LCLR FILTER DESIGN AND MODELLING FOR HARMONIC MITIGATION IN INTERCONNECTED MICRO GRID SYSTEM

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Abstract

Today many people are attracted towards distribution generation (DG) because of low energy cost power supply, local generation, highly reliable system, supply with good power quality. Increasing attention and investment in renewable energy that is DG energy sources give rise to rapid development of high penetration renewable energy sources like solar energy, wind energy, hydro energy. Out of this most important and best is the solar energy. There are multiple ways to interface PV arrays with the power grid, but in there is problem of power quality. Today's important concern of the power system is the power quality in case of renewable energy sources. The power quality improvement in the interconnected micro grid systems and grid interconnection with Distribution Generation (DGs) is the challenging task and to overcome the power quality problem passive filters are the best and cost effective solution. In this paper the LCLR filter is implemented between inverter and grid. The complete system consists of photovoltaic cell (PV), DC-DC boost converter, DC-AC inverter, LCLR filter and the grid. This paper also consists of complete MATLAB simulation of PV cell, DC-DC boost converter and inverter with LCLR filter.

Key Words: *Renewable energy, PV module, DC-DC boost converter, DGs, LCLR filter, power quality, micro grid (MG) and THD*

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1. INTRODUCTION

Nowadays the cost of fuel increased due to increasing demand of fuel and use of it, but the fuels are exhaustible in nature so in the future they will be completely vanished in one day. Other reasons are the tremendous increase in population and global warming. The best solution for to reduce the fuel cost and reduce unlimited use of fuel and to save the fuel for future is the use of renewable energy sources for the generation of electrical energy. Some best renewable energy sources for generation of electricity are: (1) Wind energy (2) solar energy (3) Tidal energy (4) Hydro energy [1]. The distribution generation (DGs) means the use of renewable energy sources for generation of electricity and electricity generation is local and own generation. In these the solar energy and wind energy sources are the very popular energy sources because of its availability and suitability. That is in the distribution system electrical energy is generated using wind mill, solar panel with DC-DC converter and DC-AC converter i.e. inverter with its suitable controlling system [1]. The main objectives of use renewable energy sources are: i) provide low cost energy with local generation ii) Reduce the cost of conventional energy sources. iii) Provide good quality power supply. The power quality is obtained using the various power quality improvement devices and equipment's like DSTATCOM (distribution static compensation), DVR (dynamic voltage restorer), filters (active and passive), and zigzag transformers, etc. For the grid interconnection of renewable energy sources with power grid or micro grid is done using

inductor in past cases [2] and in recently *LCL* (Inductor *(L)*- Capacitor *(C)*- Inductor *(L)*) filters are used [2]-[5].

The higher order harmonic attenuation of *LCL* filter allows the use of lower order switching frequencies to find the harmonic limitations and these harmonic constraints are defined by IEEE standards. IEEE 1233 standard is for power quality definitions [6]. IEEE 519 standard is for harmonic control in electrical power system [7]. The higher-order *LCLR* filter has been used in place of the traditional single *L* i.e. only one inductor in series with line for getting the ripple free the output currents at output of the inverter which is formed by using IGBTs or MOSFETs as power electronic devices. The *LCLR* filter achieves the higher harmonic reduction along with simple design, the overall weight and size of the *LCLR* filter is reduced due to appropriate design and modelling. In addition *LCLR* filter does not produce very high voltage drop across it. *LCLR* filters have been used in between inverters connected with renewable energy sources with pulse width modulation techniques (PWM) for inverters.

In this paper detailed description about *LCLR* filter modeling, designing procedure is given. The objective of this paper is to carry out the detailed study about modeling and designing of *LCLR* filter for inverter with renewable energy sources as solar (PV panel). The MATLAB simulation of PV model with boost converter and full bridge inverter with *LCLR* filter is done with MATLAB Simulink software. The proposed block diagram is shown in fig-1.
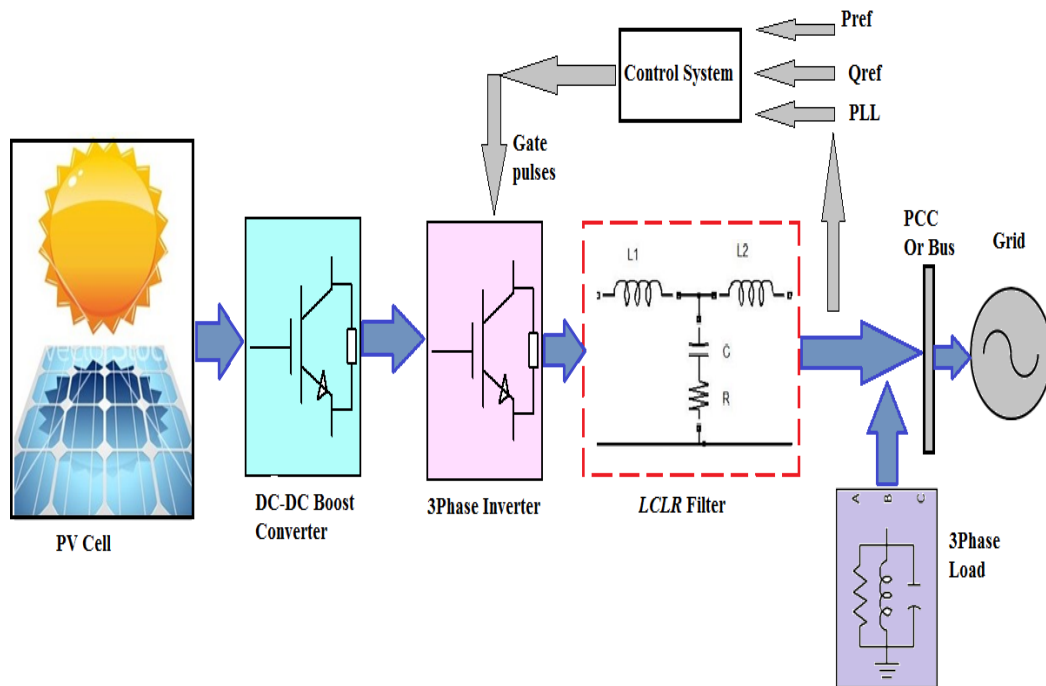
Fig-1: Proposed Block Diagram of Inverter with *LCLR* Filter

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2. PV MODULE AND BOOST CONVERTER

2.1 PV Module (Photovoltaic Cell)

PV solar energy is a best, clean, renewable energy with a long service life and high reliability. But because of its high cost, energy contribution is not as much of as other energy sources. It is therefore important to have effective and flexible models. In the photovoltaic (PV) system the solar energy is converted into electrical energy using semiconductor device to generate the charge. Two parameters are very important in the PV systems that are temperature (T in ºC) and solar irradiation is nothing but the light intensity which is in watt per meter square; W/m^2. The equivalent electrical circuit of PV cell is shown in fig-2, which consists of semiconductor diode D, series resistance (R_s), shunt resistance is (R_{sh}), current flowing through diode (I_d) and I_{sc} is short circuit current and I is the current of PV
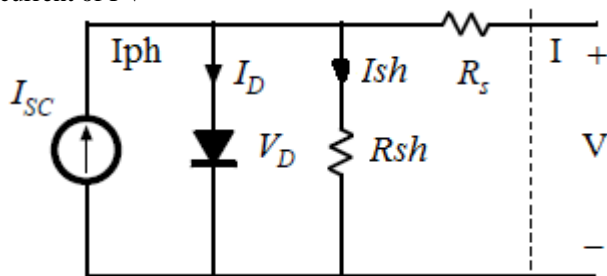

Fig -2: PV cell Equivalent Electrical Circuit.

Under the standard conditions solar radiation 1000 W/m^2 and temperature 25^0 C is considered [8].
By applying Kirchhoff's Current Law (KCL) to circuit which is given by,

$$I = I_{ph} - I_d - I_{sh} \tag{1}$$

Now, the shunt current is given by equation

$$I_{ph} = I_r . \frac{I_{sc}}{I_{r0}} \tag{2}$$

The diode current I_d and the diode characteristics is given by

$$I_d = I_s . \left(e^{\frac{(V + I.R_s)}{n.V_t.N_s}} - 1 \right) \tag{3}$$

The shunt current is given by,

$$I_{sh} = \frac{(V + I.R_s)}{R_p} \tag{4}$$

The equation of thermal voltage is given by

$$V_t = \frac{K.T}{q} \tag{5}$$

Where, K is Boltzmann constant, T is temperature and q is the charge [16].

The output voltage of the PV cell is depends upon the number cells connected in series with each other. Adding cells in series will increase the voltage. In the proposed

system single cell PV gives output voltage 21.07V DC and by increasing seven series cells then output voltage become 147.49V DC. The PV module model is done in the MATLAB Simulink Soft wares with considering table-1 parameters. The PV curve and IV curve are shown in fig-3 and fig-4 respectively [17, 18].
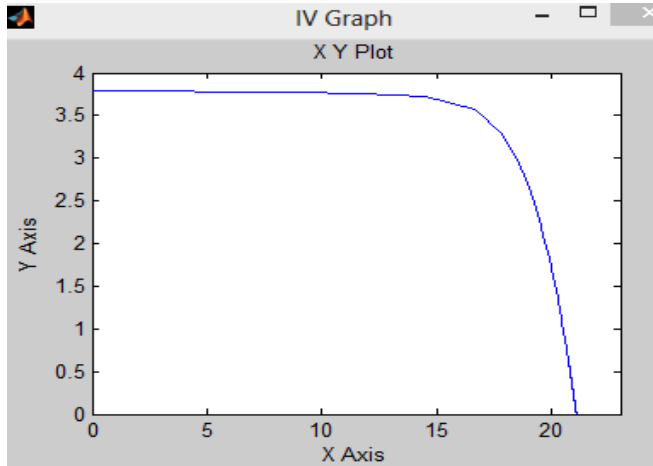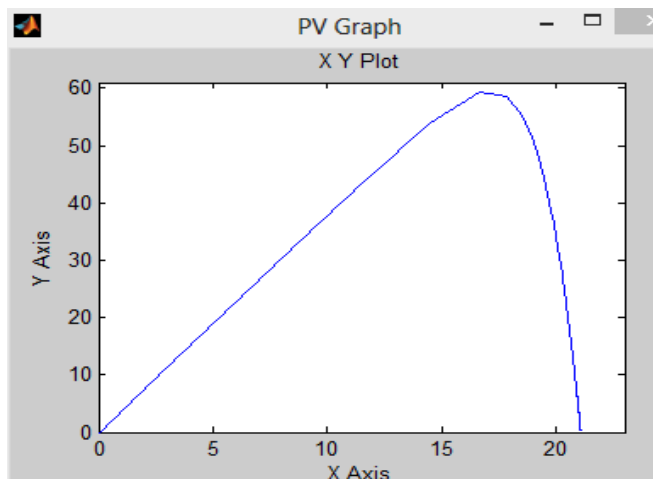

Fig -3: IV curve of PV cell

Fig -4: PV curve of PV cell

The single PV cell output voltage output voltage which is 21.07V DC shown in fig-5 and seven cell PV output voltage is shown in fig-6 which is near about 147.49V DC.
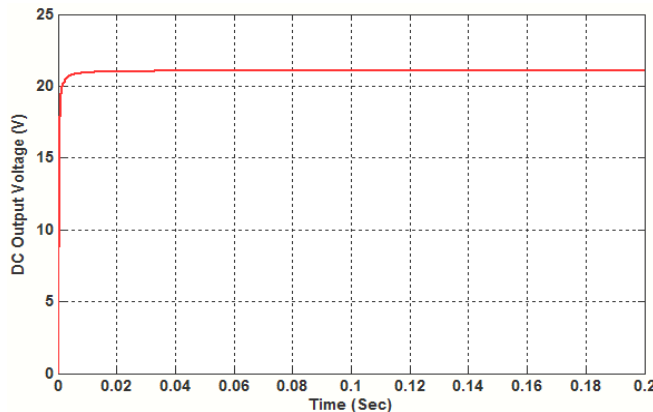

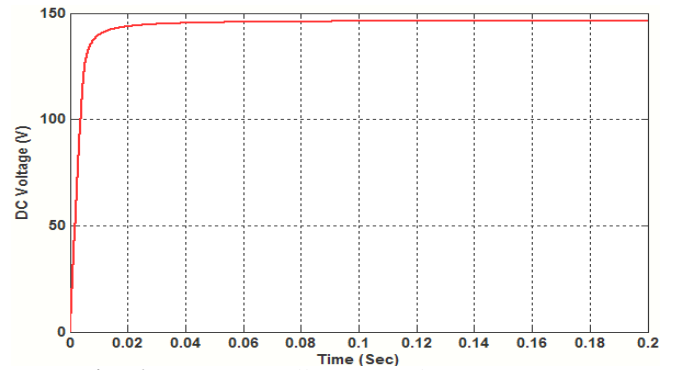**Fig-5:** One PV cell output voltage (21.07V)

Fig -6: Seven PV cell output voltage (147.49V).

2.2 DC-DC Boost Converter

DC-DC Boost converters are used to convert DC non-uniform voltage from the PV cell to required fixed high level regulated or uniform DC voltage. In addition the boost converter boosts the voltage level from low to high. The boost converter circuit consists of input DC voltage from PV cell, Inductor (*L_boost*) for boosting, IGBT with pulse generator for getting the suitable control output, diode, capacitor (*C_boost*) and load resistance *R* [9]. In this paper seven PV cells produces 147.49V DC, but using this 147.49V boost converter boost the DC voltage up to 312V DC. The parameters of DC-DC boost converter are calculated using following equations-
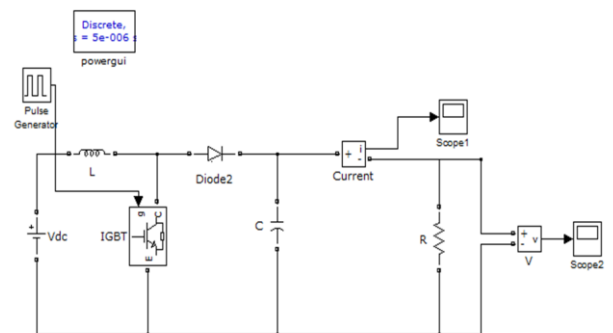

Fig-7:Simulation model of DC-DC boost converter

(a) *Duty Cycle*: Duty cycle (*D*) of the boost converter is intended by considering converter efficiency (η) 95%, for the more sensible results of the duty cycle efficiency is added in duty cycle [10]. Mathematical expression for duty cycle is given by,

$$D = \frac{V_{in}}{V_{out}} \times \eta \qquad (6)$$

(b) *Inductor Selection*: To finding good inductor value equation (7) is used, *di* is the ripple current [11]

$$L_{boost} = \frac{V_{in}(V_{out} - V_{in})}{di \times f_s \times V_{out}} \; ; \text{mH} \qquad di = 2I \frac{Vin}{Vout} \quad (7)$$

(c) *Capacitor Selection*: To select best capacitor value equation (8) is used. [11-12]

$$C_{boost} = \frac{I \times D}{f_s \times dV} \quad \text{F} \qquad (8)$$

Where,

dV is the ripple voltage

$$dV = \frac{I}{(1-D)} + \frac{dI}{2}$$

(d) Resistance Selection: The resistance value is calculating using following equation,
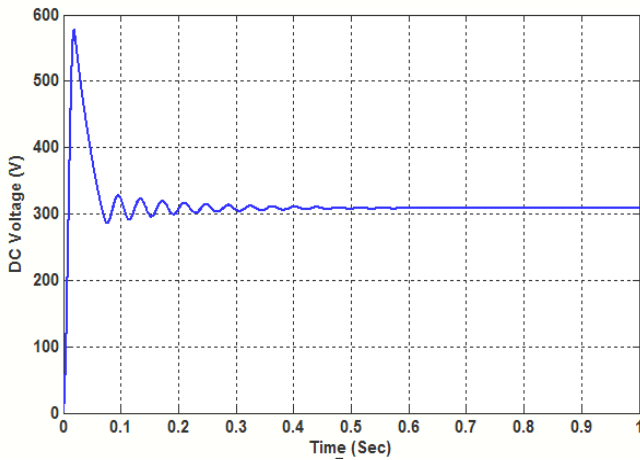
$$R = \frac{V_{out}}{I_{out}} \qquad (9)$$

Fig-8: DC-DC Boost Converter Output Voltage (312V DC)

3. *LCLR* FILTER MODELLING

A. Per Phase Equivalent Circuit Modelling of LCLR Filter
The per phase equivalent model of *LCLR* filter is fully described in case of its modeling and designing. Fig-9 shows the per phase model of *LCLR* filter. *L, C, L* and *R* are the important parameters, L_1 is the inverter side inductor, L_2 is the grid side inductor, *C* is the capacitor and *R* is the damping resistance. The capacitor *C* is connected in series with resistance *R*.
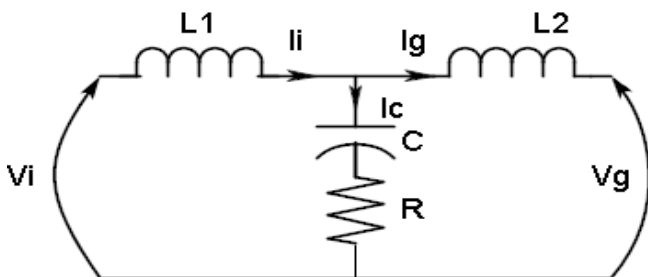

Fig-9: Per Phase Model of *LCLR* Filter

The resistance R is connected to avoid the damping in the circuit. V_i is the inverter side voltage i.e. output voltage of the inverter, V_g is the grid side voltage, I_i is the inverter

output current, I_c is the current flowing through capacitor and I_g is the grid current.
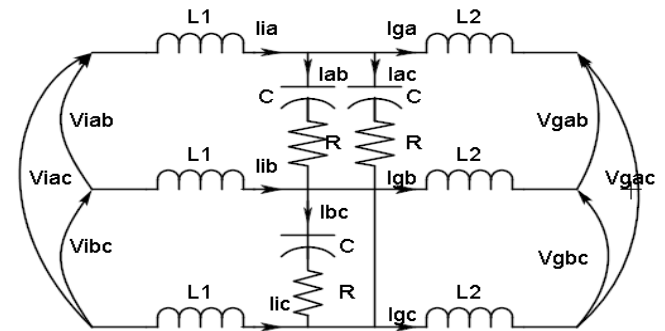The three phase model of the *LCLR* is shown in the fig-10.

Fig-10: Three phase model of *LCLR* Filter.

Transfer function of *LCLR* filter i.e. transfer function of *LCLR* filter with damping resistance
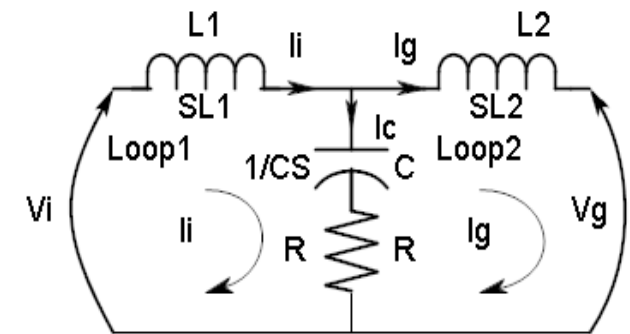

Fig-11: Per Phase model of LCLR filter for finding TF

By applying Kirchhoff's Voltage Law to loop1 we get equation,

$$Vi - L1SIi - \frac{1}{CS}(Ii - Ig) - R(Ii - Ig) = 0 \ (10)$$

By applying Kirchhoff's Voltage Law to loop2 we get equation,

$$Vg - R(Ig - Ii) - \frac{1}{CS}(Ig - Ii) - L2SIg = 0 \ (11)$$

Vg=0 because grid voltage assumed to be ultimate so to dumping out all harmonic frequencies we set the *Vg=0*

$$-RIg + RIi - \frac{Ig}{CS} + \frac{Ii}{CS} - L2SIg = 0 \qquad (12)$$

$$-\left(R + \frac{1}{CS} + L2S\right)Ig + \left(R + \frac{1}{CS}\right)Ii = 0 \qquad (13)$$

By some manipulation we get *Ii* i.e. inverter side current

$$Ii = \left(\frac{RCS + L2CS^2 + 1}{RCS + 1}\right)Ig \qquad (14)$$

From equation (10)

$$Vi - L1SIi - \frac{Ii}{CS} + \frac{Ig}{CS} - RIi + RIg = 0 \qquad (15)$$

$$Vi = \left(L1S + \frac{1}{SC} + R\right)Ii - \left(\frac{1}{SC} + R\right)Ig \qquad (16)$$

Putting value of Ii from equation (14) in the equation (16)

$$Vi = \frac{(L1CS^2 + RCS + 1)}{CS}\frac{(L2CS^2 RCS + 1)}{(RCS+1)}Ig - \frac{(RCS+1)}{CS}Ig \qquad (17)$$

By solving brackets we get,

$$Vi = \frac{\left[L1L2C^2S^4 + L1RC^2S^3 + L1CS^2 + L2RC^2S^3 + R^2C^2S^2 + RCS + L2CS^2 + RCS + 1\right]}{CS(RCS+1)}Ig$$
$$- \frac{(RCS+1)}{CS}Ig$$
$$(18)$$

By taking denominator as CS

$$Vi(RCS+1) = \frac{\left[L1L2C^2S^4 + L1RC^2S^3 + L1CS^2 + L2RC^2S^3 + R^2C^2S^2 + RCS + L2CS^2 + RCS + 1\right]}{CS}Ig$$
$$- \frac{(RCS+1)^2}{CS}Ig$$
$$(19)$$

Now by cancelling plus and minus terms we get,

$$\frac{Vi(RCS+1)}{Ig} = \frac{L1L2CS^3 + (L1+L2)RCS^2 + (L1+L2)S}{1} \qquad (20)$$

Now by rearranging terms we get important transfer function

$$\frac{Ig}{Vi} = \frac{SCR+1}{S^3CL1L2 + S^2CR(L1+L2) + S(L1+L2)} \qquad (21)$$

$$H_{LCLR}(S) = \frac{Ig}{Vi} = \frac{SCR+1}{S^3CL1L2 + S^2CR(L1+L2) + S(L1+L2)} \qquad (22)$$

B. Frequency Response of LCLR filter

To know the frequency response of the *LCLR* filter system essentials to find transfer function of the filter. The transfer function of the *LCLR* which is the compensation characteristics of the filter and given by $H_{LCLR} = \dfrac{I_g}{V_i}$,

where I_g is the grid current and V_i inverter output voltage, in this case grid side voltage is assumed to be an idyllic voltage. Equation (23) gives the transfer function of *LCLR* with damping resistance. [12]

$$H_{LCLR}(S) = \frac{CRS+1}{L_1CL_2S^3 + CR(L_1+L_2)S^2 + (L_1+L_2)S} \qquad (23)$$

The filter parameter values are achieved from filter design procedure which is shown in table-2. Response of filter is shown in the Bode plot of *LCLR* with damping resistance in fig-12
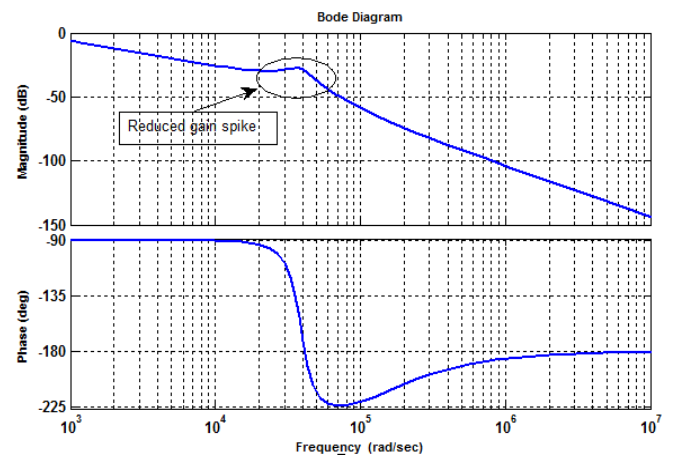

Fig-12: Bode plots of the *LCLR* filter showing response of filter with damping resistance.

The insertion of resistance in series with capacitor affects the frequency response of the *LCLR* filter which is easily observed in the fig-12. Without series resistance very high gain spikes are present in the magnitude Bode plot. When series resistance with capacitor inserted in filter then gain spike in the magnitude plot is almost reduced which smoothing the overall current response, in addition the series resistance plays important role in the filter to damp out the oscillations and its value is very small so very less voltage drop will occurs.

4. FILTER DESIGN PROCEDURE

A. Methodical Filter Design

Some important characteristics of filters must be considered in the designing of *LCLR* filter, such characteristics are: (i) filter size (ii) filter design (iii) amount of current ripple (iv) cost of the filter (v) switching attenuation performance of the filter. In case of the only *LCL* filter there is chance of resonance due to the reactive power requirement and because of this capacitor of filter will interfere with grid resistance; therefore must add passive component as like resistor in series with the capacitor. The passive component-resistance is added in series with capacitor to smooth the current ripples. The active components can be used to solve these problems.

The important parameters required for the filter design are:

V_{ph} : Phase voltage of inverter output

V_{LL} : Line to line voltage of inverter output

P : Rated active power

V_{DC} : DC voltage from renewable energy sources i.e. input voltage to the inverter

f_{sw} : Switching frequency of the inverter

f_g : Grid frequency

ω_g : Grid angular frequency

f_{res} : Resonance frequency

m : Inverter modulation factor

k_a : Desired attenuation constant

Firstly need to find base values of the system so that filter values is in percentage of base values, the base capacitance (C_b) and base impedance (Z_b) which are given by,

$$Z_b = \frac{E_n^2}{P} \tag{24}$$

$$C_b = \frac{1}{\omega_g Z_b} \quad ; \quad \omega_g = 2\pi f_g \tag{25}$$

In the normal power system, it is supposed that highest variation of power factor in grid is 5 %, when this value multiplied by base capacitance value to get capacitance value i.e. $C = 0.05 C_b$. The design factor greater than 5% can used to compensate the reactance of the filter which is inductive reactance [13]. The highest ripple of the current at output of the inverter is given by

$$\Delta I_{L\max} = \frac{2V_{DC}}{3L_1}(1-m)mT_{sw} \tag{26}$$

T_{sw} : Is the switching time of the inverter and m : modulation factor depends upon which PWM technique used by the inverter. It is seen that highest peak to peak current distortion occurs at $m = 0.5$, therefore inductor maximum current given by

$$\Delta I_{L\max} = \frac{V_{DC}}{6f_{sw}L_1} \tag{27}$$

Where, L_1 is the inductor of inverter side. For the maximum rated current consider 10% ripple in current. Rated maximum current given by,

$$\Delta I_{L\max} = 0.1 I_{\max} \tag{28}$$

Where

$$I_{\max} = \frac{P\sqrt{2}}{3V_{ph}} \tag{29}$$

Therefore L_1 is given by,

$$L_1 = \frac{V_{DC}}{0.6 f_{sw} I_{\max}} \tag{30}$$

The *LCLR* filter minimizes current distortion to very low level so ripple value will be below 2 %. The relation between harmonic current of inverter and the grid is given by,

$$\frac{i_g(h)}{i_i(h)} = \frac{1}{\left|1 + r\left(1 - L_1 C_b \omega_{sw}^2 x\right)\right|} = k_a \tag{31}$$

Where k_a is the desired attenuation factor of the inverter and r is the constant which is ratio of grid side inductor (L_2) to the inverter side inductor (L_1) and equation (32) gives its relation.
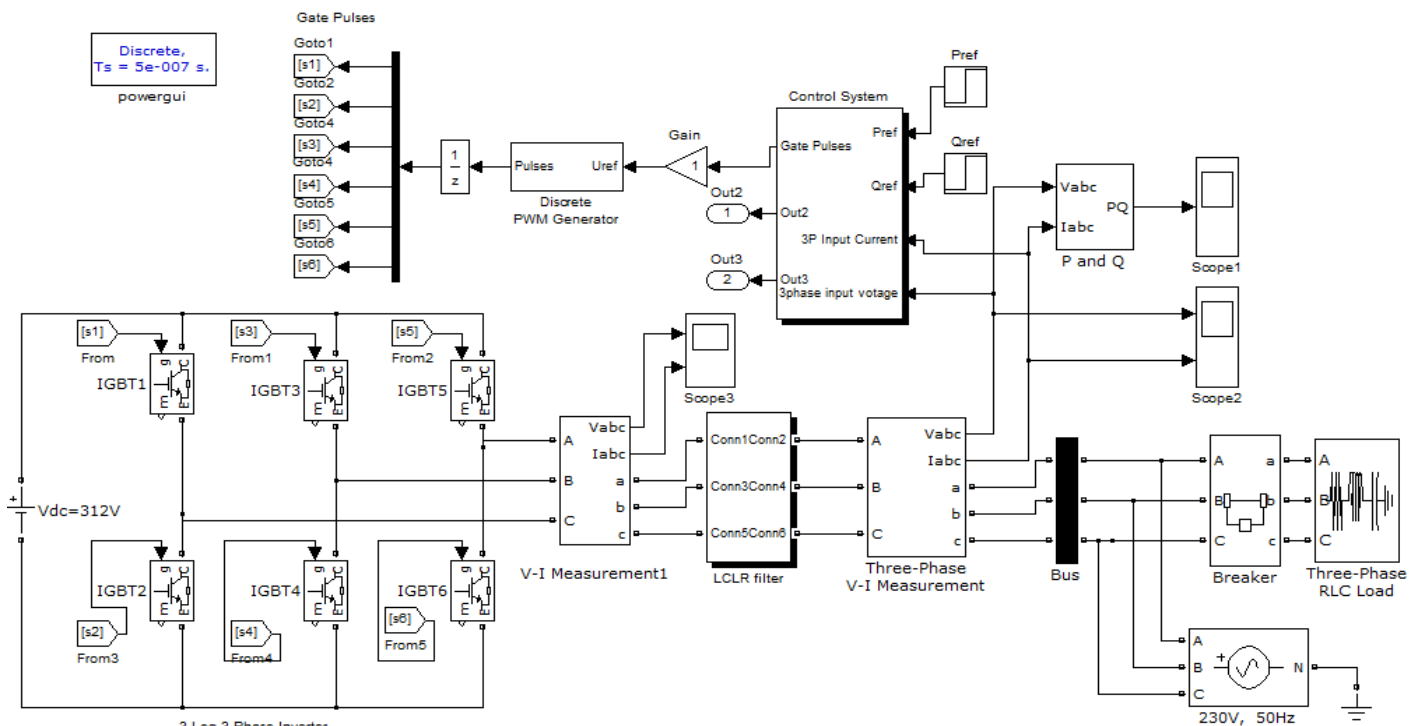
$$L_2 = rL_1 \tag{32}$$

Fig-13: Implemented System of Inverter with *LCLR* filter.

The scheming for the various values of *r* any can assess transfer of filter at specific resonance frequency which depends on the nominal impedance of the grid. [14]

The value of grid side inductor in terms of desired attenuation factor is given by,

$$L_2 = \frac{\sqrt{\frac{1}{k_a^2} + 1}}{C\omega_{sw}^2} \qquad (33)$$

The resistance (*R*) in series with capacitor (*C*) compensates the part of ripples in the switching frequency to avoid the resonance of the *LCLR* filter. The resonance frequencies in terms of *LCLR* filter parameters given in,

$$\omega_{res} = \sqrt{\frac{L_1 + L_2}{L_1 L_2 C}} \qquad (34)$$

The range of resonance frequency should satisfy

$$10f_g < f_{res} < 0.5f_{sw} \qquad (35)$$

The resistance value should be one third of capacitor impedance at the resonance frequency [15]. The equation (36) gives the value of resistance of *LCLR* filter.

$$R = \frac{1}{3\omega_{res}C} \qquad (36)$$

Table-1: PV Cell Parameters

PARAMETER	SYMBOLS	VALUE
Temperature	T	25+273.15 ^{0}C
Irradiance (p. u.)	$G = Irr$	1 W/m^2
Nominal Irradiance	$Ir0$	1000 W/m^2
Boltzmann Constant	K	1.38e-3
Charge	q	1.6e-19 C
Emission coefficient	n	1.36
Open circuit voltage	Voc	21.3 V
Short circuit current	Isc	3.8 A

Table-2: DC-DC Boost Converter Parameters

PARAMETERS	SYMBOLS	VALUE
Duty Cycle	D	0.575962
Boost Inductor	L_boost	0.0019 H
Boost Capacitor	C_boost	0.0044 F
Load Resistance	R	16.4211 Ω

Table-3: System Parameters

PARAMETERS	SYMBOLS	VALUE
Phase Grid Voltage	Vg	230V
DC Link Voltage	V_{DC}	312V
Nominal Power	P	5 KW

Grid Frequency	f_g	50 Hz
Switching Frequency	f_{sw}	15 KHz
Modulation Factor	M	0.05
Attenuation Factor	K_a	0.2

Table-4: *LCLR* Filter Parameters

| PARAMETERS	SYMBOLS	VALUE
Inverter Side Inductor	L_1	1.9729 mH
Grid Side Inductor	L_2	0.04495 mH
Capacitor of Filter	C	15.043 µF
Damping Resistance	R	0.5694 Ω

6. SIMULATION RESULTS AND DISCUSSION

A. *Inverter controller and LCLR Filter*

The model of Inverter with *LCLR* is done using MATLAB in Simulink Power System Tool Box shown in fig.13. The *LCLR* filter plays very important role in the Power Quality Improvement and better interconnection of renewable energy sources inverter with grid. For the inverter dqo algorithm is used for the power quality improvement which reduces THD to very low level. dqo Means the direct-quadrature-zero transformation is mathematical transformation which rotates the reference frame of three phase systems. The dqo transformation decreases three AC quantities (phases a, b, c) to two DC quantities so that simplified calculations can be done with DC quantities. These are done to simplify the calculations for control of the any three phase inverters.

B. *Inverter Without LCLR Filter*

Without *LCLR* filter inverter output current contains harmonics. The Fig-14 shows the inverter output voltage (230V) and fig-15(a), (b) and (c) shows phase a, b and c currents respectively and fig-16 shows inverter output current of combined phases a, b and c (0.015A). THD of the system is very high which is up to 50.38%. In this case current is much distorted so in the power system it is very dangerous and harmful. The Fig-17 shows THD analysis of the current.
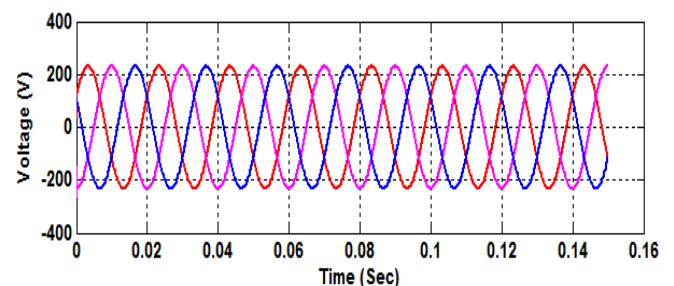
Fig-14: Inverter output voltage without *LCLR* Filter (230V)
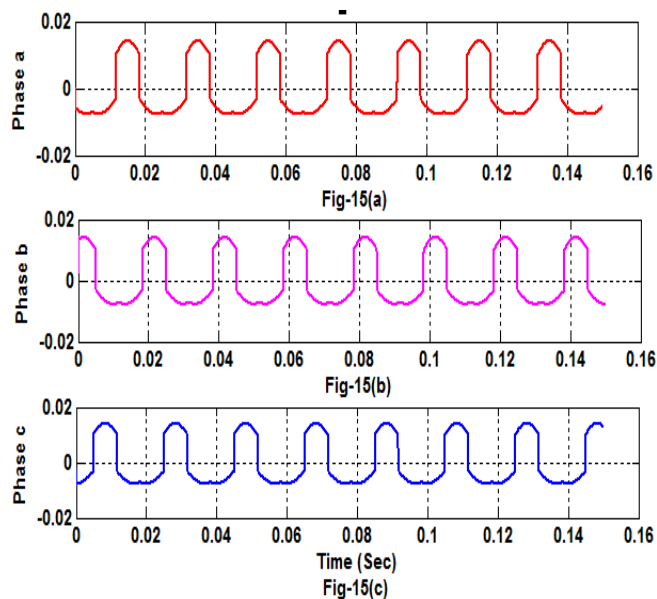
Fig-15(a), 15(b), 15(c): Inverter output Current without *LCLR* Filter of phase **a**, **b** and **c** respectively.
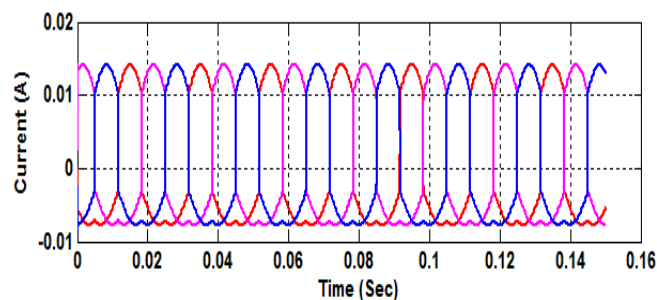

Fig-16: Inverter output Current without *LCLR* Filter of combined phases **a, b** and **c (0.015A)**.
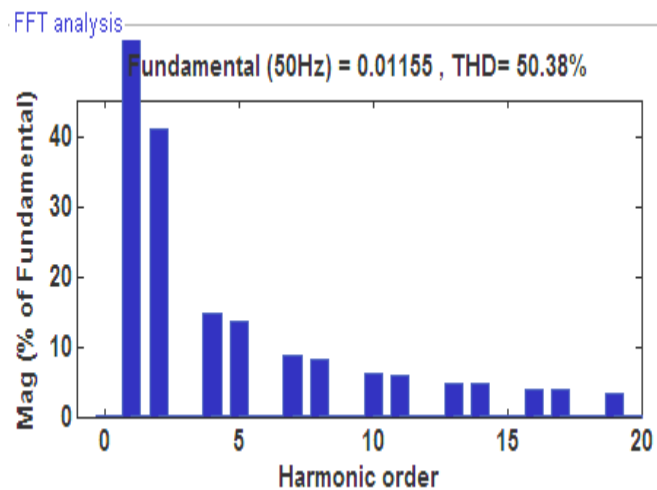

Fig-17: THD analysis of Inverter output Current without *LCLR* Filter.

C. Inverter With LCLR Filter

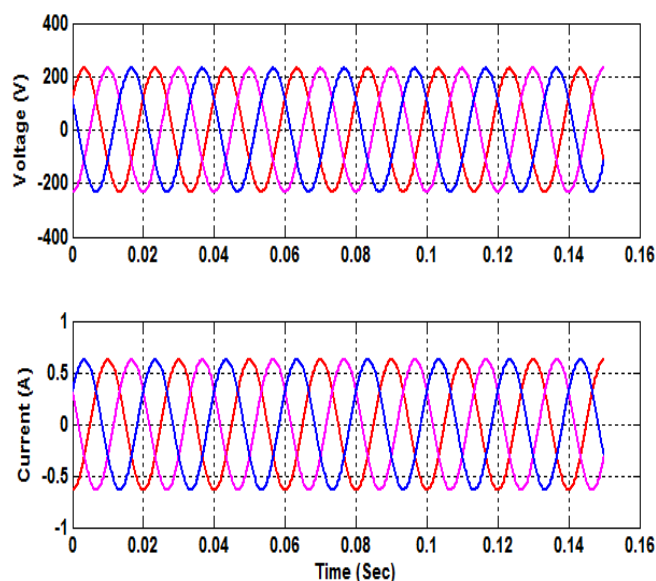With the *LCLR* filter the THD of the system is reduced to very low level which improves the power quality.

Fig-18: Inverter output active, reactive power, Voltage and Current with *LCLR* Filter.

Fig-18 shows the inverter output voltage (230V), current (0.6A); these quantities are nearly sinusoidal from the MATLAB simulation results. Means the total harmonic distortion percentage is almost reduced. Fig-19 shows the THD analysis of the current and THD of the system is only 0.94%.
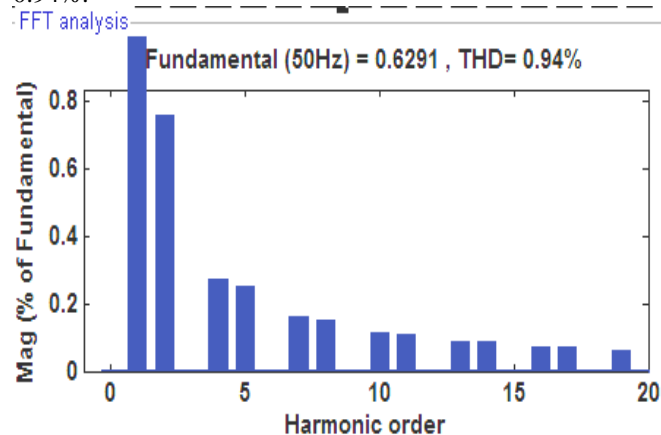

Fig-19: THD analysis of Inverter output current with *LCLR* filter

7. CONCLUSIONS

In this paper *LCLR* filter is designed systematically with grid connected inverter system. The inverter is fed by renewable energy sources as PV cell and generates required DC voltage; these papers also proposes DC-DC Boost Converter for regulating the voltage of PV cell and boost the voltage level up to optimal required voltage for inverter. The very cheap *LCLR* filter with grid connected inverter reduces system THD and it is found that proposed *LCLR* filter meets THD within prescribed range which is up to 0.94 % therefore power quality would be improved as well as grid interconnection of inverters with renewable energy sources is done bitterly.

ACKNOWLEDGEMENT

REFERENCES

[1]. 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

[2]. F. Bouchafaa, D. Beriber, and M. S. Boucherit, "Modeling and control of a grid connected PV generation system," in Proc. 18th MED Conf. Control Autom., 2010, pp. 315–320

[3]. Singh Bhim, Jayaprakash P, Somayajulu TR, Kothari DP. "Reduced rating VSC with a zig-zag transformer for current compensation in a three-phase four wire distribution system,'' IEEE Trans Power Deliv 2009; 24 (1): 249.

[4]. Singh Bhim, Jayaprakash P, Kothari DP. "A T-connected transformer and three leg VSC based DSTATCOM for power quality improvement," IEEE Trans Power Electron 2008; 23 (6):2710–8.

[5]. Zaveri Tejas, Bhalja Bhavesh, Zaveri Naimish. "Comparison of control strategies for DSTATCOM in three-phase, four-wire distribution system for power quality improvement under various source voltage and load conditions," Electr. Power Energy Syst 2012; 43: 582–94.

[6]. IEEE 1233 standard for power quality definitions.

[7]. IEEE 519 standard for harmonic control in electrical.

[8]. KHELIF Messa oud, M'RAOUI Abdelhamid, MALEK Ali. "Simulation optimization and performance analysis of an analog, easy to implement, perturb and observe MPPT technique to be used in a 1.5 KW p photovoltaic system," Centre de Development des Energies Renouvelables, CDER, 16340, Algiers, Algeria.

[9]. Sajib Chakraborty, Saila Ishrat Annie and M. A. Razzak. "Design of Single-Stage Buck and Boost Converters for Photovoltaic Inverter Applications," 3rd Inter. Conf. on Informatics, Electron & Vision 2014.

[10]. http://www.scribd.com/doc/53012897/slva372b/access ed on July, 2013.

[11]. R. O. Caceres, I. Barbi, "A boost dc-ac converter: Analysis, design, and experimentation,'' IEEE Trans. Power Electron., vol. 14, no. 1, pp. 134--141, 1999

[12]. Ravish R. Singh, "Electrical Networks," Tata McGraw-Hill Publication, first edition, 2008.

[13]. V. H. Prasad, "Average current mode control of a voltage source inverter connected to the grid: Application to different filter cells," M.S. thesis, Dept. Elect. Eng., Virginia Polytech. Inst. State Univ., Blacksburg, VA, USA, 1997.

[14]. Y. Tang, S. Member, P. C. Loh, P. Wang, and F. H. Choo, "Generalized Design of High Performance Shunt Active Power Filter With Output LCL Filter," IEEE Transactions on Industrial Electronics, vol. 59, no. 3, pp. 1443-1452, 2012.

[15]. S. V. Araújo, A. Engler, B. Sahan, V. U. Kassel, F. Luiz, and M. Antunes, "LCL filter design for grid-connected NPC inverters in offshore wind turbines," in Proc. 7th Int. Conf. Power Electron., 2007, pp. 1133–1138.

[16]. M.G. Villalva, J.R. Gazoli, E. Ruppert "Modeling and Circuit Based Simulation of Photovoltaic Arrays", Brazilian Journal of Power Electronics, Vol. 14, No. 1, pp. 35-45, 2009.

[17]. C. Osorio. Matlab-Simulink models, Math works.

[18]. http://ecee.colorado.edu/~ecen2060/matlab.html.

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