A simple method to optimize DC-bus capacitor in 3-phase shunt Active power filter system

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Abstract

This paper introduces a shunt active power filter with a small DC bus capacitor by adding additional low-pass filter (LPF). The DC link voltage fluctuation is impressively suppressed with a small value in spite of the low value of DC-link capacitor under the steady-state condition. Consequently, the cost and volume of power converter are significantly reduced thanks to the reduced value of DC-bus capacitor. On the other hand, an indirect control strategy is used to maintain grid-side current when non-linear loads are connected to the system. By using proportional-integral (PI) and modified repetitive controller (RC) in dq0 frame, the calculation time is greatly decreased by 6 times compared with the conventional RC, and the number of measurement devices is also minimized. As a result, the acquired total harmonic distortion (THD) is lower than 2% regardless of the load conditions. Simulation results are carried out in order to verify the effectiveness of the proposed control strategy.

1. Introduction

Non-linear loads such as diode-bridge are concerned as a current source which generates a large amount of harmonic components into the grid. In order to improve the power quality, harmonic problems are carefully considered due to its influence to system, and they can be solved by using passive power filter or active power filter (APF).

This paper proposes a shunt APF with small DC bus capacitor by adding a low pass filter (LPF) to the feed back DC bus voltage signal. The proposed shunt APF can achieve low cost as well as reduced volume without degrading the compensation performance and dynamic response because a low value DC-link capacitor (e.g. 400μF) is installed. Moreover, a low-range of fluctuation of DC-link voltage is obtained (± 10V). And also, the power loss is properly controlled with a fixed switching frequency. Additionally, a parallel modified PI-Repetitive controller (PI-RC) [1], [2] is executed in order to regulate both fundamental and oscillating components of source current.

The control strategy is verified with the aid of computer simulation by using PSIM.

2. The control strategy

In fundamental dq0 frame, a well maintained grid-side current can be normally considered as a purely DC signal. Hence, the reference value of direct component of source current in dq0 frame has to be accurately generated from DC-bus voltage regulator.

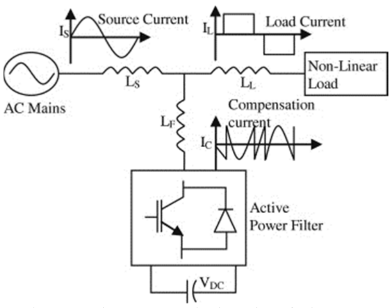

Fig. 1: The general circuit of shunt APF

However, in case of a low value of DC-link capacitor, it becomes difficult to acquire a purely DC signal from the output of PI controller. In order to solve this problem, an additional LPF is utilized. The inserted LPF ensures the output of the PI controller of this stage to be nearly constant.

Ideally, the main source supplies only fundamental current component to the load side without exchanging the reactive power, so that the reference value of the quadrature component in the proposed control strategy can be set as zero [1]. Theoretically, the direct and quadrature components of the source current can be simultaneously compensated by a parallel PI-RC structure. The PI controller ensures both d and q component of the source current to track their DC reference values. Sequentially, RC operates as a group of resonant controllers [1], [3], [4] to reduce the oscillating components as close to zero as possible. On the other hand, by using Park transformation, the (6n ± 1) orders in 3-phase system are converted into ±6n orders, respectively [1]. Basically, only the 6n orders are needed to be compensated in this situation. Therefore, the computational burden of the RC controller can be dramatically reduced by 6 times [4]. The discrete transfer function of a RC is expressed as follows:

$$G_{RC}(z) = \frac{K_r Q_z z^{-N}}{1 - Q_z z^{-N}} \quad (1)$$

$$N = \frac{f_s}{6.f_n} \quad (2)$$

where, K_r is a gain of the controller, Q_z is a closed to unity factor, z is backward operator, f_s is sampling frequency and f_n stands for fundamental frequency [1] – [3]. Finally, a feed-forward stage is also inserted to the end of calculation progress to ensure a good performance of the whole system. The obtained reference signals are modulated by conventional space vector theory with a fixed switching frequency [1].

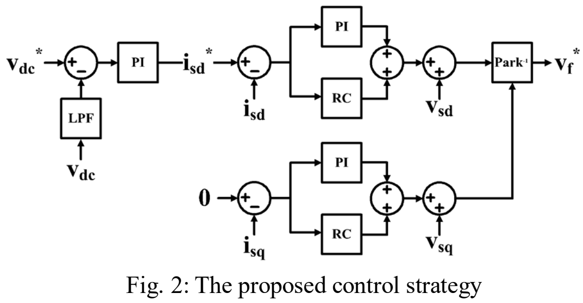

Fig. 2: The proposed control strategy

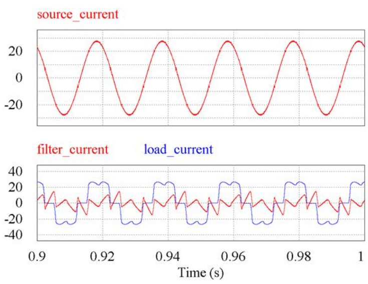

Fig. 3: System current in steady-state

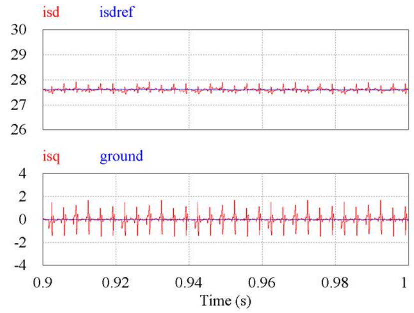

Fig. 4: System current in dq0 frame in steady-state

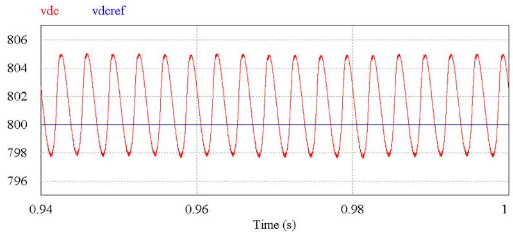

Fig. 5: DC-bus voltage in steady-state

3. Simulation results

A non-linear load is initially used to verify the effectiveness of the proposed control strategy under the steady-state condition. From Fig. 3, it can be seen that the total harmonic distortion (THD) factor of source current is lower than 1.8%, while the load current is highly distorted. The waveform of source current in dq0 frame is shown in Fig. 4. Two reference values are tracked well by two instant signals. Moreover, the fluctuation of the voltage of DC-bus capacitor whose value is only 400μF is suppressed within ±10V around the reference value as shown in Fig. 5.

In order to evaluate the dynamic performance of the whole system, the transient cases are simulated. A high power-rating 3-phase load is suddenly connected to the system through the point of common coupling. Consequently, the load current is significantly increased and its THD is also increased. From Fig. 6, it can be pointed out that the source current is well adapted to this kind of variation within an acceptable time period (approximately 5 cycles). Theoretically, the faster response can be easily achieved by trading off with compensating performance and vice versa. Moreover, the detail reaction of source current in dq0 frame is screened in Fig. 7.

The behavior of DC bus voltage is shown in Fig. 8. Reasonably, it costs a respect time period to force the actual value back to the desired voltage.

4. Conclusion

In this paper, a shunt APF is introduced to dramatically reduce cost and size of the whole system by minimizing the value of DC-

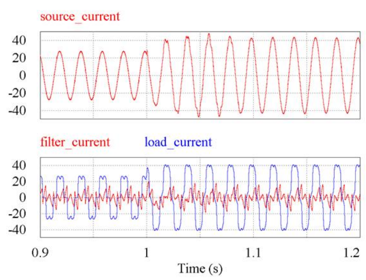

Fig. 6: System current in transient-state

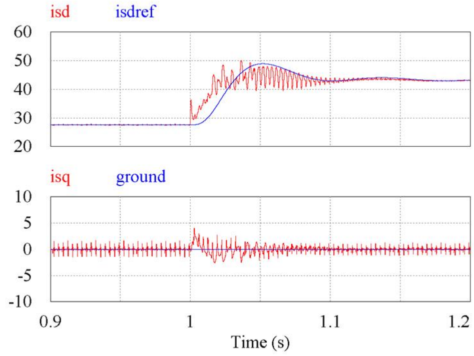

Fig. 7: System current in dq0 frame in transient-state

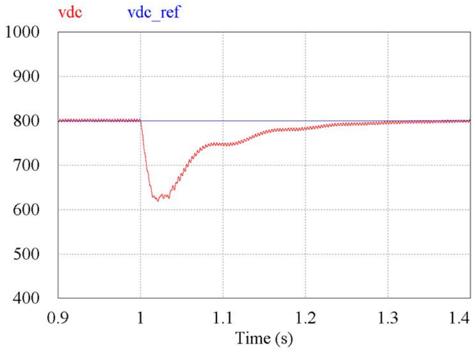

Fig. 8: DC-bus voltage in transient-state

link capacitor. Additionally, a parallel PI-RC is applied in order to regulate the source current in the fundamental rotating frame. All acquired simulation results verify that the fluctuation of DC-bus voltage is suppressed within a very small range. The performance of the proposed shunt APF is evaluated through the simulation, and it is proven to meet the power quality standard for the low-voltage system such as IEEE Std. 519 – 1992 (THD < 2% within 5 cycles). Moreover, computational burden is greatly reduced by 6 times compared with that of the conventional RC. Due to the fixed switching frequency, the energy loss consumed by the power converter can be controlled easily.

Acknowledgement

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