ISSN 2348 – 8034
Impact Factor- 5.070

GLOBAL JOURNAL OF ENGINEERING SCIENCE AND RESEARCHES

DESIGNING OF LCL FILTER FOR THE GRID CONNECTED PV SYSTEM

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ABSTRACT

Grid connected inverters with LCL filters is complicated to designing. The system resonances and the power quality standards burden the task. System damping has to be implemented in order to deal with resonances. In addition, paralleled grid-connected inverters in photovoltaic (PV) plants are coupled due to grid impedance. Generally, this coupling is not taken into account when designing the control laws. In consequence, depending on the number of paralleled grid-connected inverters and the grid impedance, the inverters installed in PV plants do not behave as expected. In this paper, the inverters of a PV plant are modeled as a multivariable system. The analysis carried out enables to obtain an equivalent inverter that describes the totality of inverters of a PV plant. The study is validated through simulation and field experiments. The coupling effect is described and the control law design of paralleled grid-connected inverters with LCL filters in PV plants is clarified.

Keywords: *Filters; Photovoltaic; grid connected; power quality*.

I. INTRODUCTION

There are many design considerations for one to develop inverters for grid connected photovoltaic systems. The design trade-off decisions are the key to implementing a successful system as well as achieving customer satisfaction. A key aspect in the performance of grid connected PV systems is that the power injected into the grid must meet utility power quality requirements. These requirements are specified in the IEEE 929-2000 [1]. The primary trade-offs that drive power quality, once a topology has been selected, are the transistor switching frequency used and the output filter components. Higher switching frequencies result in higher power quality as measured by total harmonic distortion, total demand distortion and the levels of individual harmonics, for a given filter configuration. This is at the expense of higher switching losses. The size of filter components is driven by the magnitude of the ripple current at the switching frequency. This ripple current decreases as the switching frequency increases. The quality of the power provided by the PV system for the on-site loads and the power delivered to the utility is governed by practices and standards addressing voltage, DC injection, flicker, frequency, distortion/harmonics and power factor. These parameters must, unless otherwise is specified, be measured at the point of common coupling [2].Meanwhile the AC output power ripple which has double fundamental frequency oscillation unavoidably introduces the double-line-frequency voltage ripple unlike the balanced operation of maximum power point tracking. To minimize the DC voltage ripples and then enhances the solar energy transfer efficiency, a large value DC link capacitor is normally employed, which however cannot fully eliminate this problem and leads to the increase of system size and cost.

II. GRID CONNECTED FILTER TOPOLOGIES

In order to supply the grid with a sinusoidal line current without harmonic distortion, the inverter is connected to the supply network via filter. The filter is an important part of every semiconductor converter. The filter reduces the effects caused by switching semiconductor devices on other devices. [3].

The filter cost depends basically on the amount of components and materials used, for example the magnetic material for the core of inductors. In addition the filter shall be able to perform its task within a certain degree of independence of the grid parameters, like resonance susceptibility and dynamic performance are of major importance. We analyses different topologies of grid connected filters [4], [5] [7] [8] [9]. The filters include L-filter, L-C filter and L-C-L filter as shown in Fig.1. Advantages and disadvantages are pointed out based on the most important features for designing and performance of filters. Harmonic attenuation, better decoupling between filter and grid impedance and system dynamics of these types of filters are among the performance features.

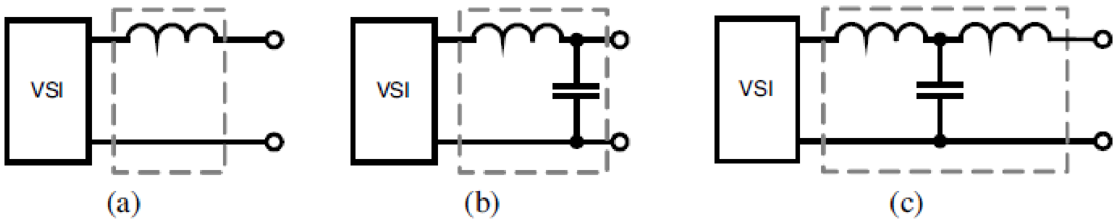

Fig.1: Filter Topologies (a) L-Filter (b) L-C Filter (d) L-C-L Filter [8]

L-C-L Filter
The main functions of filter [4] includes convert the voltages from switch devices to current, to reduce high frequency (HF) switching noises and protect the switching devices from transients.. As explain in [4] [8] [9] the L-filter and L-C filters has excellent performance in terms of voltage to current conversion but the damping of the HF noise is rather poor. The capacitor to these filters may be exposed to line voltage harmonics that results in large currents. The L-C-L filter has good current ripple attenuation even with small inductance values [3]. In addition to good voltage-current conversion L-C-L filter damps the HF noises due to its extra inductance. Unlike L and L-C filters, the capacitor in L-C-L filter is not exposed to line voltage distortion [4]. Low grid current distortion and reactive power production and possibility of using a relatively low switching frequency for a given harmonic attenuation are among the advantages of L-C-L filter [9]. L-C-L filter is a third order filter and has attenuation of -60 dB/decade for frequencies in excess of the resonance frequency [3] [7]
[9].

Though the LCL filter can sometimes cost more than other more simple topologies depicted in Fig. 1, its small dependence on the grid parameters is of major importance at high power applications, in order to guarantee a stable power quality level. Furthermore, it provides better attenuation than other filters with the same size and by having an inductive output; it is capable of limiting current inrush problems [7]. On the other side, L-C-L is unstable may cause both dynamic and steady state input current distortion due to resonance [9]. In order to reduce oscillations and unstable states of the L-C-L filter, the damping resistor is added. This solution is sometimes called “passive damping”. Damping technique is simple and reliable, but it increases the heat losses in the system and it greatly decreases the efficiency of the filter. In general there are four possible places where the resistor can be placed series/parallel to the inverter side inductor or series/parallel to filter capacitor. The characteristics and advantages of L-C-L filter, over other filter topologies are among the reasons made this paper to use L-C-L filter. The filter will have a damping resistor in series with the filter capacitor. The filter is common to voltage source inverters (VSI).

L-C-L Filter Design
Analysis and estimation approach of the L-C-L filter with damping resistance as seen in Fig. 2 have been discussed in [2] [3] [7] [10]. The simplified formulae to estimate the parameters of the filter has stipulated in these literatures. The same approach will be used in this thesis to determine inverter side inductance, L_i, grid side inductance, L_g, filter capacitance, C_f and the damping resistance R_d . Equations 4.7 to 4.14 have been derived in [3] [6] [7] and used to estimate the filter parameters. The main function of the LCL filter is to reduce high-order harmonics on the output side; however poor design may cause a distortion increase. Therefore, the filter must be designed correctly and reasonably [6].

ISSN 2348 – 8034
Impact Factor- 5.070

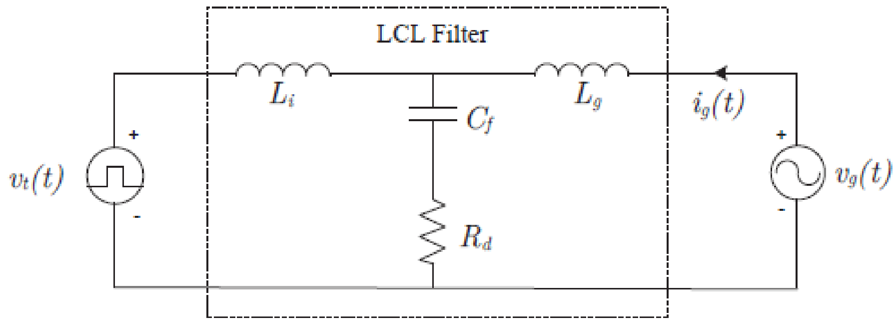

Fig.2: L-C-L filter and components [2]

Table 1 summarizes parameters for calculating filter components. The data provided are important and are the rating of the power stage of the inviter designed in this thesis. These parameters are designed to handle an approximate power of 1kVA. The most important assumption made is the use of unity power factor.

Table 1: Filter design specifications

Parameter	**Value**
Grid Voltage	230 V
Output Power of the Inverter	1KVA
DC-Link voltage	400 V
Grid frequency	50 Hz
Switching frequency	10kHz
Power factor	1

During design of L-C-L filter it is important to take care of some necessary factors. This factor includes inverter output ripple current, inverter to grid inductor ratios and filter capacitance maximum power variations. Typically [3] [6] [7] current ripple is usually limited to 10%-25%, inverter to grid ratio is between 0-1, the capacitor value is limited to less than 5% of the decrease of the rated power and ripple attenuation must be less than 20%. The inverter to grid side inductance ratio is derived in [6] [7] and the relation is plotted in Fig. 3 based on the equation 4.8. This factor is obtained from the ratio between the filter impedance and the difference between resonant frequency and switching frequency. Thus, this ratio is the key factor for the desired ripple attenuation of the filter which is given as the ratio of

$$\frac{i_g(h)}{i(h_{sw})} = \frac{1}{\{1 + r * [1 - (C_b * L * w_{sw}^{\ 2}) * x\}} \qquad (1)$$

Whereas, *r*, C*b*and *x* are the relation factor between inductances, base capacitance and the filter capacitance factor.

Therefore based on the important factors in estimating L-C-L filter, this paper uses outputripple current of 10% of the rated output current.

$$\Delta I_L = 10\% * \frac{\sqrt{2} * P_N}{V_{phase\_grid}} \qquad (2)$$

$$\therefore \Delta I_L = 10\% * \frac{\sqrt{2} * 1kW}{230V} = 0.615A$$

The value of the ripple output current is used in estimating the value of the inverter sideinductance, L*i* [3] [6] [7]

$$L_i = \frac{V_{DC}}{16 * f_s * \Delta I_L} \tag{3}$$

$$\therefore L_i = \frac{400V}{16 * 10kHz * 0.615A} = 4mH$$

Inverter inductance L*i* and grid inductance L*g* are related with *r* in equation 3. If 5% is taken as attenuation factor of the filter, then the approximated value of *r* = 0.6.

$$L_g = r * L_i \tag{4}$$

$$\therefore L_g = 0.6 * 4mH = 2.4mH$$

The filter capacitance C*f* of the L-C-L filter in this thesis is limited to 5% of the rated output power. Usually is taken as the fraction of the base capacitance, C*b*

$$C_f = 5\% * C_b = 0.05 * \frac{P_N}{\omega_{grid} * U^2_{phase\_grid}} \tag{5}$$

$$C_f = 0.05 * \frac{1kW}{2 * \pi * 50Hz * 230^2} = 3\mu F$$

Literatures [3] [6] [7] explain the importance of the damping resistance to L-C-L filter as discussed in previous section of this thesis. The passive damping resistor, R*d* , is obtained at the resonance frequency,f0 of the L-C-L filter. The values of damping resistance and resonance frequency are given in the equations 6 and 7 respectively.

$$R_d = \frac{1}{3 * \omega_o * C_f} \tag{6}$$

$$f_o = \frac{1}{2\pi} * \sqrt{\frac{L_i + L_g}{L_i * L_g * C_f}} \tag{7}$$

$$\therefore f_o = \frac{1}{2\pi} * \sqrt{\frac{4mH + 2.4mH}{4mH * 2.4mH * 3\mu F}} = 23.4kHz$$

Resonance frequency is then calculated by using the filters components in equation 7.

Then the damping resistance R_d is found to be 0.755Ω.Filter components are summarized in

Table 2: L-C-L filter components

Components	**Value**
Inverter side inductor L*i*	4mH
Filter capacitor, C*f*	3μF
Grid side inductor, L*g*	2.4mH
Damping resistance, R*d*	0.755Ω
Resonance frequency, f0	23.4kHz

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III. RESULT AND SIMULATION

The simulation model studied is explained in fig 4 and L-C-L output filter is designed to minimize the harmonics that present in the inverter output due to switching. The output voltage of the power stage inverter is shown in Fig 5 as unfiltered output voltage. Its amplitude of peak voltage switched to approximately between -400V and +400V through zero. When all the parameters in the inverter reach steady state, the output of the inverter will switch between positive to negative peak of the DC-link voltage. This voltage is then filtered by the L-C-L filter designed in this to minimize these distortions. The clear output voltage is depicted in Fig. 5.

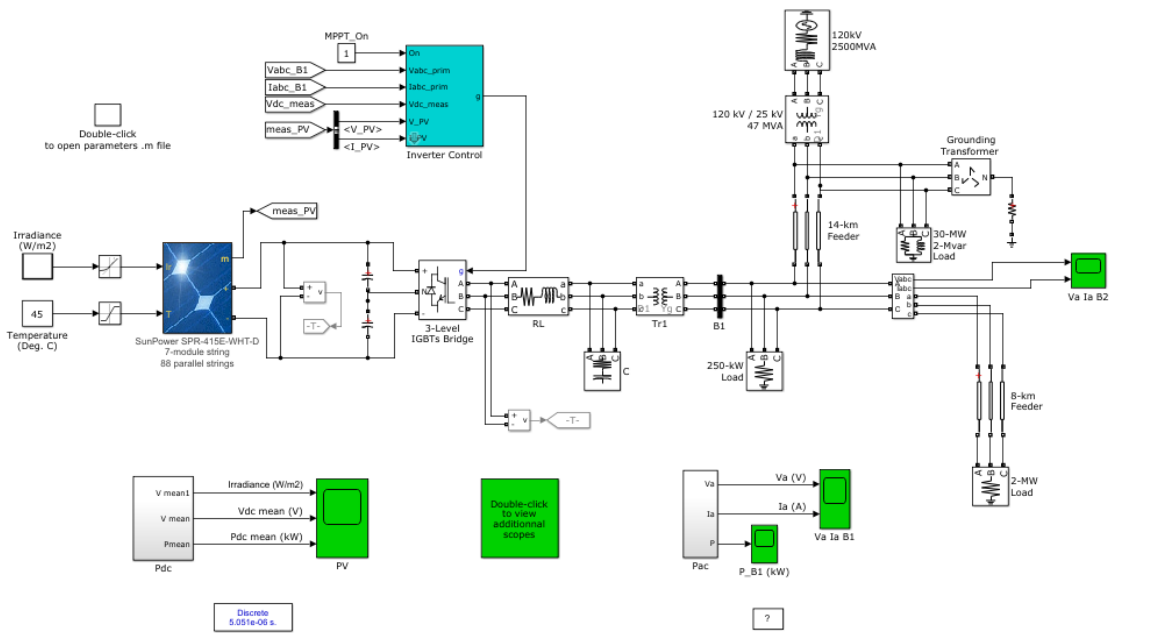
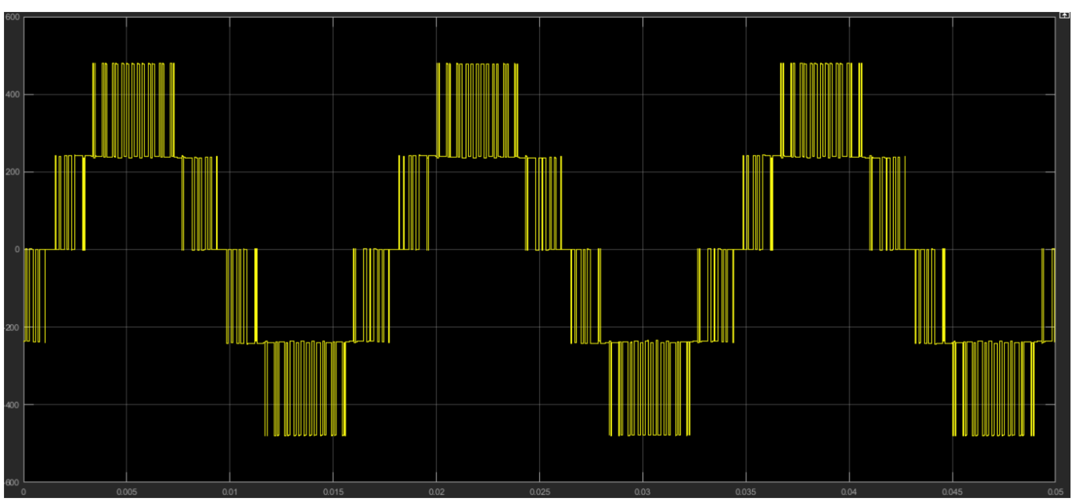
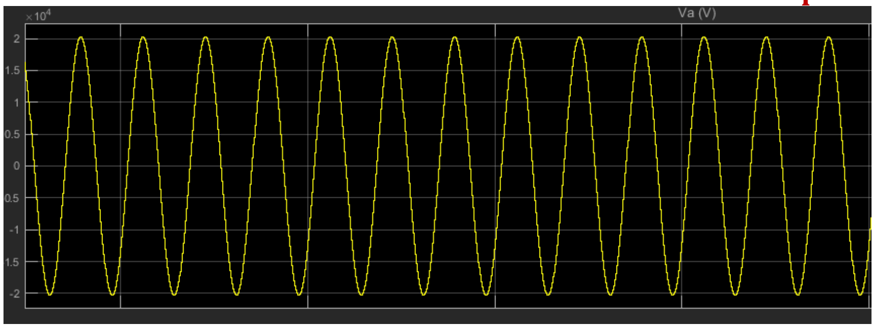


Fig 4: PV designed model



(a) Unfiltered Inverter output voltage



(b) Filtered output

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