Study of LCL filter performance for inverter fed grid connected system

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Abstract The abandoned use of power electronic converters in the application of grid connected system paves a way for critical injected harmonics. Hence the use of filter becomes a significant play among the present scenario. Higher order passive filter is mostly preferred in this application because of its reduced cost and size. This paper focuses on the design of LCL filter for the reduction of injected harmonics. The reason behind choosing LCL filter is inductor sizing and good ripple component attenuation over the other conventional filters. This work is simulated in MATLAB platform and the results are prominent to the objectives mentioned above. Also, the simulation results are verified with the implemented hardware model.

1. Introduction

The power electronic inverter connected to the grid has been popularly used in the renewable power generated distribution system [1]. In most of the grid connecting applications, three phase voltage source inverter (VSI) is used widely. The distorted grid current replicates the performance of VSI. Most of the researchers utilized pulse width modulation (PWM) as a standard technique for the proper operation of inverter power switches which results in best quality voltage at the output [2].

Most of the literatures utilize current sources that are connected to the grid which tries to exhibit maximum real power from renewable energy systems such as photo voltaic or wind turbine for exactness in harmonic standards and a predominant harmonic reduction in the place of “L” filter than “LC” filters are used. LCL filter can make the current harmonics in and around the operating frequency within the restricted limits. However, it leads to an adverse challenge in suppressing LCL resonance that result in instability in system. There are multiple ways for suppressing the resonance like including a series resistor with the capacitor or by adding an additional feedback [3-5].

In this work, systematic design procedures for calculating the LCL filter components are presented step by step. Both fundamental as well as operating switching frequency is considered for the modelling of VSI. The filter values are calculated from the design equations so as to produce grid current ripple, current ripples in inverter and filter capacitor reactive current within the acceptable range.
Section II explains the system description and filter design. Section III describes simulation results and finally experimental results are given in section IV.

2. System description and filter design
The proposed system comprises of a solar panel, grid connected VSI and a LCL filter as shown in figure 1. In the case of L filter, the attenuation is -20dB/decade in the whole range of frequency. This makes the higher switching frequency of the inverter. On the other hand, second order filter i.e LC filter the attenuation is around -40 dB/decade. This shunt component of LC will further attenuate the operating switching frequency elements. Hence it must be designed in such a way to produce lower reactance but higher impedance magnitude within the prescribed limits [6, 7]. Also, the load impedance across the filter capacitor must be high enough.

The reactive power consumption and cost are economically high in LC than L filter. The major advantages of the third order filters are, lesser grid current distortion and production of reactive power, relatively lower switching frequency and better attenuation i.e -60 dB/decade. The resonant frequency of the system while using LCL filter is given in equation (1). Figure 2 represents the per phase equivalent model of LCL filter.

\[ f_{res} = \frac{1}{2\pi} \left( \frac{L_{s1} + L_{s2}}{L_{s1} \cdot L_{s2} \cdot C_p} \right) \]  

Where \( L_{s1} \) and \( L_{s2} \) are the LCL series filter inductance and \( C_p \) is the shunt filter capacitor.

By analysing the per phase equivalent model of LCL filter, the design equations of filter inductances and filter capacitance are given below.

\[ L_{s1} = \frac{V_{dc \, lin}}{\epsilon f_{avg} \Delta f_{MAX}} \]  

Figure 1 Block Diagram of the proposed system

Figure 2 Per phase equivalent model of LCL filter
Where, $f_{sw}$ – Switching frequency, $\Delta I_{\text{max}}$ – Maximum current ripple, $k_a$ – Desired attenuation, $\alpha$ – maximum power factor variation, $Z_b$ – Base impedance, $w_g$ – Grid frequency, $w_{\text{reso}}$ – Resonance frequency.

3. Result Discussion
The proposed system is modelled in matlab simulink platform as shown in Figure.3. The output voltage of PV panel is about 350 V as in Figure.4.

Figure.3 Simulink model of LCL Filter
The PV panel output is connected to grid through three phase voltage source inverter. The corresponding inverter output is shown in figure.5

Figure.4 Output Voltage of PV Panel
The filter inductors and capacitor are calculated using equations 2-6 and it is implemented in software. This implementation offers the better performance in the proposed system than the system without filter.
Total Harmonic Distortion (THD) is noticed as 68% when the system is considered without filter and it has been drastically reduced when the system is considered with LCL filter. Figure .7 depicts the real and reactive power consumed by the grid connected system.

4. Conclusion
In application to grid connected system, power electronic converters play a major role. In specific, voltage source inverter fed grid connected system is subjected to severe distortions. Hence it is mandatory to reduce the harmonics. In this paper LCL filter is designed and implemented for the above mentioned problem and the results are projecting the better harmonic reduction for the grid connected system. Also it promises the reduced inductor size and ripple component attenuation. The simulation results are also verified for the aforementioned advantages.

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