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A Novel Design and Optimization Method of an *LCL* Filter for a Shunt Active Power Filter

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ABSTRACT

This paper analyses the characteristics of LCL filter in active power filter (APF) and provides an accurate for mula to determine the resonant frequency of system. Based on a single-phase equivalent circuit model, a systematic approach to design APF with LCL filter is proposed. Total inductance is determined by the capability of APF. Moreover, damping ratio, resonant frequency and attenuation degree of switching ripples are the most crucial factors to design parameters of LCL filters. A method to consider them comprehensively is provided. Meanwhile, LCL filter deteriorates the compensation effect of APF. To address this problem, a novel control strategy is presented to correct the magnitude and phase of output current. Simulation results demonstrate the validity of proposed methods.

***Index Terms*—Damping, power harmonic filters, power quality, system analysis and design.**

I. INTRODUCTION

Nowadays, the power quality in the distribution system deteriorates due to the excessive application of reactive, nonlinear and unbalanced load [1], [2]. To resolve this problem, shunt active power filter (SAPF) plays an important role and has been an area of intense investigation in recent years. Unlike passive power filter (PPF), which is sensitive to the parameters of components and apt to resonate with other loads in the grid, APF provides a flexible and rounded solution [1].SAPF has been used extensively for harmonic suppression, reactive power compensation and grid current equilibrium in the distribution system [3], [4]. However, switching ripples produced by APF inject to the grid and result in a considerable harm. For example, capacitor loads will increase their losses and reduce service lives; moreover, high frequency noise existing in the common voltage will disturb the sensitive equipment [5]. To address this problem, switching noise filter is indispensable for APF.

Compared with L or LC filter, LCL filter ensures a better smoothing output current from APF. As a result, decreasing the inductance is easy to achieve, which guarantees the dynamic performance of APF [6]. Despite increasing the complexity, LCL filter has been widely used in medium and high power applications. Meanwhile, the design of LCL filter.APF applications [16]. Despite some algorithms can be references, to design LCL filters for APF is much more difficult due to the high bandwidth of output current. In ref[16], a set of methods on design, control, and implementation of LCL-filter-based SAPF are presented. Unfortunately, the part of design methods for LCL filter is not detailed.

Despite having many advantages, resonance peak of LCLfilter system enlarges harmonic seriously at certain frequency, which distorts grid current and may make system unstable[16]. Fortunately, this problem can be resolved by applying damping technologies. In recent years, active damping has received lots of attention for reducing losses of system. There are several mainstream control methods for active damping. The first one is to detect the current of filter capacitor and generate a virtual damping resistor [17]–[18]. Another method is to construct an element with negative resonance peak characteristic. On one hand, some state variables can beefed back to construct notch filter element to achieve this goal[19]–[20]; on the other hand, notch filter or double band-pass filter can be applied directly to generate negative resonance peak without additional sensors [21].Despite active damping methods have some advantages, unfortunately, the stability of system is decreased due to the function of feed-back or filter elements, which means the damping coefficient can be regulated only in a small scale to guarantee system's stability margin. Meanwhile, active methods have lower bandwidth, poor performance on dynamic response and noise immunity. Moreover, additional sensors are usually needed and the complexity of control is increased. The last but not the least, due to the restriction of system's bandwidth, effect of active damping is much inferior to corresponding passive damping [22]. Consequently, most of damping strategies in actual industrial applications adopt passive damping or combined method. Hence, it is still of positive engineering significance to research design methods for passive damping.

II.PROPOSED SYSTEM

Figure 1 shows the topology of SAPF system. SAPFconsists of two basic units: one is three-phase voltage source inverter (VSI) with a capacitor in DC side, the other one isLCL output filter.

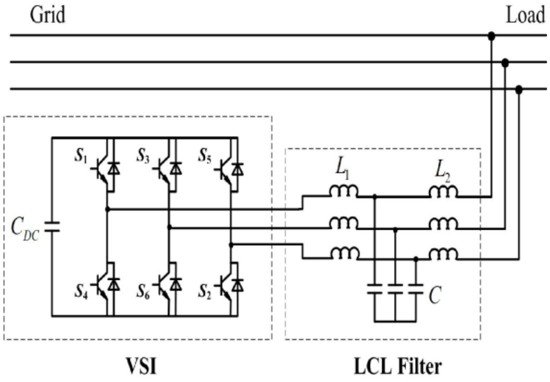

Fig. 1. Topology of SAPF system.

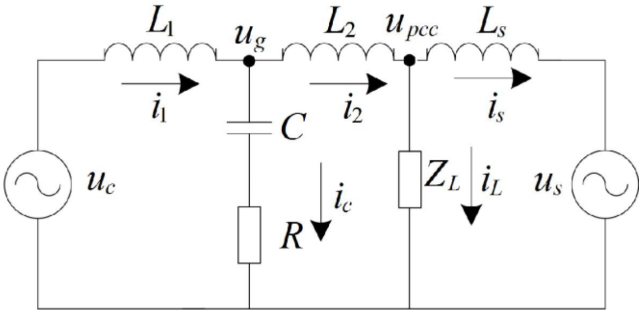

Fig. 2. Single-phase equivalent circuit.

Figure 2 shows the model of single-phase equivalent circuit. Where *L*1 , *L*2 and *C* comprise LCL output filter. *uc* is the output voltage of three-phase VSI; *us* denotes the grid phase voltage. *Ls* , R and *ZL* are respectively grid equivalent inductor, damping resistor and load. The capacitor presents a low resistance for high frequency signal, which will shunt the switching ripple current. Unlike LC filter, which require a large capacitance and is influenced by *Ls* seriously, LCLfilter has a larger grid–side equivalent resistance and better filter performance.

No-load condition (*ZL* is open circuit) is the most significant situation for analysis and design.

III.CONTROL STRATEGY

If grid load is harmonic source, the model of single-phase equivalent circuit of system is as follows as in Fig. 3

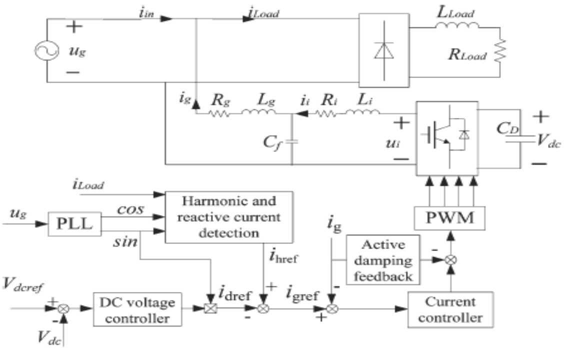

fig 4.. Control block diagram of the SAPF.

Advantages

An intuitive contrast of the traditional and proposed design methods can be explained through Fig. 6. In the

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existing design methods, one or some boundary conditions are first used to fix one or some parameters, such as setting the inverter- and grid side inductance equal to each other (i.e., λ is set as 0.5), and then test whether there exists any eligible point on the boundary conditions. Under the condition $\lambda = 0.5$, the corresponding points are barely on the curve $f2(K)|\lambda=0.5$ in Fig. 6, and the eligible points could be found only on segment AB. If the selected point is not on segment AB, it will result in repeated design. In addition, the other points of the selectable area except segment AB, which might get a more optimized result, could not be obtained through this method. On the contrary, the boundary conditions and relationships of the parameters are depicted on the same graph by the proposed method, and then, the filter parameters can be chosen in the selectable area which meets all design requirements. With this method, the curve variation tendencies are intuitive, and the selectable area(shadowed area of Fig. 6) is larger than the previous ones.

The error-tolerance capability can be guaranteed with the point away from the boundaries. For these advantages, it is easy to obtain a more suitable result without trial and error.

IV.SIMULATION RESULTS

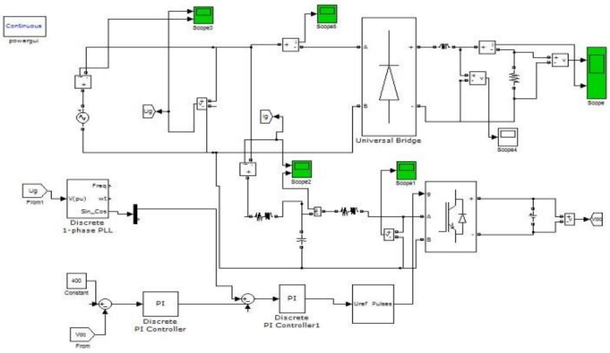

Fig.5.simulation circuit

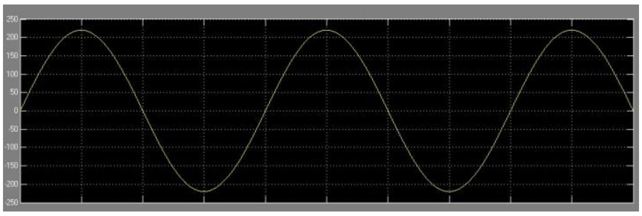

Fig.6 INPUT VOLTAGE

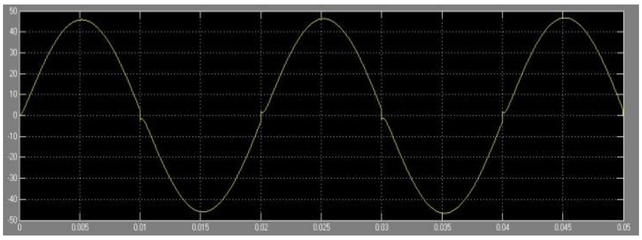

Fig.7 INPUT CURRENT

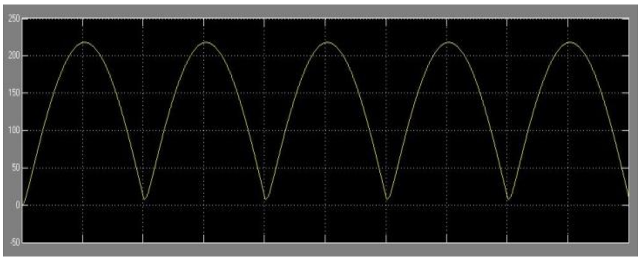

Fig.8 LOAD CURRENT

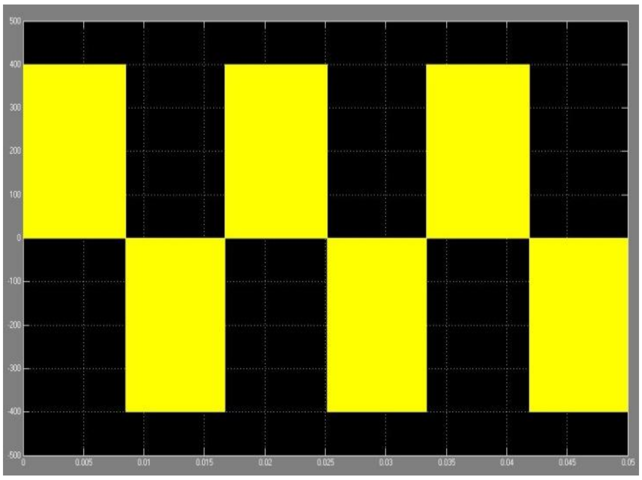

Fig.9 INVERTER VOLTAGE

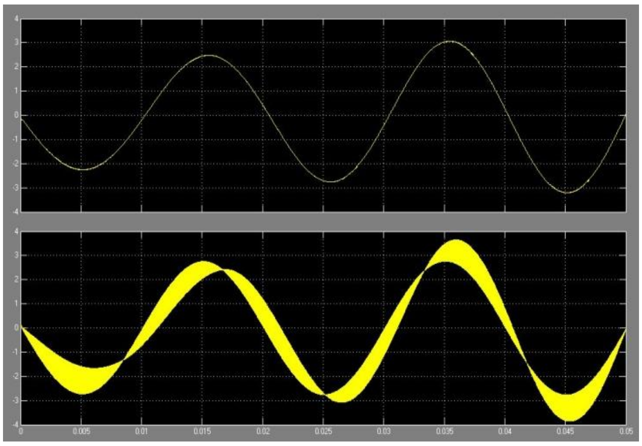

Fig.10 GRID AND INVERTER CURRENTS

V.CONCLUSIONS

This paper has made the following conclusions on the basis of previous studies:A single-phase equivalent circuit model has been established to analyse the characteristics of LCL filter applied in APF. Oscillating element leads to a resonance peakenlarging harmonic. Resonant frequency depends upon total grid-side inductor with no relation to inverter-side inductor owing to the function of inverter current loop. We proposed a set of methods to design LCL filter. Total inductance is restricted by the capability of APF. Damping ratio, attenuation degree of switching ripples and resonant frequency are the crucial factors to determine the performance of LCL filter. Intrinsic relation of them has been presented and a comprehensive consideration is essential.LCL filter has an adverse effect on magnitude and phase of compensation current. A correction method using synchronous rotating transformation has been proposed and demonstrated by simulation results. Further studies may be needed on adapting to varying parameters of system.

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