PERFORMANCE ANALYSIS OF GIRD CONNECTED PV MODULE WITH HARMONIC MITIGATION USING PASSIVE LCL FILTER

Amey W. Nale[1], Dr. K. Vadirajacharya[2]

M.Tech Student[1], Supervisor[2]

[1,2]Department of Electrical Engineering, Dr. B.A.T.U., Lonere

Abstract

Renewable energy sources, being important reform of energy due to increasing power demand and poor feedback of non-renewable energy sources on the environment. Among the various available renewable energy sources, solar is of more importance due to abundant availability and its non-pollution effect. The power generated from PV module need to be converted so as to increase the power transfer capability from source to grid. DC-DC boost converter is used for efficient operation of solar panel. The dc power generated from solar PV panel is converted to ac form by means of inverter, So as to supply it to the utility grid .But the converted power is of low quality as continuous switching operation is carried out in dc to ac inversion. The harmonic due to continuous switching is mitigated by means of LCL filter before it interfacing at utility. By means of proper control technique on ac side the dc system is interfaced with grid. The state space mathematical modeling of LCL filter is described and proposed control technique is implemented.

Index Terms: pv module, DC-DC boost converter, inverter, power quality, harmonics, LCL filter.

I. INTRODUCTION

In the modern era, with increase in the population the requirement of electrical energy is of greater importance. This has been resulted into formulation of widely interconnected power system network. As the energy requirement is going on increasing day by day, but due to increase in load demand power generated from sources available is not up to the mark to fulfill the load requirement efficiently and effectively. Renewable and non-renewable energy sources are used to generate electricity. Being the non-renewable source of energy coal, petrol, diesel, and natural gas cannot be reformed. Also the cost of energy generation from this is very high. Also this liberates flue gases which cause pollution and afterwards which becomes the cause for global warming. The availability of non-renewable energy sources is reducing day by day so now its time to move towards renewable energy sources [1].

As compared to various available renewable energy resources solar is of greater importance as it has various advantages over other renewable sources of energy. Also its availability plays wide role for a reason to go for solar as a source for electricity generation. The generation of electricity from solar energy is based on the principle of the photoelectric effect. According to this principle the energy stored in the photons striking the plate is absorbed by the electrons on the photoelectric plate. By absorbing this energy electron goes into conduction state and current flows when closed path is provided. The electricity generation depends on two parameters, one is intensity of the light i.e. irradiance and second is the temperature [2].

DC-DC boost converter plays an important role in improving the efficiency of the solar PV module. The chopper converts the variable dc voltage to the fixed dc voltage. Switching technique is the constant frequency process i.e. the pulse modulation technique where by varying

the duty ratio output voltage can be controlled. Boost converter are used so as to obtain the maximum power from the solar pv module. Switch used for this circuit depends basically on the turn on and turn off time required for the circuit. So frequency of the operation is selected as per the requirement. Either IGBT or MOSFET can be used which acts as a controlled switch [3]-[4].

Majority of the utility loads basically operate on ac supply. So energy obtained from solar pv module need to be inverted [5]-[7]. By means of proper controlled switching technique the dc from the boost converter is converted into ac. But because of this continuous switching operation in the inversion the harmonics are injected into the system which results into the decreased power quality. By means of LCL filter the harmonic mitigation is carried out and the improved quality supply is injected into the grid or supplied to the load [8].

II. PV SYSTEM

A. General Introduction

Solar power utilization is of greater importance now days because of its availability and its advantages over other non- renewable as well as respective renewable energy sources. Also the various research and enhancement has done on technologies in the field of solar pv system. Solar energy is converted into electrical energy by means of solar PV module. PV system basically works on a principle of photoelectric effect, according to which energy stored in the photon striking the photoelectric plate is absorbed by the electron on it [1]. The energy stored in the photon is given by,

$$E = \frac{hc}{\lambda} \qquad (1)$$

From this absorbed solar energy electron turns into excited state and currents starts flowing through the circuit when load is connected. Lot of research work has done to improve the efficiency of the solar pv system. One of such attempts is MPPT techniques.
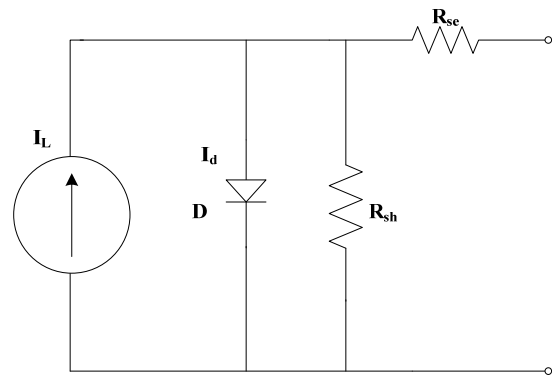

Fig 1: Equivalent circuit of pv system

B. PV Modeling

Modeling of solar cell is of importance for analysis purpose [2]. Equivalent circuit of solar cell is shown in the fig. 1. By applying KVL we can find out the output current of a pv cell.

$$I = I_L - I_d - I_p \qquad (2)$$

From the theory of semiconductors the current through diode can be found. Hence above equation can be modified by diodes saturation current equation as follows

$$I = I_L - I_0 \left(\exp\left(\frac{V + R_{se}I}{\frac{\alpha k \tau}{q}} \right) \right) - \frac{V + R_{se}I}{R_{sh}} \qquad (3)$$

Generally cells are connected din series (N_s) and in parallel (N_p) in a panel so as to achieve much more significant output from one panel. So by considering N_s and N_p the current equation (3) can be modified as

$$I = N_p I_L - N_p I_0 \left(\exp\left(\frac{V + \frac{N_p}{N_s} R_{se}I}{\frac{\alpha k \tau * N_s}{q}} \right) \right) - $$

$$\frac{V + \frac{N_p}{N_s} R_{se}I}{\frac{N_p}{N_s} R_{sh}} \qquad (4)$$

The two major parameters on which the working of pv cell depends .i.e. intensity of light falling on the pv panel and second is the effect of temperature on solar panel. We know that electrical resistance highly depend upon the temperature conditions, but by theory of semiconductor devices, diode will be affected more significantly with temperature conditions, because of its reverse saturation current (I_0). Let us consider reference temperature as (T_0) and modified temperature as (T_1). The modified saturation current will be

$$\frac{I_0(T_1)}{I_0(T_0)} = \frac{T_1}{T_0} \exp\left(\frac{E_g}{K} \left(\frac{1}{T_0} - \frac{1}{T_1} \right) \right) \qquad (5)$$

Where E_g is the material band gap energy at no temperature difference and K is the Boltzmann constant. Considering following parameters and

above equation one solar module is implemented for analysis purpose.

Table 1

Parameter	Symbol	Value
Reference temperature	T_0	25^0C
Actual temperature	T_1	27^0C
Solar irradiation	I_{rr}	$1000Wb/m^2$

With the help of above parameters and mathematical equations mentioned above the modeling of solar pv module is done in matlab. The characteristics of the model are plotted by connecting a rheostat in series with the model and by varying its values from 0 to large value.
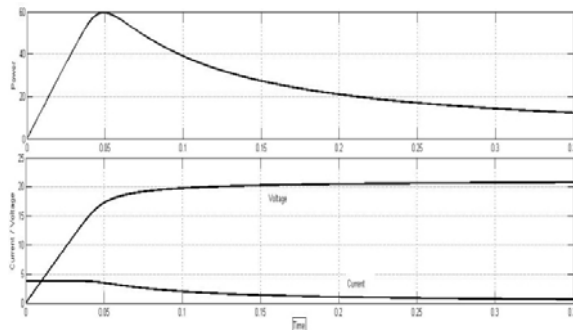

Fig 2: Simulation results of pv module

Above results show that pv module has a maximum power at unique value of V and I. the value of V and I depends upon the load connected to the pv module. For efficient operation of the pv module we need to go for Dc-DC converter.

III. DC- DC CONVERTER

By controlling the switching of the dc-dc converter we can vary the dc output either to fixed or to variable dc by means of dc-dc converter depend upon its operation in the circuit [3]. Boost converter is used to obtain the maximum power from the solar pv module.
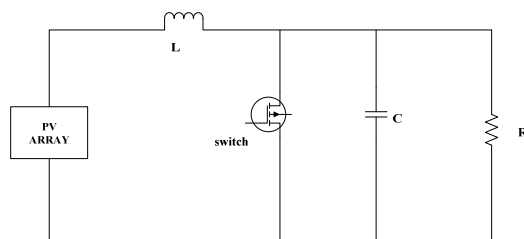

Fig 3: Schematic diagram of boost converter

In the boost converter we can use either MOSFET or IGBT as switch, which control the output of the boost converter. By providing proper gate signal we can control the on-off of the switch. (As shown in fig. 3)

To design a boost converter need to assume certain parameters which would be useful for designing the values of R, L, and C for boost converter [4]. In implementation of boost converter following parameters are considered.

Table 2

Parameter	Symbol	Value
Input voltage	V_i	205 V
Output voltage	V_0	400 V
Output current	I_0	6 A
Switching frequency	f_{sw}	5 KHz
Converter efficiency	η	90 %

By considering above parameters we can easily determine the R, L, C for boost converter. Duty ratio plays an important role in operation of the boost converter. So we need to provide proper control technique to control the switch which supplies the gate pulses to the converter. The main concern is to find values of L and C to meet the required specification.

The duty ratio (D) in the circuit is given by,

$$D = 1 - \frac{V_{in}}{V_o} * \eta \qquad (6)$$

For the calculation of the inductor it is must to find the ripple current in the circuit. Ripple current can be found by,

$$di = 2 * I_o * \frac{V_{in}}{V_o} \qquad (7)$$

Using this ripple current it is possible to find the value of inductor in the boost circuit by applying KVL in the circuit at opening and closing mode of switch.

$$L = \frac{V_{in}(V_o - V_{in})}{di * f_{sw} * V_o} \qquad (8)$$

Similarly the value of C could be designed by considering the ripple voltage. The ripple voltage is given by:

$$dv = \frac{1}{1 - D} + \frac{di}{2} \qquad (9)$$

By considering this voltage the value of C is given by:

$$C = I * \frac{D}{f_{sw} * dv} \qquad (10)$$

Hence by the above equations it is possible to design the value of L & C in the circuit. By the specified parameters the system has been implemented in MATLAB software and its output waveforms are shown below:
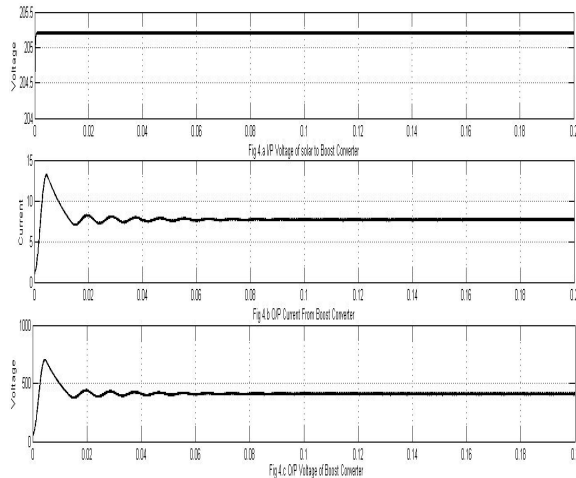

Fig 4: Simulation results of boost converter

IV. DC- AC CONVERTER

The power generated from solar panel is in the Dc form. We need to convert it into ac form as most of the utility loads are designed for ac power. So we need to convert that DC into Ac by means of Dc-AC converters which are usually termed as inverter [5]. To operate these converters we require proper gate pulse which can be generated by various means as lot of literature available for it. We need to form a proper control algorithm so as to form the gate pulses.

The control of three phase is complicated process so we need to convert it into single phase which can be easily achieved by Clarke's transformation [5]-[6]. Where by using proper control algorithm we can generate reference waves and pulses are provided using PWM technique. Following equations are useful for three phase to single phase transformation,

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \qquad (11)$$

After finding error in actual and reference it is required to convert the single phase controlled signal to 3-phase controlled signal. For this inverse Clarke transform of the controlled signal is taken.

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_d \\ V_q \end{bmatrix} \qquad (12)$$

Hence from this transformation three phase controlled signal could be generated and further the gate pulses could be generated, using these controlled signals as reference waves and comparing it with carrier wave. These pulses are provided to inverter by which it converts the DC-AC.

V. LCL FILTER

Power quality is of important concern while injecting power into the grid. As ac power formulated by converting it from dc by means of inverter, it contains harmonics. These harmonics are present because of continuous switching taking place in the inverter while DC – AC transformation. Hence for mitigation of harmonics modeling and designing of filter is of major concern. Here we have designed 3rd order filter whose one terminal is connected to inverter whereas another to the load [8].
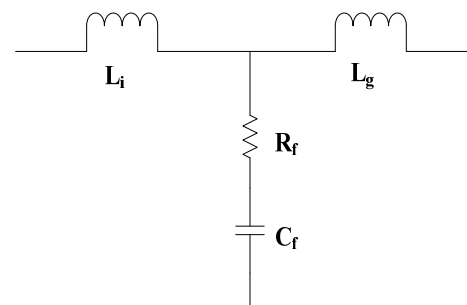

Fig 5: Schematic diagram of per phase LCL filter

For designing of LCL filter proper procedure should be followed [8]. Where by considering certain parameters we can determine the proper values for Li, Lg, Cf, and Rf.
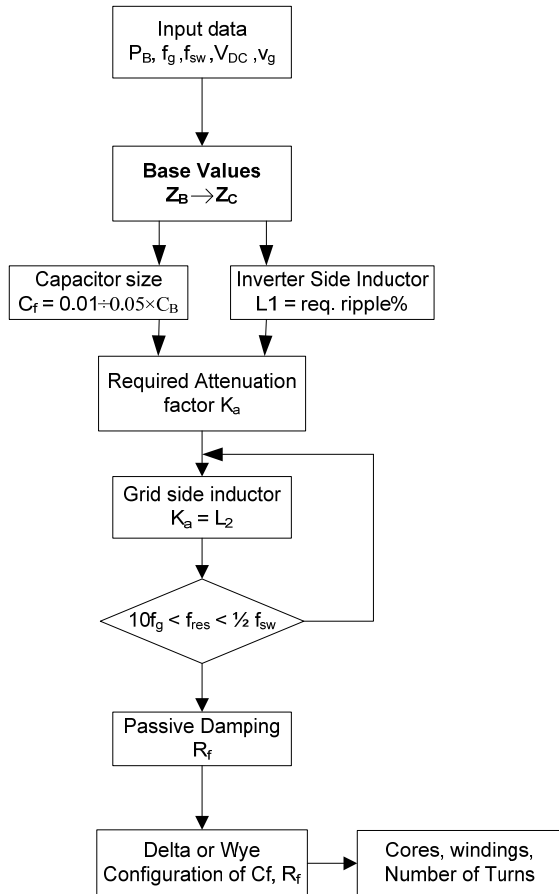
Fig 6: LCL filter design algorithm

For analysis purpose we need to consider following parameters,

Table 3

Parameter	Symbol	Value
Input DC voltage	V_{DC}	400 V
PWM carrier frequency	f_{sw}	10 KHz
Nominal power	P_g	10 Kw
Grid frequency	f_g	60 Hz
Attenuation factor	K_a	20 %

Stability analysis of filter is of major concern, because if filter operates in unstable mode then system could be damaged. Hence transfer function of filter should be found in s- domain. Consider the calculated L and C in the system.

$$H_{LCL}(s) = \frac{C_f R_f s + 1}{L_1 C_f L_2 s^3 + C_f (L_1 + L_2) R_f s^3 + (L_1 + L_2)s} \quad (13)$$

From the transfer function stability analysis can be done by the frequency domain magnitude and phase response of the LCL filter.
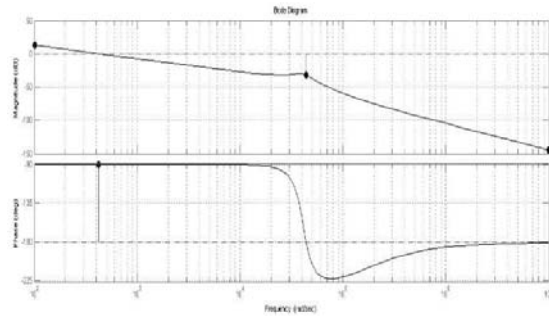

Fig 7: Frequency response of LCL filter
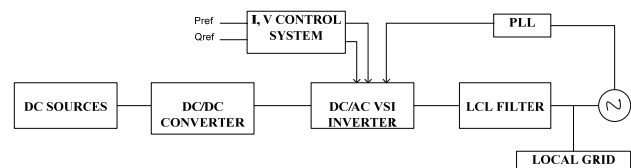
VI. SIMULATION RESULTS

Fig 8: Simulated system

The performance of the simulated system analyzed in MATLAB/SIMULATION as shown in fig.8. The system was tested considering following parameters,

Table 4

Parameter	Symbol	Value
Inverter side inductor	L_i	2.432 mH
Grid side inductor	L_g	0.085 mH
Capacitor/phase	C_f	9.564 µF
Resistor/phase	R_f	0.987 Ω
Output phase voltage	V_{rms}	230 V
Output capacity	P_{cap}	10KWp

The output at the utility terminals has been analyzed for THD with and without LCL filter. The THD analysis is performed by means of FFT analysis tool in MATLAB. For system without LCL filter the THD is around 97%. The output waveforms at utility level after connecting LCL filter is as follows,
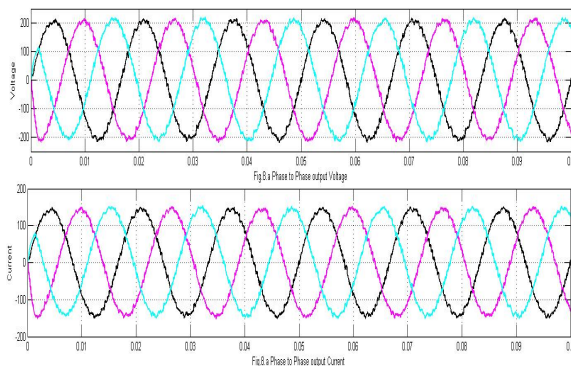
Fig 9: Output waveforms at utility bus

Hence to mitigate the harmonics in the system we need to connect specially designed LCL filter in series with the system. After connecting LCL filter the THD is found to be 3.43% in FFT analysis of MATLAB.
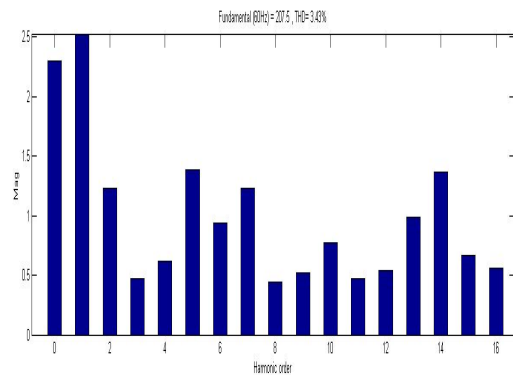

Fig 10: FFT results of the simulated system

VII. CONCLUSION

This paper proposes the simulated model for pv module with the help of mathematical equations for the solar cell. Also this paper proposes the proper design module to enhance the efficiency of the pv module with the help of boost converter. Also it proposes the model to integrate the dc power generated from the solar to the grid by means of inverter with proper control technique. And at the end, this paper gives design algorithm with proper flowchart to design 3rd order LCL filter with its analysis in the MATLAB simulation. Overall this paper proposes complete implementation of pv system at utility level with its analysis in MATLAB.

REFERENCES

[1] Chetan Singh Solanki 'Solar Photovoltaics 'Fundamental, Technologies and Applications', *PHI Publication,*2nd Edition, 2011

[2] G.Bhuvaneshari, R. Annaamalai, "Development of a Solar Cell in matlab for PV based Genration system" in *Proc. INDICON,* IEEE 2011

[3] Sajib Chakraborty, Saila Ishrat Annie, etal "Design of single stage buck boost Converters for Photovoltaic Inverter Applications" *3rd International Conference on Informatics, Electronics and Vision 2014*.

[4] G. Seshagiri Rao, S. Raghu, etal "Design of Feedback Controller for Boost Converter Using Optimization Technique", in *Proc. IJPEDS* Vol.3, 1 march 2013 pp no. 117-128.

[5] Irvin J. balaguer, Quin Lei, Shuitao Yang and Zheng Peng "Control For Grid Connected and Intentional Islanding Operations of Distributed Power Generation" *IEEE Trans. On Industrial Electronics*, Vol. 58, No. 1, January 2011,pp-147-157.

[6] J.Selvarajand, N.A.Rahim, "Multilevel inverter for grid- Connected PV system modeling using digital PI controller", *IEEE Trans. Ind. Electronics* vol.56, no.1, pp.149-158, Jan 2009.

[7] J.M.Espi Huerta, J.Castello, etal, "A syncronous refrence frame robust predective current control for three phase grid-connected inverter", *IEEE Trans. Ind. Electronics,* vol.57,no.3, pp. 954-962, Mar. 2010.

[8] Aleksandr Reznik, Marcelo Godoy Simoes, Ahmed Al-Durra and S. M. Muyeen, "LCL Filter Design and Performance Analysis for Grid-Interconnected Systems," *IEEE Trans. Ind. Appl.*, vol.50, no.2, pp. 1225-1232 Mar/April. 2014.