A New Method of LCL Filter Parameter Design Based on Fish Swarm Algorithm

Sining Liu¹,a, Wei Wang²,b, Ruize Zheng³
¹Changchun University of Technology Changchun, China
²Changchun University of Technology Changchun, China
³Changchun University of Technology Changchun, China
¹13630554785@163.com, bwe9520@126.com

Abstract. Aiming at the problem that LCL filter is better than L, LC filter in filtering performance. However, the selection of parameters is more complicated, and it is prone to resonant spikes in the filtering process, this study introduces passive damping to measure its resonant spikes suppression, and combined with the attenuation of the grid-connected harmonic current of the LCL filter to measure its excellent filtering performance. Based on this, the objective function model is established, the fish swarm algorithm is adopted to optimize its parameters, and the grid-connected simulation model is found in MATLAB/Simulink. Its filtering effect is compared with the traditional method. The simulation proves that the filter after parameter optimization can effectively suppress and filter the harmonic components of the inverter output voltage compared with the conventional filtering method, and provide positive theoretical guidance for the stable grid connection of new energy power generation.

1. Introduction
In recent years, with the deterioration of the energy crisis and environmental problems, people have begun to seek a new kind of energy that can replace primary energy to improve their environmental problems and energy shortages. New energy power generation has shown great advantages in energy saving, emission reduction and economic and environmental protection [1]. Countries have successively taken protection measures and made relatively complete grid-connected standards for new energy power generation, and researchers from various countries have widely applied new energy power generation technologies to military and heavy industries (Ships, coal mines) and other fields [2-5], which have greatly promoted economic development. Grid inverter is indispensable for new energy grid in power electronic device, its function is to convert the direct current output from the new energy generation system into the alternating current needed by the power grid. As the scale of investment in new energy generator sets increases year by year, the processing capacity of inverter for harmonic voltage and current can't meet the new energy grid harmonic standards, so they need additional filters to suppress high-order harmonics of the filter, but because of its simple design structure, which also determines that its filtering ability is limited. Currently, the most commonly used filters are mainly L and LC filters. Currently, the most frequently used filters are mostly L and LC filters. They are widely used due to their small size and low construction cost. LCL filter has better filtering performance than the former two. As is known to all, The LCL filter is a third-order filter, and its high-frequency attenuation characteristics can better suppress high-frequency harmonics [6], but the filter design structure is complicated, and the parameter setting is challenging, which often requires repeated debugging and a large number of
Experiments to determine the rationality of its parameter selection. Reference [6] proposed a method based on particle swarm algorithm to optimize the design of filter parameters and its control parameters. The method proposed in [7] selects power constraints, current tracking constraints, and reactive power constraints to determine the inverter inductance and filter capacitor parameter values, which reduces the complexity of parameter design. Reference [8] proposed a method for parameter quantization design of LCL filter for three-level PWM grid-connected converter based on the analysis results of three-level PWM output harmonic double Fourier, which reduces the volume and cost of the filter. In [7] and [8], although the number of attempts in filter parameter selection is decreased, it is still inevitable to make trial and error for its parameters, and the design of parameters is still relatively complicated. Reference [9] proposes a new parameter optimization design scheme for LCL filter. And through this scheme to optimize the ripple current, harmonic attenuation, power loss multi-objective function, and using the entropy weight method to integrate multiple goals into a single goal to optimize through genetic algorithm. Compared with the previous method, this method can attenuate the higher harmonics better and maintain better grid-connected power quality. Aiming at the problems such as the complex selection of filter parameters in the above literature, low precision and unclear optimization object, and the excellent results obtained by the fish swarm algorithm in economic dispatching of micro-grid, fault location of an active distribution network and reconstruction of a distribution network are comprehensively considered. This paper presents a parameter design method of LCL output filter based on fish swarm algorithm, and introducing the passive damping control links of resonant peak control, the simulation shows that the technique can better optimize the filter parameters. It also avoids the situation that it is difficult to control each controlled object independently due to mutual coupling, which reduces the difficulty of filter design, improves the power quality of new energy grid connection, and meets the relevant standards of national grid connection.

2. Structural analysis of three-level filter

Fig.1 shows the topology diagram of LCL three-level inverter, capacitor C1 and C2 are the dc side capacitors, which play an important role in supporting circuit voltage, and the diode in the circuit plays the role of clamping potential, L1k, L2k are three-phase inverter side filter inductance, mesh side filter inductance and filter capacitance respectively. Ek (k=a, b, c) are rms values of each phase voltage of the three-phase power grid. i1k, i2k (k=a, b, c) are the output phase current and grid-connected phase current of each phase inverter, respectively. Rkd (k=a, b, c) are damping resistance to suppress the resonant peak.

![Figure 1: Three-phase three-level LCL filter topology](image)
obtained by equivalent transformation of Fig.1, as shown in Fig.2. In Fig.2, the a-phase output voltage of the inverter is replaced by the equivalent voltage source Uain, and the a-phase grid voltage is replaced by Uaout. According to the equivalent circuit diagram, filter structure block diagram is shown in Fig. 3. It can be seen from Fig. 2 that the equivalent circuit diagram has two more resistance elements than the non-equivalent circuit diagram before. R1a and R2a are the parasitic resistance of the filter, and the ratio of the resistance value to the total impedance in the circuit is almost zero. Therefore, they can be ignored in the process of simplification.

\[ \frac{I_a(s)}{U_{ain}(s)} = \frac{L_2aCaS^2+1}{L_1aL_2aCaS^3+(L_{total})S} \]  

\[ \frac{I_a(s)}{U_{ain}(s)} = \frac{1}{L_1aL_2aCaS^3+(L_{total})S} \]  

\[ \frac{I_a(s)}{I_a(s)} = \frac{1}{L_2aCaS^2+1} \]  

The resonant angular frequency is

\[ w_0 = \sqrt{\frac{L_{total}}{L_1a+L_2a+Ca}} \]  

The resonant angular frequency

\[ f_0 = \frac{1}{2\pi} \sqrt{\frac{L_{total}}{L_1a+L_2a+Ca}} \]  

Among them, the total inductance \( L_{total} = L_1a + L_2a \), the inductance ratio \( \gamma = \frac{L_1a}{L_2a} \). Through reviewing the reference [10], it can be known that when \( \gamma = 1 \), the natural resonance frequency of LCL filter can reach the minimum, and the filtering performance of high harmonic can also reach the best. The effects of the value on the natural frequency resonance and the variation of higher harmonics are analyzed.
3. The influence on the filtering performance

To facilitate the study of \( \gamma \) value for the filter natural resonance frequency and the influence of high harmonics, in this paper, depending on the total inductance \( L_{total} \), the variation of the resonance frequency and the higher harmonics at the resonance point were observed under different values. Firstly, according to the constraints of each parameter, the parameter design of the filter is discussed as follows:

According to Figure 3, the transfer function from the output voltage \( U_{ain} \) of the inverter to the grid-connected current \( i_{2a} \) can be written:

\[
\frac{1}{4\sqrt{3} \text{mf}_s} \frac{u_{dc}}{L_{total}} < \frac{\sqrt{(MU_{dc})^2 - U_{gm}^2}}{w_{g/m}}
\]  

(6)

In (6), \( M \) is the inverter output voltage modulation coefficient, \( w_g \) is the grid voltage angular frequency, and once \( L_{total} \) is determined, the corresponding values of filter inductance \( L_{1a} \) and \( L_{2a} \) can be obtained. To achieve the purpose of parameter design, the value range is then determined according to the constraint condition of filter capacitance \( C_a \), and a capacitor part is added to the filter to filter out high order harmonics. However, it is inevitable to increase the power loss in the distribution process. According to the features of the load, the introduction of the filter capacitor mainly increases the reactive power loss of the system. In order to reduce its reactive power loss as far as possible, it is generally controlled within 5% of the rated power of the grid-connected system in engineering, which can be expressed as follows:

\[
C_a \leq 5\% * \frac{P_N}{3W_gU_g^2}
\]  

(7)

\( C_a \) is the filter capacitance of the designed filter, \( P_N \) is the rated power of the system, \( W_g \) is the angular frequency of the grid voltage, whose value is \( w_g = 2\pi f_g U_g \) is the grid phase voltage. Taking the inductance ratio = 1, 5, 7, the bode diagram of the filter transfer function can be obtained, as shown in Fig. 4. According to the constraint conditions of the total inductance in (6), the reasonable value of the total inductance should not be too large. Otherwise, the system damping will be too large, the dynamic response speed will not reach the expected standard, and the cost will be high. Considering a compromise, the total inductance value is selected to be 12mH, and the values of \( L_{1a} \) and \( L_{2a} \) are determined respectively according to the inductance ratio.

(1) \( \gamma = 1 \), \( L_{1a} = L_{2a} = 6\text{mH} \)
(2) \( \gamma = 5 \), \( L_{1a} = 10\text{mH}, L_{2a} = 2\text{mH} \)
(3) \( \gamma = 7 \), \( L_{1a} = 10.5\text{mH}, L_{2a} = 1.5\text{mH} \)

According to (7), the filter capacitance \( C_a \leq 10.9\mu F \) is determined. Therefore, \( C_a \) is set as 10\( \mu F \). Considering that the series damping resistance of the capacitor branch increases the system loss accordingly, In general, it is regulated that the value of damping resistance is 1/3 of the filter’s capacitance value at the resonant angular frequency, namely \( R_d = \frac{1}{3} \frac{1}{W_0 C} \). In the equation, \( W_r \) is the resonant angular frequency, and its value is \( w_0 = 2\pi f_0 \), as shown in (4) and (5). It can be seen that when the inductance ratio is 1, the filter has the best suppression effect on the higher harmonics, and with the increase of the inductance ratio, the suppression effect on the higher harmonics decreases, and the resonant frequency point is shifted to the right. Therefore, the most suitable inductance ratio is 1.
4. **Fish swarm algorithm optimization design**

Fish swarm algorithm is a kind of swarm intelligence optimization algorithm based on animal behavior. It can optimize the variables by simulating the foraging, clustering, chasing and other behaviors of the fish swarm. Based on this, LCL filter parameters can be selected reasonably.

The inductance and capacitance parameters of the filter are initialized and randomly assigned within the allowable range to form a random array of real numbers. Because the total inductance value of the filter is selected in this paper to be certain, only if one value of $L_1a$ or $L_2a$ is determined, and the other value can be determined, given that the $L_1a$ range is $[0,12\text{mH}]$ and $C_a$ is $[0,10\mu\text{F}]$. In this paper, its objective function is established based on the attenuation coefficient of harmonic current, as shown in (8). In order to minimize the loss of grid-connected current, its attenuation coefficient should be controlled as small as possible [10].

![Figure.4](image)

**Table.1  Simulation program parameters**

| Parameter                      | values | Parameter                      | values         |
|--------------------------------|--------|--------------------------------|----------------|
| Number of fish                 | 50     | Sense of distance              | 2              |
| Maximum number of foraging     | 50     | Fish density factor           | 0.628          |
| Foraging for maximum number of temptations | 100    | Tracing step length          | 0.15           |

$$J = \frac{1}{\left[1 + \frac{L_2a}{L_1a - L_2a + C_ay_f}\right]} \quad (8)$$

The critical point of this algorithm is to establish its optimization function, so the optimization function is then established. In this paper, its objective function is established based on the attenuation coefficient of harmonic current, as shown in (8)[10].
Figure 5  Filter parameter optimization based on fish swarm algorithm.

The circled variable x in Fig.5 is the optimal parameter value of the filter inductor and capacitor. After optimizing the filter parameters through the fish swarm algorithm, the optimized parameter result obtained is [1.39mH, 10.61mH, 6.2μF]. The parameter optimization diagram is shown in Fig.5.

Figure 6  Harmonic content of grid-connected voltage before optimization.

Figure 7  Harmonic content of grid-connected voltage before optimization.
In this paper, inductance $L_1$, $L_2$ and capacitance $C_a$ are set as optimization variables. And reasonable filter inductance and capacitance values are selected according to their constraint condition. On the basis of the analysis of the choice above $\gamma=1$, in this paper, the inductors $L_1$, $L_2$, and capacitor $C_a$ are set as optimized variables, and according to their constraints, reasonable filter inductance and capacitor values are selected. According to the above analysis, $\gamma=1$ is selected. The calculated values of inductors $L_1$ and $L_2$ are both 6mH. The capacitance value is 10μF, and the resonance frequency of the system needs to satisfy $(10f_n, 0.5f_{sw})$ interval, $f_n$ is the fundamental frequency of the system, $f_{sw}$ is the switching frequency of the inverter. The parameters involved in the simulation are as follows: The inverter power is set to 10KW, the DC bus voltage is set at 750V, the switching frequency is set to 10 kHz, the grid-connected voltage frequency is set to 50 Hz, and under the Simulink three-phase three-level LCL filter grid simulation model is established, finally designing it according to the simulation parameters. Observing the voltage waveform output by the inverter after filtering through the filter and using the fast Fourier analysis method to analyze the harmonic distortion and the simulation results as shown in Fig.(6)-Fig. (9).

5. Conclusion
From the comparison of Fig. (6) and Fig. (7) above, we can see the superiority of fish swarm algorithm in suppressing higher harmonics. Fig. (9) shows that the waveform quality obtained after optimization is smoother and the waveform quality is better. The harmonic distortion rate of the grid-connected voltage before optimization is 1.2%, and the harmonic distortion rate of the grid-connected voltage after
optimization is 0.5%, and the harmonic content is reduced by 58.3%. This is very effective to improve the power quality of the grid. The stability of the system also reflects the high engineering application value of fish swarm algorithm in new energy grid connection, which verifies the correctness and feasibility of the method proposed in this paper. At the same time, this research also has its shortcomings. This article only stays at the stage of simulation. The actual hardware equipment is not built, and the results obtained from the experiment are not compared with the simulation results. The actual filtering effect of this method will be studied in future research.

References

[1] Lv Chao, Wu Yuzhe, Wang Xinlong. Compensation control of grid-connected inverters facing the demand of future distribution network[J]. Journal of Electric Power System and Automation, 2020, 32(8):104-108, 122.

[2] Wang Feng. Application of three-level filter based on LCL filter in coal mine power grid[J]. Coal Engineering, 2019, 51(1): 73-76. [J]. Coal Engineering, 2019, 51(1): 73-76.

[3] Jing Zhen, Xu Heli, Gao Lan. Design of LCL filter of marine new energy grid-connected inverter based on genetic algorithm[J]. Ship Science and Technology, 2018, 40(1): 114-119.

[4] Liu Yuan, Chen Tao, Fu Xiaohong, Xia Jun. Research on harmonic suppression strategies of grid-connected inverters adapted to grid impedance[J]. Ship, 2019, 30(6): 145-152.

[5] Yao Zhenghua, Xia Zhenglong. Parameter optimization of LCL filter of mine chain STATCOM device based on improved fish swarm algorithm[J]. Coal Mine Machinery, 2015, 36(11): 253-255.

[6] Zheng Jialong. Research on optimization of LCL filter parameters of grid-connected inverter based on nonlinear programming genetic algorithm[J]. Power Capacitors and Reactive Power Compensation, 2019, 40(5): 146-150.

[7] Liu Qian, Peng Li, Tang Shiyang, Kang Yong Wu Deliang. A graphical-based LCL filter design and optimization method[J]. Proceedings of the Chinese Society for Electrical Engineering, 2012, 32(36): 36-43.

[8] Huang Yafeng, Li Long, Yan gangui, Wang Zehui. Optimal design of LCL filter parameters for large-capacity photovoltaic inverters[J]. Power System Protection and Control, 2013, (21): 104-109.

[9] Zhang Kaige, Chi Song, Li Erping. Design and optimization of LCL output filter based on genetic algorithm[J]. Computer Simulation, 2020, 37(1): 211-216.

[10] Xuan Zhaoyan, Jia Wanyong, Chen Xuebin, et al. Compound control strategy based on LCL filter[J]. Journal of Applied Sciences, 2019, 37(4): 447-458.

[11] Ma Ruiyu. Research on photovoltaic grid-connected inverter with low harmonic LCL filter[D]. Anhui: Anhui University of Science and Technology, 2014.