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REVIEW ARTICLE

COMPARISON OF PASSIVE DAMPING SOLUTIONS OF LCL-FILTER BASED GRID CONNECTED INVERTER

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ABSTRACT

In order to interface with the power grid a filter is required for grid connected inverter. Usually L or LC filter are used. LCL-filter is a third order passive filter which is having more interest to use for grid connected inverter. Compared to L, LC filters, LCL-filter has high attenuation ability even with the lower values of L and C. As it is a third order filter, this filter suffers from stability problems around the resonant frequency. LCL-filter resonance causes a sharp phase step down of -180 with a high resonant peak which should be damped. In order to ensure system stability different passive damping solutions based on the location of the resistor are analyzed in this paper. Mathematical model and design of LCL-filter for different passive damping solutions are presented. Simulation results are provided for each damping solution.

INTRODUCTION

According to Indian Energy Agency (IEA), world electricity demand will have increased by 70% by 2040. Meeting the increased demand only by using conventional sources is not possible because they are likely to be depleting with time and also, usage of fossil fuels leads to the environmental pollution. Over the last few years, the usage of renewable energy sources increased to reduce the environmental pollution. To achieve the large scale utilization of these resources, renewable energy based distribution power generation systems (RE-DPGS) became a significant development. The main advantages of the RE-DPGS are high reliability, low power loss, environmental friendliness, cost effective. In order to interface between the renewable energy sources and the utility grid, a grid connected inverter is used. While interfacing the RES and the utility grid synchronization is very important. Synchronization can be achieved manually or automatically. Synchronization means it minimizes the difference voltage, phase angle and frequency between the corresponding output and the grid supply [Svensson, 2001]. The output current of the inverter and grid must be synchronized; otherwise it can't deliver the power unless it is running at the same frequency as the network. The purpose of synchronization is to monitor and automatically take necessary action to avoid the abnormalities in voltage and frequency. In RE-DPGS, grid connected inverter plays key role for achieving safe and stable operation.

Grid connected inverter may be single-phase or three-phase and are used to convert dc power to the high quality ac power and fed into the grid. Switching harmonics are produced by the pulse width modulation which is used in grid connected inverter. In order eliminate these harmonics, a filter is required. Usually L or LCL filter are used. Compared to the former one, latter one can able to suppress the high frequency harmonics even with the small inductance values [Sosa *et al.*, 2014; Yagnik and Solanki, 2017; Cha and Vu, 2010]. However, at resonant frequency LCL filter suffers from resonant peak which leads to system instability. To ensure the system stable resonance caused by the LCL-filter should be damped. There are two types damping methods: passive damping and active damping. In this paper LCL-filter based on passive damping is discussed. Passive damping is easy since only one resistor is to be connected into the LCL-filter. There are six basic damping solutions based on the location of the damping resistor. Design of the LCL-filter and mathematical modeling of the different passive damping solutions are discussed in following sections. The single-phase LCL-type grid-connected inverter is as shown in fig: 1

LCL-Filter design

Frequency response of LCL-filter

Fig2 shows the configuration of the LCL-filter without any damping. It consists of inverter side inductor L1, filter capacitor C, grid side inductor L2. The transfer function $H_{LCL} = \frac{i_g}{v_{in}}$

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Assume grid voltage to be an ideal voltage source which is capable of dumping all the harmonics. If one sets vg=0, then the transfer function of the LCL-filter when there is no damping is as follows.

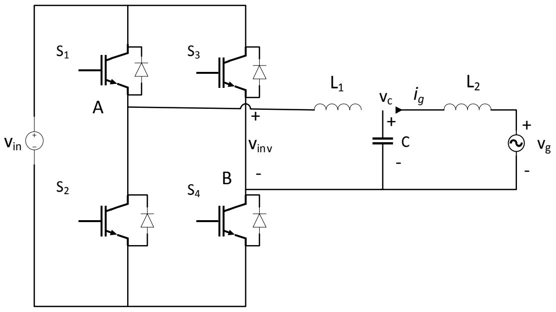

Fig. 1. single-phase LCL-type grid connected inverter

$$H_{LCL}(s) = \frac{1}{s^3 L_1 L_2 C + s(L_1 + L_2)} \qquad (1)$$

The resonance angular frequency is given by

$$\omega_{res} = \sqrt{\frac{L_1 + L_2}{L_1 L_2 C}}$$

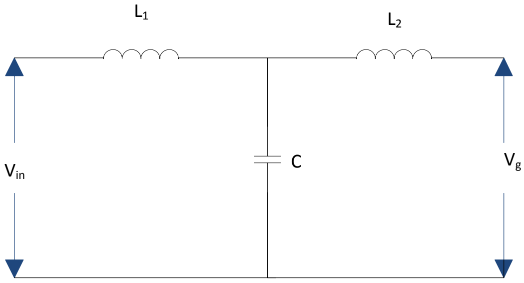

Fig. 2. Configuration of LCL-filter without any damping

Filter design

The LCL-filter has good current ripple attenuation even with small inductance values. However, it suffers from resonant peak which leads to system instability. In order to ensure the system stability, damping is required and control parameters should be properly designed. In designing the LCL-filter various features must be considered such as filter size current ripple, switching ripple attenuation. The study of the design is based on [Reznik *et al.*, 2014]. The parameters that are required for the design of the LCL-filter are:

- ✓ P-rated active power
- ✓ Vg=grid voltage
- ✓ V DC- dc link voltage
- ✓ fg- frequency of the grid
- ✓ fres- resonance frequency
- ✓ fsw- switching frequency

The below equations (2) and (3) determines the base impedance and base capacitance.

$$Z_b = \frac{E^2}{P} \qquad (2)$$

$$C_b = \frac{1}{\omega_g Z_b} \qquad (3)$$

In case of designing filter capacitor, the maximum power factor variation considered as 5%. Then the base impedance is adjusted as

$$C = 0.05 C_b \qquad (4)$$

The maximum current ripple at the phase current can be given by,

$$\Delta I_{L_{max}} = \frac{2V_{DC}}{3L_1}(1-m)mT_{sw} \qquad (5)$$

Where m-modulation factor of the inverter
At m=0.5 maximum peak-peak current ripple happens

$$\Delta I_{L_{max}} = \frac{V_{DC}}{6 f_{sw} L_1} \qquad (6)$$

10% ripple allowed for the rated current

$$\Delta I_{L_{max}} = 0.1 I_{max} \qquad (7)$$

Where

$$I_{max} = \frac{P\sqrt{2}}{3V_{p\square}} \qquad (8)$$

$$L_1 = \frac{V_{DC}}{6 f_{sw} \Delta I_{L_{max}}} \qquad (9)$$

The expected current ripple of the LCL-filter should reduce to20% then the resulting ripple is 2% of the output current.
The harmonic current generated by the inverter to that of current injected in grid is given by

$$\frac{i_g(\square)}{i_i(\square)} = \frac{1}{[1 + (1 - L_1 C_b \omega_{sw}{}^2 x)]} = k_a \qquad (10)$$

$$L_2 = \frac{\sqrt{\frac{1}{k_a}} + 1}{C \omega_{sw}{}^2} \qquad (11)$$

Where k_a is desired attenuation

$$C = 0.01 \div 0.05 C_b$$

At the resonant frequency, the resistor value should be one-third of the filter capacitor [6]. The resistance of the damping resistor is given by,

$$R_d = \frac{1}{3\omega_{res} C} \qquad (12)$$

Passive damping methods

The resonance in the LCL-filter leads to instability of the system and it should be attenuated. In order to attenuate resonance caused by the high order filters (LC and LCL), passive and active damping methods are used [Wu *et al.*, 2013]. In this paper only passive damping methods are presented. Passive damping solutions are very easy since only one resistor is to be inserted in to the filter. Equation (1) gives the transfer function of the LCL-filter without any damping. The bode plot for the LCL-filter without any damping is shown in fig.3 We can observe that without any damping, at resonant frequency there is sharp phase step down of-180° with high resonant peak which should be damped in order to stabilize the system.

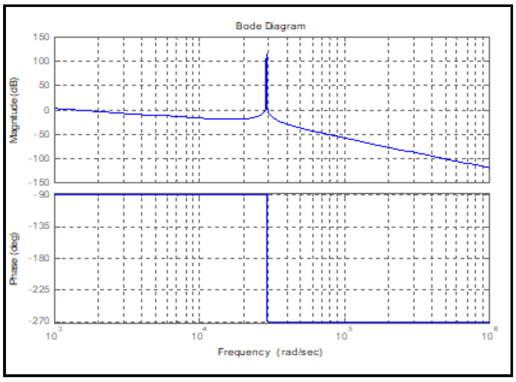

Fig. 3. Response of LCL-filter without any damping

Resistance Rd in series with L1

This is one of the passive damping methods. In this the damping resistor is connected in series with the inverter side inductor as shown in fig: 4

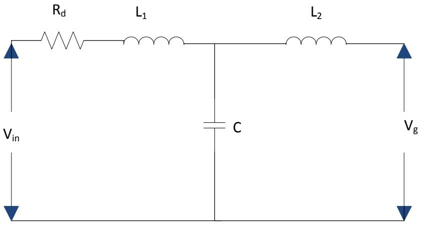

Fig. 4. Resistor in series with L_1

The transfer function for the above configuration is given by

$$H_{LCL}(s) = \frac{1}{s^3 L_1 L_2 C + s^2 R_d L_2 C + s(L_1 + L_2) + R_d} \qquad (13)$$

The frequency response is as shown in fig: 5 in this configuration the resonant peak is somewhat reduced. In this low frequency gains of LCL-filter are reduced because at low frequency range the inductor reactance is very small and the resistor increases the value of impedance for the inverter side inductor branch which reduces the gain. While at high frequency range, the inductive reactance is very large and the effect of resistor is neglected.

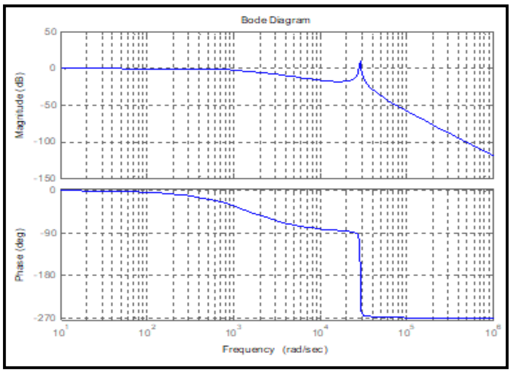

Fig. 5. Frequency response when resistor in series with L_1

Resistance Rd in series with L2

In this the resistor is connected in series with the grid side inductor L2 as shown in fig: 6 The transfer function is obtained as,

$$H_{LCL}(s) = \frac{1}{s^3 L_1 L_2 C + s^2 R_d L_1 C + s(L_1 + L_2) + R_d} \qquad (14)$$

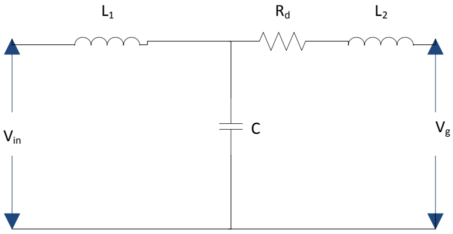

Fig. 6. Resistor in series with the grid side inductor

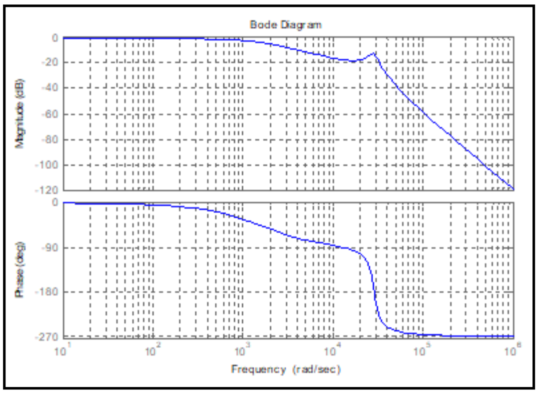

Fig. 7. Frequency response of LCL-filter when resistor in series with L_2

The frequency response is shown in fig: 7. Similar to the resistor in series with inverter side inductor, in this also low frequency gains are reduced and at higher frequency the effect of resistor is neglected.

Resistance in parallel with L1

The resistor is connected in parallel with the inverter side inductor branch as shown fig: 8 The transfer function is give by,

$$H_{LCL}(s) = \frac{\frac{sL_1}{R_d} + 1}{s^3 L_1 L_2 C + \frac{s^2 L_1 L_2}{R_d} + s(L_1 + L_2)} \qquad (15)$$

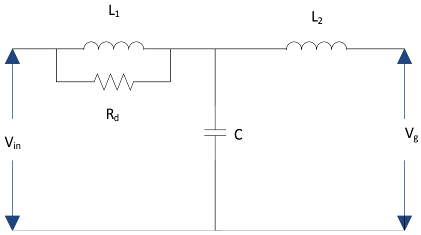

Fig. 8. Resistor in parallel with inverter side inductor

Frequency response for this configuration is shown in fig: 9. at high frequencies the inductive reactance is very large and parallel resistor reduces the impedance of the inverter side inductor branch which reduces the higher harmonic attenuation ability. And at the lower frequencies the inductive reactance is very small and the effect of resistor is neglected.

Resistance in parallel with L2

The resistor is connected in parallel with the grid side inductor as shown in fig: 10. The transfer function is obtained as,

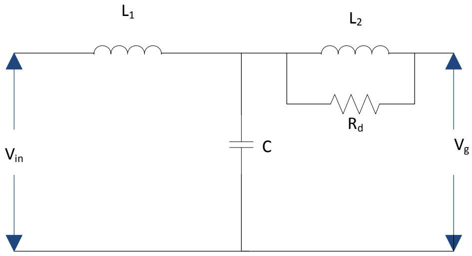

Fig. 10. damping resistor in parallel with L_2

$$H_{LCL}(s)=\frac{\frac{sL_2}{R_d}+1}{s^3L_1L_2C+\frac{s^2L_1L_2}{R_d}+s(L_1+L_2)} \qquad (16)$$

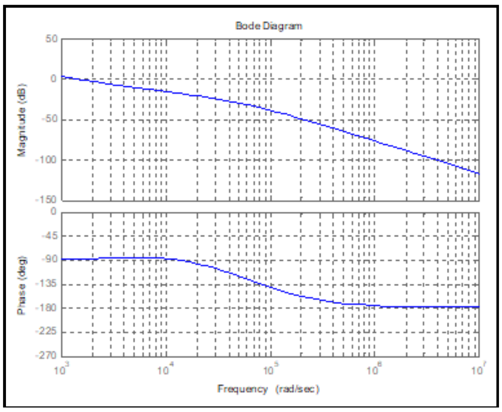

Fig. 11. Frequency responseof LCL-filter when resistor in parallel with L2

Similar to the resistor in parallel with the inverter side inductor, in thi configuration also the higher harmonic attenuation ability is reduced at high frequency range and the effect of damping resistor is neglected at the lower frequency range.

Resistance Rd in series with the filter capacitor

When a damping resistor Rd is connected in series with the filter capacitor as shown in fig: 12

The transfer function is obtained as,

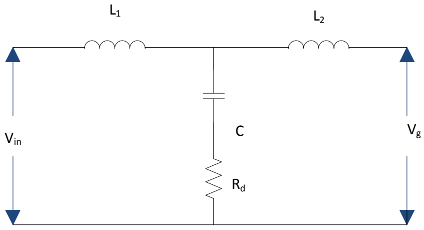

Fig. 12. Resistor in series with capacitor C

$$H_{LCL}(s)=\frac{R_dCs+1}{s^3L_1L_2C+s^2R_dC(L_1+L_2)+s(L_1+L_2)} \qquad (17)$$

It can be seen that from frequency response fig: 13 of the series damped LCL-filter, the resonant peak is reduced but the harmonic attenuation ability is reduced at the high frequency range. At the high frequency range, the series resistor increases the impedance of the capacitor branch as capacitor reactance is very small which decreases the harmonic attenuation ability.

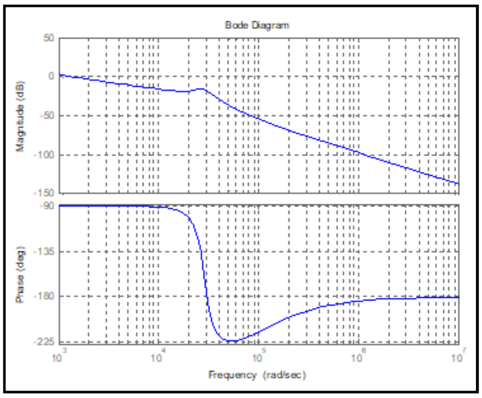

Fig. 13. Response of LCL-filter when resistor connected in series with filter capacitor

Resistance Rd in parallel with the filter capacitor

Another way to eliminate the resonance in the LCL-filter is adding a damping resistor in parallel with the filter capacitor as shown in fig: 15

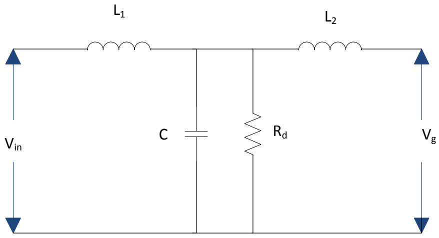

Fig. 15. Resistor in parallel with capacitor C

The transfer function is obtained as,

$$H_{LCL}(s)=\frac{1}{s^3L_1L_2C+\frac{s^2L_1L_2}{R_d}+s(L_1+L_2)} \qquad (18)$$

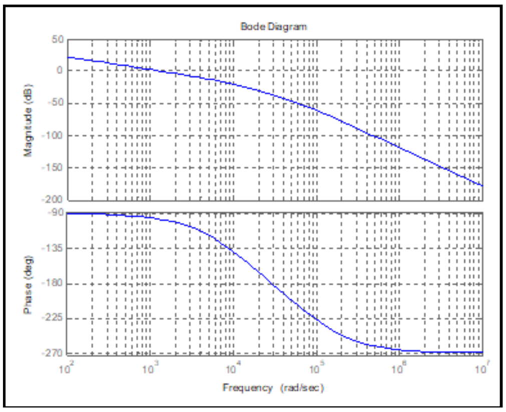

Fig. 16. Response of LCL-filter when resistor connected in parallel with filter capacitor

For both high and low frequency ranges, the resistor will not affect the magnitude-frequency characteristics as the resistor can be neglected in both cases. At higher frequencies the capacitor reactance is very small compared to the resistor. So, it can be neglected. And at low frequency ranges the inductive reactance of L2 is higher than capacitor then the capacitor is neglected.

Table 1. parameters of the single phase LCL-type grid connected inverter

P_0	6 kw
V_g	380 v
V_{DC}	700 v
f_g	50 Hz
f_{sw}	10 kHz
L_1	600 µH
L_2	150 µH
C	10 µF

Vg =220 V; Vdc =360V

Conclusion

In this paper, the design procedure of the LCL-filter used in grid connected inverter is given. Various passive damping solutions to reduce the resonance caused by the LCL-filter are discussed. Among six passive damping solutions, best damping performance is given by resistor in parallel with the capacitor. But this method gives high power loss as grid voltage is directly applied on the resistor. The resistor in series with the filter capacitor widely used in distribution systems due to its low power loss compared to other damping solutions.

REFERENCES

Svensson, J. 2001. Synchronisation methods for grid-connected voltage source converters. IEE Proceedings – Generation, Transmission and Distribution, 148(3), 229.doi:10.1049/ip-gtd:20010101.

Sosa, J. M., Escobar, G., Martinez-Rodriguez, P. R., Vazquez, G., Juarez, M. A. and Diosdado, M. 2014. Comparative evaluation of L and LCL filters in transformerless grid tied converters for active power injection. 2014 IEEE International Autumn Meeting on Power, Electronics and Computing (ROPEC). doi:10.1109/ropec.2014.7036284.

Yagnik, U. P. and Solanki, M. D. 2017. Comparison of L, LC and LCL filter for grid connected converter. 2017 International Conference on Trends in Electronics and Informatics (ICEI). doi:10.1109/icoei.2017.8300968.

Cha, H. and Vu, T.-K. 2010. Comparative analysis of low-pass output filter for single-phase grid-connected Photovoltaic inverter. 2010 Twenty-Fifth Annual IEEE Applied Power Electronics Conference and Exposition (APEC). doi:10.1109/apec.2010.5433454.

Reznik, A., Simoes, M. G., Al-Durra, A. and Muyeen, S. M. 2014. LCL Filter Design and Performance Analysis for Grid-Interconnected Systems. IEEE Transactions on Industry Applications, 50(2), 1225–1232. doi:10.1109/tia.2013.2274612.

Araújo, S. V., Engler, A., Sahan, B., Kassel, V. U., Luiz, F. and Antunes, M. 2007. “LCL Filter design for grid-connected NPC inverters in offshore wind turbines,” in The 7th International Conference on Power Electronics, pp. 1133–1138.

Wu, W., He, Y., Tang, T. and Blaabjerg, F. 2013. A new design method for the passive damped LCL and LLCL filter-based single-phase grid-tied inverter. IEEE Transactions on Industrial Electronis, 60(10), 4339- 4350.

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