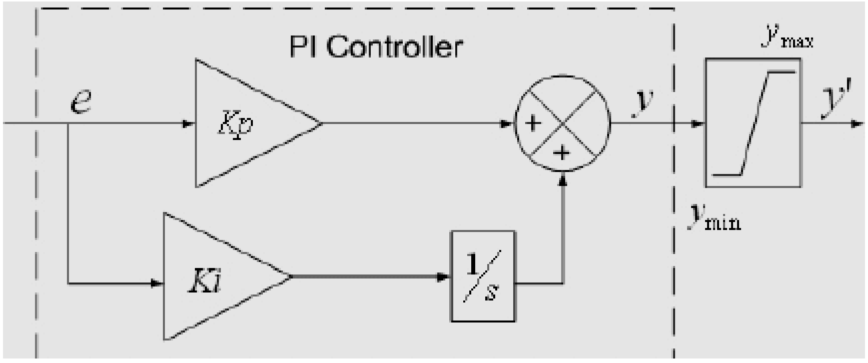


Fig 8 : PI CONTROLLER DIAGRAM

The PI current controller Gp1(s) is defined as:

$$G_{PI}(s) = K_P + K_i / S \qquad (9)$$

In order to get a good dynamic response, a grid voltage feed-forward is used, as depicted in Fig. 7a. This leads in turn to stability problems related to the delay introduced in the system by the voltage feedback filter (Ug).

In order to alleviate this problem an advanced filtering method for the grid voltage feedforward should be considered.

LCL -filter design:

A second order low pass LC filter can be used to obtain lower total harmonic distortion (THD) due to inverter switching and to improve the quality of the output power . The resonance frequency of the low pass LC filter is defined as below:

$$f = 1/2\pi\sqrt{(lf\ Cf)} \qquad (10)$$

where, Lf is the filter inductor and Cf is the filter capacitor. The transfer function of the inverter with LC filter and resistive load can be expressed by the following equation:

$$G_f(s) = \frac{V_L(s)}{V_{inv}(s)} = \frac{\frac{1}{L_f C_f}}{s^2 + (\frac{1}{R_L C_f})s + \frac{1}{L_f C_f}}$$

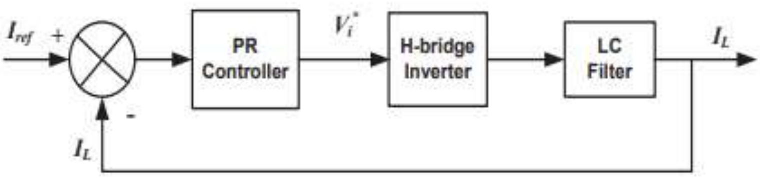


FIGURE 9: CLOSED LOOP CONTROL SCHEME

The frequency response of the second order low-pass LCfilter in terms of magnitude and phase with Lf = 5 mH and Cf = 0.22

4. Boost Mode

Duty cycle: The duty cycle of the switch with estimated efficiency of 90% to 95% is given by equation (18).

$$D = 1 - \frac{V_i \times \eta}{V_o} \quad (11)$$

where V_i= input voltage, V_o= desired output voltage, η = efficiency of the converter.

Selection of Inductor: Inductor ripple current of 10% to 20% is assumed. Hence the ripple in inductor current is given by equation (19).

$$\Delta I_L = (0.1 \text{ to } 0.2) \times I_i \quad (12)$$

Where I_i= input current. The inductor value is calculated using equation (20).

$$L = \frac{DT_s \times V_i}{\Delta I_L} \quad (13)$$

Selection of Output Capacitor: Output capacitor is chosen with 10% ripple in output voltage. Output capacitor values for a desired output voltage ripple is calculated as in equation (21).

$$C_o = \frac{I_o \times D}{f \times \Delta V_o} \quad (14)$$

where C_o= output capacitance,

ΔV_o= desired output voltage ripple [11].

Sr.no	Parameters	Values
1.	Input and output capacitors	4.35 µF and 4.63 µF
2.	Switching Frequency	10000
3.	Output Power	2kW
4.	Input DC Voltage	400
5.	Ripple in capacitor voltage	5
6	inductor	6.23 mH
7	Ripple in Inductor current	10%
8	Duty Cycle	0.0631

Table1 : shows the design values.

PID tuning

Propotional , integral and Derivative its three combination of tuning device to find the error feed back and it is easy to compensate the error value. It is done by setting the reset (integral) time to its maximum value and the rate (Derivative) to zero, and increasing the gain until the loop oscillates at a constant amplitude. (When the response to an error correction occurs quickly a larger gain can be used. If response is slow a relatively small gain is desirable). Then set the gain of the PID controller to half of that value and adjust the reset time so it corrects for any offset within an acceptable period. Finally, increase the rate of the PID loop until overshoot is minimized

Zeigler and Nichols' two **heuristic methods** of tuning a PID controller were first published in 1942. These work by applying a step change to the system and observing the resulting response. The first method entails measuring the lag or delay in response and then the time taken to reach the new output value. The second depends on establishing the period of a steady-state oscillation. In both methods, these values are then entered into a table to derive the values for gain, reset time and rate for the PID controller.

Simulation Results

In this section the results from the Simulink model is discussed using the waveform results. The waveforms are taken for maximum power point tracking, boost converter output voltage(V_{DC}), grid voltage(V_{grid}) and grid current(I_{grid}).

From this results we can observe that the integration of PV system to the grid and boost converter and LCL filter is done with less harmonics as the control strategies are designed to avoid the harmonics. The maximum power point tracking is done by using Depending on MPPT algorithm . for grid connection a full bridge inverter model is designed to convert DC to desired AC output as the grid parameters are 230V and 50Hz.

. The /MATLAB Simulink model is shown as below.

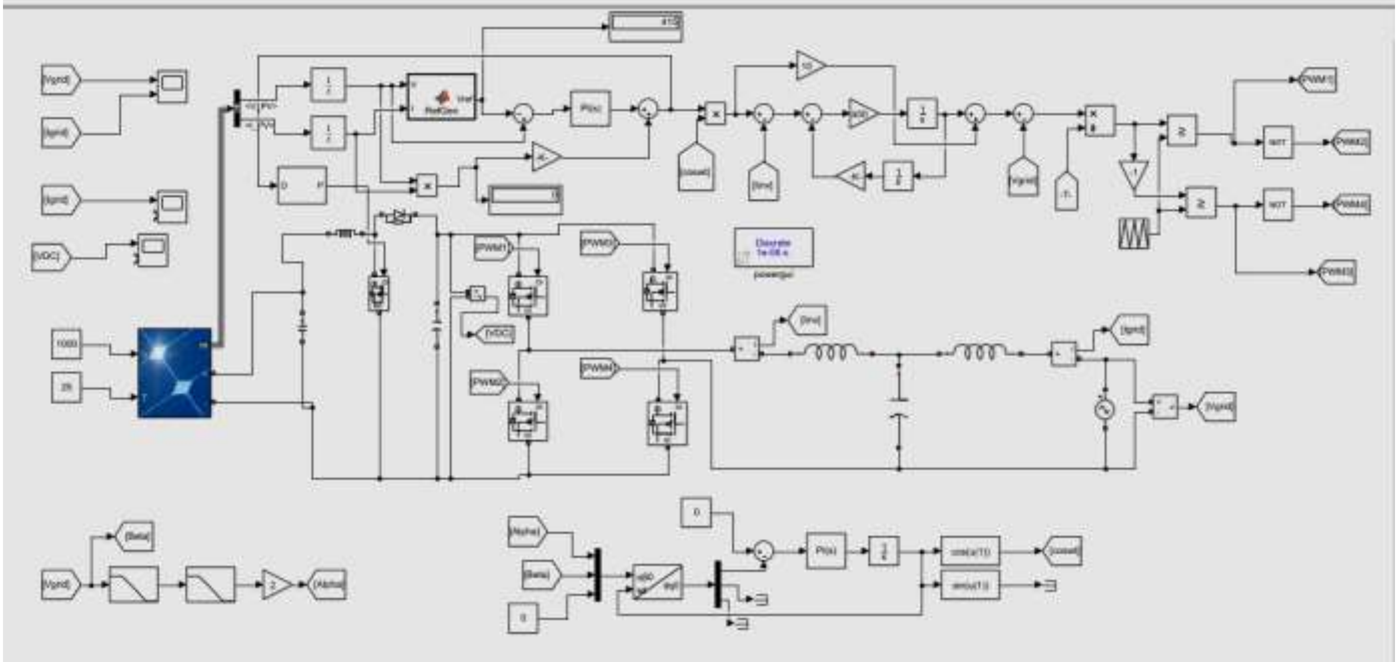


Fig 10: Simulink model of integrated PV system with single phase grid

5. Analysis of Simulink Results

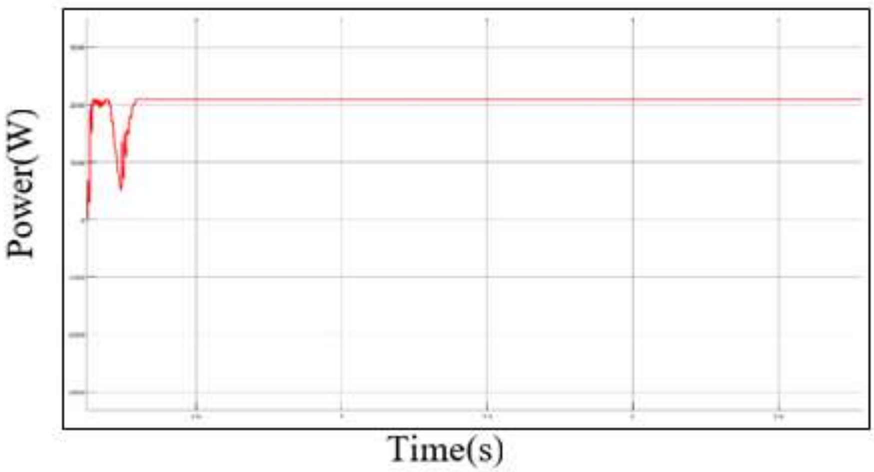


Fig 11 : Maximum power point tracking(MPPT).

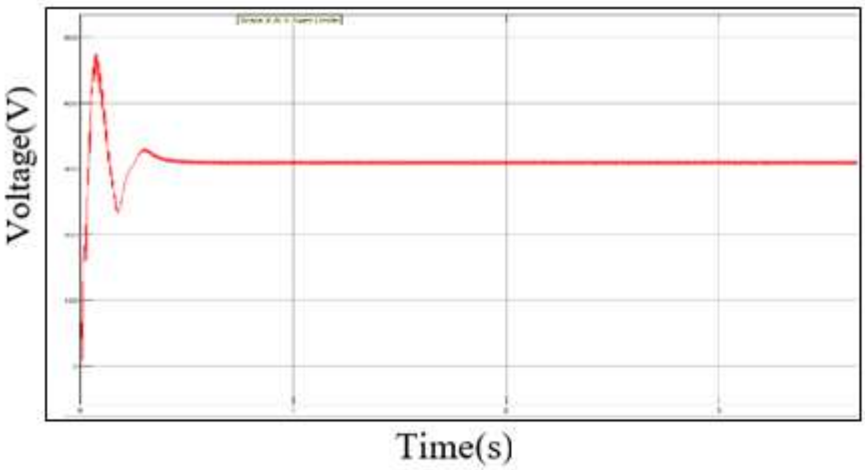


Fig 12 : Boost converter voltage(Vdc).

To extract the maximum power output from the photovoltaic module, maximum point tracking is used in this paper Boost converter and using LCL filter hence the maximum power obtained is 2000W.

FIG 13 : Grid voltage & current Waveforms

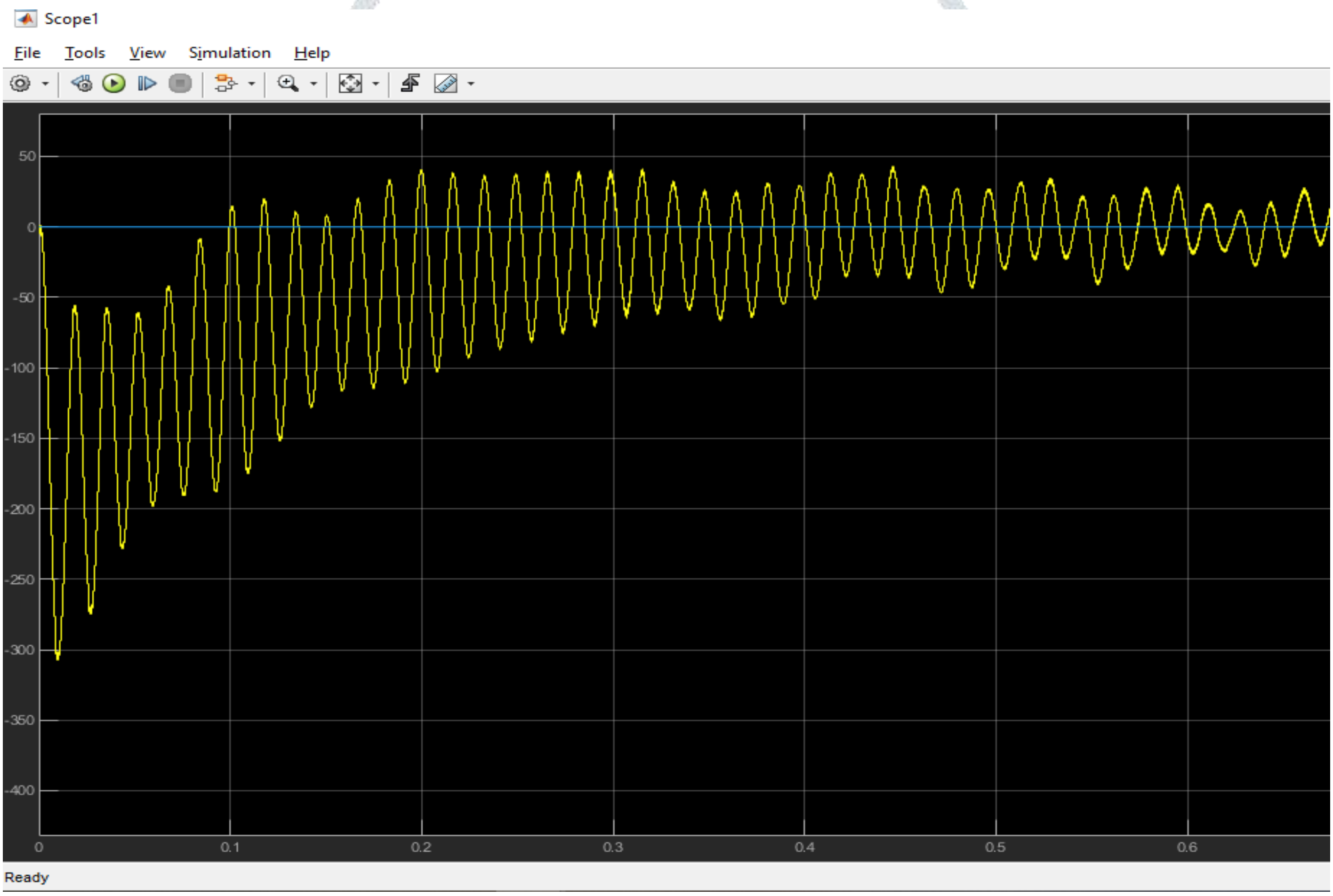


FIG 14 : Grid current Waveforms

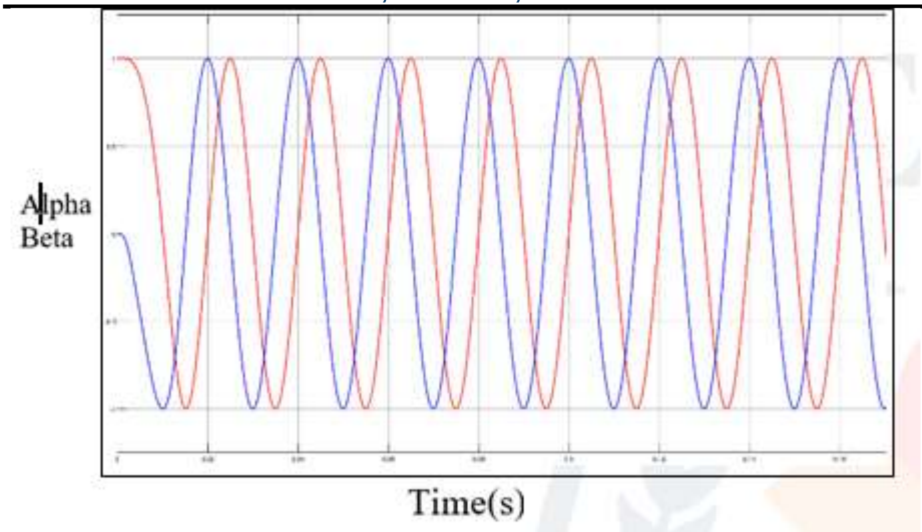


Fig 13: Alpha Beta waveforms.

The alpha beta are obtained from the grid voltage by using double first order filter which provides 45^0 phase shift each. Alpha is the phase shifted voltage where as Beta is the actual grid voltage. The alpha beta voltages are given to the phase locking loop to set the phase shift between the current and voltage. The phase between alpha and beta is 90^0

From the above graphs, initially current was stable at 0.55sec it started becoming stable by the combination battery storage the power observed at the grid is higher than the power of PV system. Phase shift between voltage and current is set to zero using the phase locked loop. The grid current rises up to 8 to 12Amps of 5.8% of total harmonics distortion (THD) and grid voltage(V_{grid}) is set to 230V. the voltage and current control of the grid is done using PI and PR controllers.

Conclusion:

This paper is combination of converters starting with boost converter, the design of boost converter and LCL filters is discussed. Control strategies for controlling the current and voltage using proportional integral controller and proportional resonant controller while converting DC-AC using voltage source inverter with less harmonics using phase locking loop is discussed and also LCL filters discussed. Finally a model is designed to integrate PV system with single phase grid system and waveforms are analyzed.

References:

[1] Xiaoting Wang, John Byrne, Lado Kurdgelashvili1 & Allen Barnett (2012). Introduction. High efficiency photovoltaics: on the way to becoming a major electricity source. Retrieved from http:// http://ceep.udel.edu/wp-content/uploads/2013/08/2012_es_WIRE_EnergyEnvironment_high efficiency-solar_xiaoting+jb+lado+barnett.pdfX. Yu, M. R. Starke, L. M. Tolbert, and B. Ozpineci, “Fuel cell power conditioning for electric power applications : a summary,” *IET Electr. Power Appl.*, vol. 1, no. 5, pp. 643–656, 2007.

[2] Cody A. Hill, Matthew Clayton Such, Dongmei Chen, Juan Gonzalez, and W.Mack Grady, “Battery energy storage for enabling integration of distributed solar power generation”, IEEE Trans. on Smart Grid. vol. 3, no. 2, June 2012.

[3] Modelling & Simulation Of PV System With Fuzzy Mppt Based Converter Jyotirmayee Priyadarshini Dept.of electrical engineering International Conference on Recent Innovations in Electrical, Electronics & Communication Engineering - (ICRIEECE).

[4] Hao Qian, Jianhui Zhang, Jih-Sheng (Jason) Lai, and Wensong Yu, “A high-efficiency grid tie battery energy storage system,” IEEE Trans. Power Electron., vol. 26, no. 3, pp. 886-896, March 2011.

[5] Takun, Pongsakor, Somyot Kaitwanidvilai, and Chaiyan Jettanasen. "Maximum power point tracking using fuzzy logic control for photovoltaic systems."Proceedings of International MultiConference of Engineers and Computer Scientists. Hongkong. 2011.

[6] DC-DC Boost Converter Design for Fast and Accurate MPPT Algorithms in Stand-Alone Photovoltaic System Norazlan Hashim, Zainal Salam, Dalina Johari, Nik Fasdi Nik Ismail, International Journal of Power Electronics and Drive System (IJPEDS).

[7] DC To DC Converter in Maximum Power Point Tracker, V.C. Kotak, Preti Tyagi. International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering.

[8] S. S. Mohammed and D. Devaraj, "Fuzzy based maximum power point tracking controller for stand-alone photovoltaic system using MATLAB/Simulink," Int. J. of Appl. Eng. Research, vol. 10, no. 55, pp. 3101-3106, 2015.

[9] Control of single-stage single-phase PV inverter Mihai Ciobotaru, Remus Teodorescu and Frede Blaabjerg Institute of Energy Technology Aalborg University.

[10] R. Teodorescu, F. Blaabjerg, M. Liserre, U. Borup. A New Control Structure for Grid-Connected PV Inverters with Zero Steady-State Error and Selective Harmonic Compensation, Proc. of APEC'04, Vol. 1, pp. 580-586.

[11] D.P. Hohm and M.E. Ropp. Comparative Study of Maximum Power Point Tracking Algorithms Using an Experimental, Programmable, Maximum Power Point Tracking Test Bed, Proc. of Photovoltaic Specialists Conference, 2000, pp.1699 - 1702.

[12] Bidirectional DC-DC converter in Solar PV System for Battery Charging Application Seema Jadhav, Neha Devdas, Shakila Nisar and Vaibhav Bajpai.

[13] A. K. S. Bhat and F. Dong Tan, “A Unified Approach to Characterization of PWM and Quasi-PWM Switching

Converters: Topological Constraints, Classification, and Synthesis," *IEEE Trans. Power Electron.*, vol. 6, no. 4, pp. 719–726, 1991.
[14] Study and design of LCL filter single-phase grid connected PV inverter. Hanju cha, Trung kien. https://www.researchgate.net/publication/329714403.
[15] PID controllers theory, design and tuning, 2edition K. Astrom and T. Hagglund.
[16] Fundamentals of Phase Locked Loop, MT-086, Analog Devices.