Design of LCL-LCL Harmonic Filter for Grid Connected Photo Voltaic Cell Array

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Abstract: **This paper represents a control method for a three-phase grid interaction voltage source inverter (VSI) that links a renewable energy source to utility grid through a *LCL*-type filter. The use for Distributed or Disperse Generation is rapidly increasing in modern distribution networks because for their potential advantages.LCL filters have very high gain at filter cutoff frequency, so naturally if that frequency gets excited then system will oscillate. As a result system becomes highly sensitive to outside disturbances. One way for reducing resonance oscillation in current & voltage for system is by adding a passive damping circuit to filter. This damping circuit may be purely resistive or more complex solution consisting for a combination for resistors, capacitors and inductors. A more attractive option is use for active damping where output voltage from converter is used (suitable control action) to damp out resonance oscillations. Greater emphasis is given to active damping in current work. few for techniques are available in literature based on current control strategy for converter, however all above methods resolve problem up certain level however still problem remains that to deal with switching frequency and so harmonics may be reduced proposed work has come up with a new design in which 2-LCL type filter which has high efficiency and high attenuation than previous and better response at high frequencies.**

Keywords: **THD – Total Harmonic Distortion, VSI – Voltage Source Inverter, RMS – Root Mean Square, PID - Proportional, Integral and Derivative**

I-INTRODUCTION

The grid interfacing converters are basically power electronic converters acts as an interface between electrical load and distributed generation to grid. This inverter match features for renewable energy source and requirements for grid connections, provides DPGS with power system control capabilities, improves power quality and their effect on power system stability [9].However, because for non-linear switching features for inverter switches, grid current waveform contains higher order harmonics A filter connected in series with inverter makes sure that harmonic content is below specified limit.

There are various kinds for filters like L, LC and LCL are extensively studied in available literature. Among all for them, LCL filter is proved to have better harmonic attenuation for same value for inductance [10]. Resonance problem in filter is overcome by using various damping methods. LCL filter is connected in series with inverter on output side. Schematic diagram for single-phase grid connected inverter is shown in Fig.1 with incorporation for LCL filter on grid side.

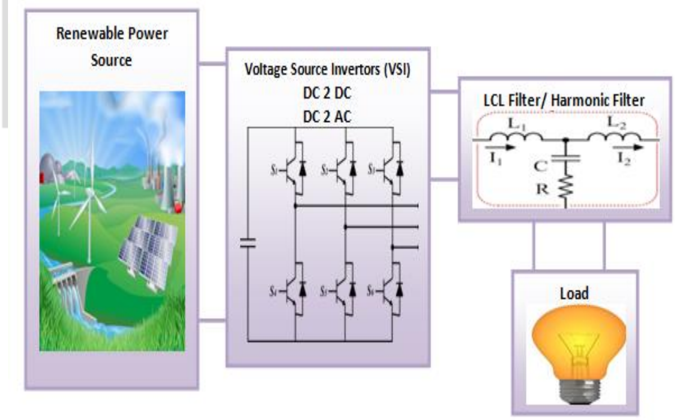

Fig.1. Single phase grid connected inverter with LCL filter

In this thesis optimal design for LCL filter for grid connected inverter system is also studied. Here, initially normal design is studied. Then conduction and switching losses that are caused by filter are calculated and are optimized considering level for decrease for harmonics. Hence our main aim is to attenuate harmonics along with decrease in switching losses. Also various switching schemes for single phase unipolar full bridge inverter are studied and compared to get switching scheme which gives lesser switching losses. LCL filter is designed accordingly and optimal inductance and capacitance values are obtained. All related models are simulated using MATLAB software and graphs are studied.

II- HARMONIC FILTERS

Harmonic voltages and currents in an electric power system are a result for non-linear electric loads. Harmonic frequencies in power grid are a frequent cause for power quality problems. Harmonics in power systems result in increased heating in equipment and conductors, misfiring in variable speed drives, and torque pulsations in motors decrease for harmonics is considered desirable
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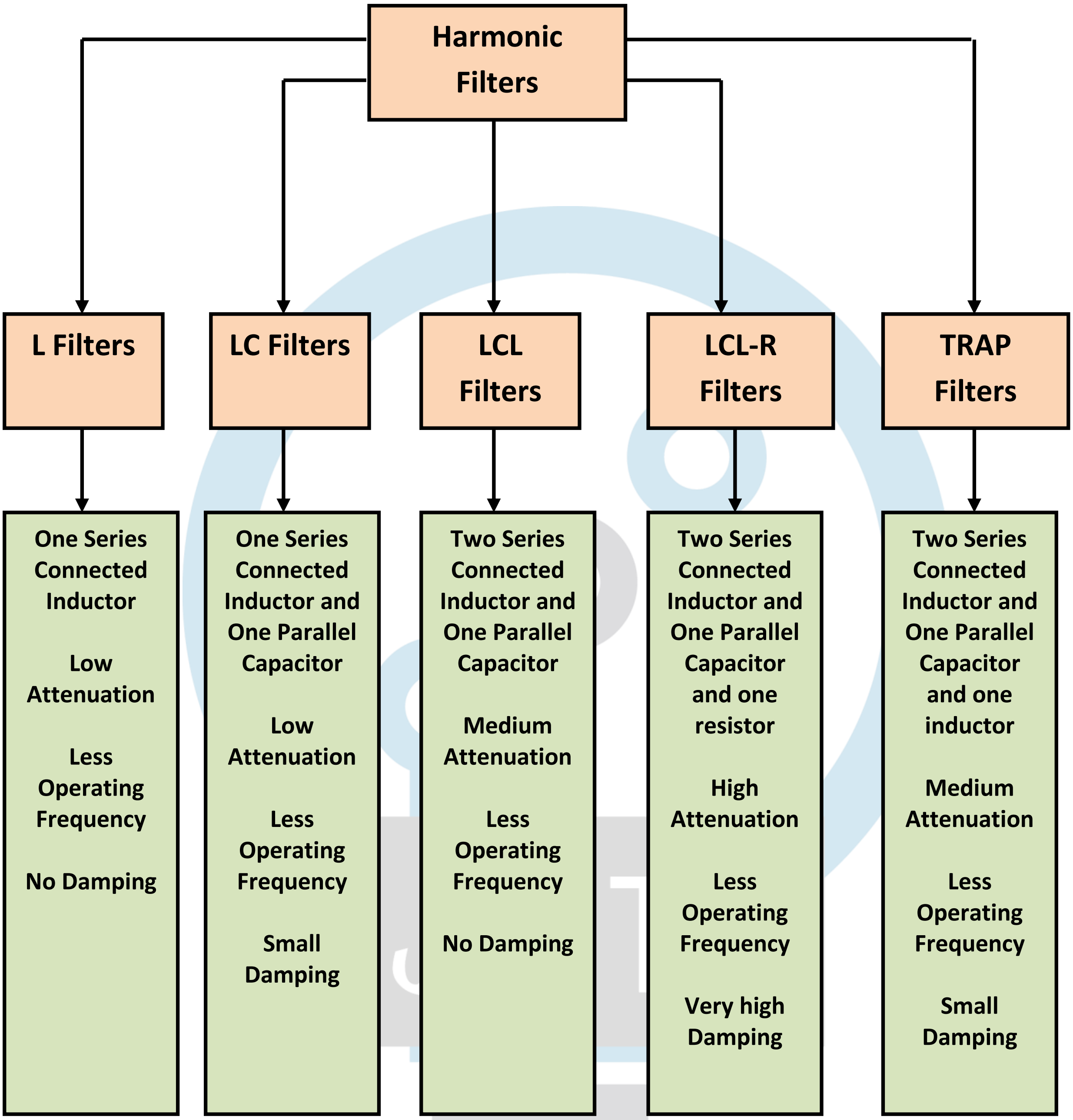

Figure 2 Harmonic Filters types

Filter Type	Attenuation	Damping at resonant freq	Maximum Freq

L Filter	15 db	0 db	4 KHz
LC filter	18 db	2 db	5-6 KHz
LCL Filter	20 db	0 db	10 KHz
LCL-R filter	37 db	100 db	10 KHz
TRAP filter	25 db	10 db	20 KHz

Table 1 Harmonic Filter Analysis

L filters: Firstly an L filter is an easy filter designed to mitigate harmonics in grid side current. But there are lots drawbacks for L filter like poor system dynamics, low attenuation and long time response for improve mitigation level, we have to either increase value for inductor or increase switching frequency where both for them cause increased losses.

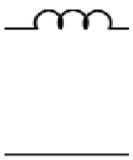

Figure 3 L harmonic Filter[17]

LC filters: A shunt element is added to an L filter to improve attenuation for switching frequency components. Since a capacitance gives low reactance at high switching frequency it is selected as shunt element. However it is observed that load impedance across capacitor is very high.

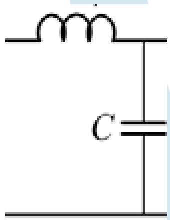

Figure 4 LC harmonic Filter[17]

LCL filters: It provides better decoupling between filter and grid impedance. It also has better attenuation ratio with smaller values for L and C. Hence LCL filter is designed for grid connected applications. Resonance is main problem with LCL filter and it may be damped either by using active damping methods or passive damping methods. However for grid connected applications passive damping procedure is necessary in case when inverter is switched off and filter is still connected to grid.

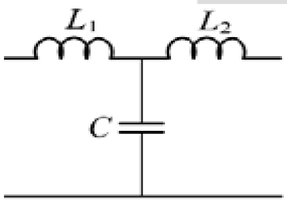

Figure 5 LCL harmonic Filter[1]

$$\frac{i_{L_2}}{U_{inv}} = \frac{1/(L_1 + L_2)}{s(1 + s^2(L_1||L_2.C))} \qquad Eq(1)$$

U_{inv} is applied voltage from transfer function it is clear that, at frequency for

$$f_0 = \frac{1}{2\pi\sqrt{(L_1||L_2.C)}} \qquad Eq(2)$$

Eq1 above shows the transfer function trans-conductance of LCL filter and Eq (2) show the resonance frequency of the LCL filter.

LCL-R filter design with passive damping: Drawback for LCL filters has very high gain at filter cutoff frequency, so naturally if those frequencies get excited then system will oscillate. As a result system becomes highly sensitive to outside disturbances. One way for reducing resonance oscillation in current & voltage for system is by adding a passive damping circuit to filter. Here a resistor is connected in series with capacitor as a part for passive damping scheme.

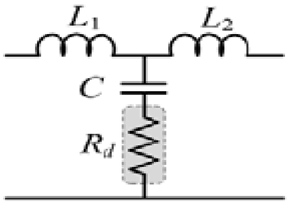

Figure 6 LCL-R harmonic Filter[3]

$$\frac{i_c}{U_{inv}} = \frac{L_2}{L_1 + L_2} . \frac{sC}{(1 + CR_d s + s^2(L_1||L_2.C))} \qquad Eq(3)$$

$$\frac{i_{L_2}}{U_{inv}} = \frac{1 + sCR_d}{(s^3 L_1 L_2 C + s^2(L_1 + L_2)CR_d + s(L_1 + L_2)} Eq(4)$$

Eq2 above shows the transfer function trans-conductance of LCL-R filter and Eq 4 show the resonance frequency of the LCL-R filter.

TRAP filter: In LCL-R larger resistance tends to reduce attenuation above resonant frequency. It is undesirable from harmonic filtering point for view, So an inductor is connected in series with capacitor as a part for damping scheme called as TRAP filter. In TRAP filter attenuation at switching frequency is improved however at same time damping is bit affected. However major advantage for this type damping loss at fundamental frequency is considerably improved

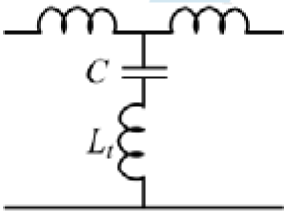

Figure 7 TRAP harmonic Filter[1]

$$G_{\text{trap}}(s) = \frac{L_r C s^2}{(L_1 L_2 C + (L_1 + L_2) L_r C) s^3 + (L_1 + L_2) s} \quad Eq(5)$$

Eq5 above shows the transfer function trans-conductance of Trap.

II- LITERATURE REVIEW

The importance for renewable energy sources is given by [2]. Paper [3] gave initial idea for filter for why it is used how it is to be connected. Then further study continued when more about single phase inverters is studied in [5]. Reference [4]-[7] aided in comparative study between unipolar and bipolar switching schemes and also in study where LCL filter is proved to be a better one in attenuating higher order harmonics. Later in this work, filter design is optimized by following work for [11] taking losses caused by filter. Further research continued to reduce switching loss for inverter [12] so that efficiency for whole system is increased. One may reduce switching losses by simply applying soft switching scheme however external components that are used are sometimes for higher rating than that for switches for inverter and hence soft switching is not a better option. It is important that inverter supplies appropriate voltage and frequency waveform in island mode. Voltage must comply with amplitude and frequency conditions regardless for type for load connected, for study stability for system, transfer function is found out by making small signal analysis [15].

Fei Li et al. [1] presented a paper for further cut down cost for filter for grid-connected pulse width modulation (PWM) converter under more and more stringent grid code, a new kind for high-order filter, named *LCL-LC* filter, is presented in this paper. Resonant frequency features for filter are analyzed, and a parameter design procedure on base for features is also proposed in paper. Proposed parameter design procedure may easily make full use for existing research results about traditional *LCL* filter parameter design. And then a parameter robustness analysis procedure based on four-dimensional graphics is proposed to analyze parameter robustness for presented filter. Compared with traditional one, proposed analysis procedure may analyze filter performance under variations for several parameters at a time without any iteration. Comparative analysis and discussion considering *LCL* filter, trap filter, and *LCL-LC* filter, are presented and verified through experiments on a 5 kW grid-connected converter prototype

In this paper [1], a type filter for grid-connected converter, named *LCL-LC* filter, has been presented. Paper [1] models and analyzes presented filter. And then two resonant frequency features for filter are obtained. A parameter design procedure for presented filter based on obtained features is proposed. Then a parameter robustness analysis procedure is proposed to check filter performance under conditions for parameter variations. Following may be concluded:

Presented filter has a higher harmonic attenuation rate in high-frequency band than that for a trap filter and ability for bypassing switch current harmonics, which is advantage for a trap filter. Proposed parameter design procedure decomposes whole filter parameter design into a traditional *LCL* filter part and an *LC* series resonant circuit part. Procedure may easily make full use for existing research results about traditional *LCL* filter parameter design.

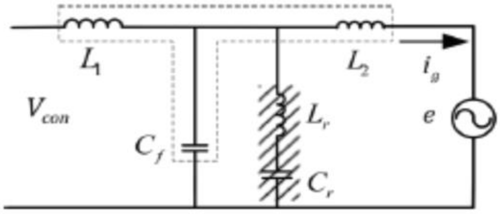

Figure 7 LCL-LC filter by Fei Li et al[1]

LCL-LC [1] filter: topology for filter, as shown in Fig. 7, is composed for a traditional *LCL* filter (dotted box) and a series resonant circuit (dashed area). Transfer function $i_g(s)/V_{con}(s)$ for presented filter may be derived as follows:

$$G_{LCL-LC}(s) = \frac{L_r C_r s^2}{As^5 + Bs^3 + Cs}$$

Where
$A = L_1 L_2 L_r C_r C_f$
$B = L_1 L_2 (C_f + C_r) + L_r C_r (L_1 + L_2)$
$C = L_1 + L_2$
The *LC* circuit resonates at switching frequency

$$\omega_{sw} = \frac{1}{\sqrt{L_r C_r}}$$

The current harmonic amplitude at switching frequency in *LCL-LC* filter is almost equal to zero. It proves that presented filter has ability for bypassing switching current harmonics and damping resistor has no effect on this ability
.

Year	Author	Journal	Method	Outcomes
2015	Fei Li, Xing Zhang,	IEEE TRANSACTIONS	LCL-LC filter developed for Harmonicas removal form VSI output	60 db attenuation with 6 db damping at resonance
2017	Subash chandar, Sanjib Kumar Panda	IEEE TRANSACTIONS	Active Front End Rectifier (AFER) used along with LCL Filter for harmonics removal	THD equal to 6.47
2015	Mojgan Hojabri, Mehrdad Hojabri,	International Journal of Electrical	Second and third-order passive filters (LC and LCL) for harmonics removal	THD equal to 7.73
2014	S. Arul Murugan1,	IJIRSET	proportional-integral (PI) controller are implemented to remove harmonics instead of LCL filter	8.91 THD
2014	Mohammadamin Heidari	Research Journal of Recent Sciences	active power filter is included to eliminate the harmonics	9.11 THD

Table 2 Literature Review

III- CONCLUSION

Energy demand has increased dramatically and also amount for fossil fuels has been depleting to a minimum extent. So renewable Energy demand more, however conversion efficiency for these sources is very less which leads to a very high cost for production. In photovoltaic system, cost for PV panel is very high and at same time energy conversion only around 18%. After this another losses that further occurs like an inverter that is used to convert DC to DC first than DC to AC introduces lots for harmonics to grid side current which may lead to damage for load and reduce efficiency. The switching frequency for converters is generally between 5 kHz and 20 kHz and causes high order harmonics that may disturb other EMI sensitive loads/equipment on grid side. Choosing a high value for line-side inductance may resolve this problem, however this makes system expensive and bulky. On contrary, to adopt an LCL-LC [1] filter configuration allows to use reduced values for inductances (preserving dynamic performance) and to reduce switching frequency pollution emitted in grid. Main goal is to ensure a decrease for switching frequency ripple at a reasonable cost and, at same time, to obtain a high performance active rectifier. Usually converter side reactor is bigger than grid side one because it is responsible for attenuation for most for switching ripple. Ac capacitor is limited in order not to reduce too much reactive power drawn and grid side reactor is chosen for properly tune cut-off frequency for LCL-LC [1] filter. So, it is necessary to design for a filter is necessary to remove these harmonics. Also, power loss decrease is needed to improve efficiency for system, [2] has used LCL with passive resistance in parallel there they achieve harmonic attenuation around -60db however problem in load power few power consumed in resistance and hence it reduces efficiency for system. [1] has design to overcome problem for efficiency from [2] for that they develop LCL-LC filter which reduces harmonics upto -60db maximum and another issue with LCL-LC filter that it was frequency dependent at low frequency attenuation was very good and -60db however at high frequency attenuation reduces to -40 db.

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