Optimum Design of LCL Filter Parameters for Photovoltaic Inverters

Jihong Zhang [a], Hao Xue [b]

Information Engineering School, Inner Mongolia University of Science and Technology, Baotou 014010, Inner Mongolia, China.

[a] zjh00318@163.com, [b]597156524@qq.com

Abstract. In the interconnection of large capacity photovoltaic inverters, the total inductance of LCL filters will directly affect the size and cost of the filters. Therefore, a parameter optimization method is proposed to minimize the total inductance according to the filter performance requirements. This method establishes the functional relationship between the total inductance and the main design parameters by shunt ratio parameters of capacitor branch and inductance branch of power grid. The parameter conditions of minimum total inductance and the solution method are given.

Keywords: inverter; LCL filter; parameter optimization.

1. Introduction

With the increase of energy demand, fossil energy as the main energy source is drying up. [1]. At the same time, over-exploitation and other conditions are destroying the ecological balance, affecting the global environment and human health. Solar energy is widely used and studied as a widely distributed and pollution-free energy. As the main technology of solar energy, photovoltaic power generation technology is gradually improving. In practical application, it can support the load and play a regulating role [2].

L-type inductance filters with simple structure are usually used in grid-connected power generation systems with small power inverters; however, in the practical application of larger power and switching frequency, larger inductance value is needed to achieve the desired harmonic current suppression effect, but this requires a larger size of filters, which also increases the cost. When LCL filter achieves the same high frequency harmonic suppression effect, its volume is much smaller than L filter.

Since LCL filter itself belongs to the third-order resonant circuit, two inductance values and one capacitance value need to be designed when designing parameters. Each parameter has an important influence on its filtering performance[3].

2. Principle Analysis of LCL Filter

Fig. 1 is an LCL filter connected between the photovoltaic inverters and the power grid. The inductance and capacitance are set to be components with neglected resistance and ideal consumption-free, and controlled by SPWM. Among them, U_{inv} is the output voltage of the inverter bridge, which is mainly based on fundamental wave, and contains high-order harmonics near switching frequency and switching frequency doubling.

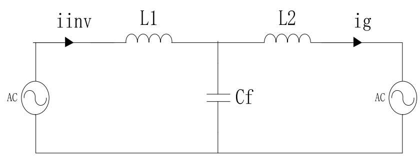


Fig. 1 LCL filter schematic diagram

LCL filter is different from L filter in that it utilizes the difference of impedance between inductance and capacitance in different frequency components. The filter adds filter capacitorC_f and filter inductance L_2. In high frequency, the impedance of inductance branch is large, while the impedance of capacitance branch is small. Its function is to shunt the output current I_{inv} of inverter bridge with high harmonic, and C_f shunt the impedance of inductance branch is small. To provide low resistance path for high frequency part, so as to reduce the harmonic component of current Ig flowing into power grid side[4].

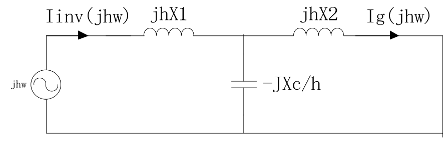


Fig 2. LCL harmonic analysis model

Figure 2 is the LCL high-order harmonic analysis model. Unlike the fundamental-wave analysis circuit, the grid-side voltage is regarded as short-circuit in the circuit model, where $X_1 X_2 X_c$ represents the fundamental-wave reactance in the branch of LCL filter, respectively.

According to the harmonic analysis model, the transfer function between the H-th harmonic current flowing to the grid side and the H-th harmonic voltage output from the inverter can be obtained as follows:

$$H_{LCL}(jh\omega) = \frac{I_g(jh\omega)}{U_{inv}(jh\omega)} = \frac{-j}{h(X_1+X_2-h^2\frac{X_1X_2}{X_C})} \quad (1)$$

In the case of L-type filter, according to the model of high-order harmonic analysis, it can be known that the transfer function of the current and voltage flowing into the h-order harmonic is as follows:

$$H_L(jh\omega) = \frac{I_g(jh\omega)}{U_{inv}(jh\omega)} = \frac{-j}{hX_T} \quad (2)$$

Where X_T represents the fundamental reactance of L-filter

According to formula (1) (2), the amplitude-frequency relationship characteristics of transfer functions of L-type filters and LCL-type filters can be obtained.:

$$|H_{LCL}(jh\omega)| = \frac{1}{h(X_1+X_2-h^2\frac{X_1X_2}{X_C})} \quad (3)$$

$$|H_L(jh\omega)| = \frac{1}{hX_T} \quad (4)$$

Since LCL filter can be regarded as a third-order resonant circuit, its resonant frequency f_{res} can be expressed as

$$f_{res} = \frac{1}{2\pi}\sqrt{\frac{L_1+L_2}{L_1L_2C_f}} \quad (5)$$

3. Parameter Design of LCL Type Filter

The LCL filter is configurated in the inverters, and its parameter design will directly affect the performance of the whole system. In order to discuss the specific design and optimization methods of LCL, three parameters λ, μ, κ are introduced in this paper, which are expressed as follows:

μ——Amplitude Ratio of Harmonic Current to Harmonic Voltage at Switching Frequency f_{sw} of Power Grid; κ——Harmonic Current Shunt Ratio at Switching Frequency f_{sw} of Network Side Branch and Capacitor Branch.

3.1 Parameter Design of Capacitor C_f

Capacitance voltage can be regarded as grid side voltage, and the reactive power absorbed by it can be controlled within 5% of the rated power of the system. Capacitance value can be set through λ, and its expression is as follows:

$$C_f = \lambda \times \frac{P_n}{3\omega_1 U_s^2} \tag{6}$$

In the formula, P_n denotes the rated active power of the inverters, ω_1 denotes the fundamental angle frequency of the power grid, and U_s denotes the phase voltage of the power grid side.

3.2 Design of Inductance L_2 on Power Grid Side

The branch of inductor $L_2$and capacitor C_f side accomplishes the shunting of high frequency ripple current. Capacitance provides high frequency component and low resistance channel. To realize the function of diversion, $1/h\omega_1 C_f$ Needs are much smaller than $h\omega_1 L_2$,The switching frequency f_{sw} is discussed in detail. The relationship between inductance branch impedance and capacitance branch impedance is set as follows.

$$h\omega_1 L_2 = k\frac{1}{h\omega_1 C_f} \tag{7}$$

In style,$h = \frac{2\pi f_{sw}}{\omega_1}$

The expression of inductance L_2 on network side is deduced from formula (7):

$$L_2 = \mathrm{k}\frac{1}{(h\omega_1)^2 C_f} \tag{8}$$

3.3 Design of Inverter Side Inductance L_1

Parameter μ is an important parameter of filter performance,

$$\mu = |H_{LCL}(jh\omega_1)| = \frac{1}{h\left(X_1+X_2-h^2\frac{X_1X_2}{X_c}\right)} \tag{9}$$

Based on the above formula, it can be deduced that the inverter side L_1 is:

$$L_1 = \frac{kX_c+h/\mu}{h^2\omega_1(k-1)} \tag{10}$$

3.4 Optimal Design Method of Minimum Total Inductance

According to formula (8) and formula (10), the mathematical expression of total inductance L_T can be deduced as follows.

$$L_T = \frac{1}{h^2\omega_1}\frac{k^2X_C+h/\mu}{k-1} \tag{11}$$

Generally, the parameter λ is a given value, so the total inductance L_T can be regarded as a function of the parameter λ and κ.

4. Modeling and Simulation Analysis

For example, and simulation system parameter design, the total inductance is the smallest when K is 11, taking $\lambda = 1\%$, μ=0.05, respectively. Through the parameter design above, the specific parameters are shown in the table. The values of the parameters are as follows: P_n =500 kW,U_s=270V,R_d=0.17Ω, L_1=0.108 mH,L_2=0.117mH,C_f=280μF,f_{sw}=3.3 kHz,f_{res}=1.44 kHz.

Among them, P_n denotes rated power, U_s denotes the effective value of grid line voltage, f_{sw} denotes switching frequency, L_1, L_2 denote inductance of inverter side and grid side respectively, C_f denotes capacitance of filter, and resonance frequency f_{res} can be obtained by calculation.

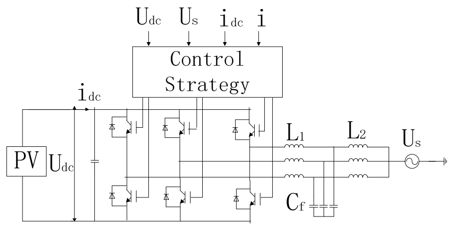
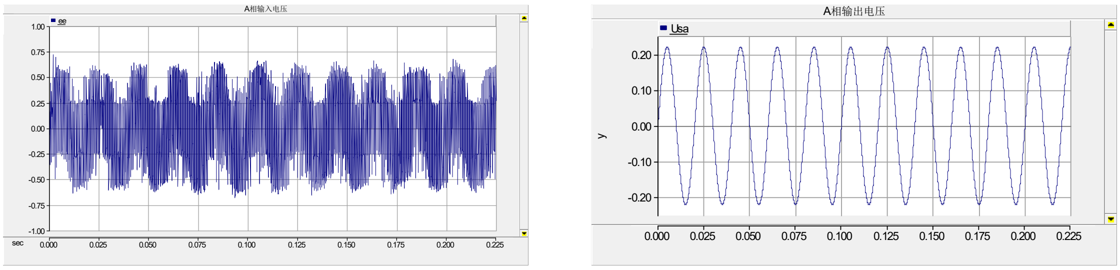


Fig. 3 Control system diagram of three-phase photovoltaic grid-connected inverter

The results of three-phase voltage waveform analysis are obtained by LCL filter input and output respectively. It can be seen that the filtered harmonic voltage attenuates significantly and presents better sinusoidal waveform through the parameter optimization design in this paper.



(a)input (b)output

Fig 4. Input/ Output Voltage Waveform of LCL Filter

5. Conclusion

The simulation results show the effectiveness and accuracy of the proposed design method. It can be seen that the load requirements of LCL filter designed in this paper are optimized and improved. By reducing the total inductance of the filter to reduce the overall size of the filter, not only can the cost of manufacturing be saved, but also has practical application significance.

References

[1]. Yan Gangui. Stability Analysis of Three-Phase LCL Photovoltaic Inverter Based on Output Impedance[J]. Journal of Solar Energy. 2018,39(2):558-565 (in Chinese).

[2]. Bao Chenlei, Ruan Xinbo, Wang Xuehua. Design of Grid-connected Inverters With LCL Filter Based on PI Regulator and Capacitor Current Feedback Active Damping[J] Proceedings of the CSEE.2012,32(25):133-142(in Chinese).

[3]. Wei Xing, Xiao Lan, Yao Zhilei, et al. Design of LCL filter for three-phase grid-connected inverters[J]. Power Electronics, 2010,44(11):12-15(in Chinese).

[4]. Huang Yafeng.Research on feasible operation region of large capacity photovoltaic inverter system connected to weak grid[D]. Bei Jing: North China Electric Power University,2014(in Chinese).