Research of Hybrid Three-phase equilibrium Technology

K Xu[1,3], **Z Z Liu**[1], **G Z Qi**[1] and **Y J Hou**[2]

[1] School of Electrical Engineering, Shandong University, Jinan 250061, China
[2] Shandong Academy of Sciences, LiXia District, Jinan 250061, China

Email: xuzuokai@foxmail.com

Abstract. This paper puts forward a kind of managerial method based on the combination of PPF (passive power filter) and APF (active power filter) for the problem of three-phase current balance in three-phase four-wire system. This method uses two special reactors to filter zero-sequence current and uses APF to filter negative-sequence fundamental current, positive-sequence and negative-sequence harmonic current. It is more effective, reliable and economic. This paper proves feasibility of the method by the simulation results.

1. Introduction

Now, electricity load is bigger and bigger. Proportions of nonlinear load like LED lights, computers are increasing in building low voltage power distribution system. Load distribution between the three phases changes over time, so three-phase unbalance degree is variable. Even if three-phase load balancing, on account of nonlinear load, neutral current is often too large, even more than the phase current. Therefore, building low voltage power distribution systems often have serious problems of three-phase current unbalance [1].

The problems of three-phase current unbalance seriously affect the power quality and safety [2], [3]. Governance methods of three-phase current unbalance mainly include: 1) Load management of power station area like [4],[5], it can make three-phase unbalance degree to reduce, but it doesn't take nonlinear load into consider; 2) reactive compensation between the three phases like [6], to a certain extent, it can adjust the asymmetric three-phase load, but its dynamic performance is poor.

APF is power electronic device to dynamically suppress harmonic and compensate reactive power. Compared with PPF, it has a better response speed and compensation characteristics. But its capacity of compensation of zero-sequence current is smaller, about 25% of the rated capacity. When APF compensates zero-sequence current, the dc side capacitor voltage fluctuation is increscent, which cause degradation of APF performance. So this paper uses two special reactors to filter zero-sequence current. Compared to the traditional LC filter, it can filter out all the number of zero-sequence current and its dependence on the parameters of the system is tiny. APF only is used to filter negative-sequence fundamental current, positive-sequence and negative-sequence harmonic current. Therefore, this method is more effective, reliable and economic.

2. The basic principle and system structure

[3] Address for correspondence: K Xu, School of Electrical Engineering, Shandong University, Jinan, 250061, China. E-mail: xuzuokai@foxmail.com.

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System's basic structure is shown in figure 1. ① is PWM voltage source converter. It can generate offset current according negative-sequence fundamental current, positive-sequence and negative-sequence harmonic current, equivalents to controlled current source. ② is ZSBT (Zero-Sequence Blocking Transformer) [7]-[9]. It is not impedance for positive-sequence, negative-sequence current and is impedance for zero-sequence current. ③ is Zig-Zag TR (Zig-Zag transformer). It allows only zero-sequence current to pass and is about 0.005Ωon the impedance of the zero-sequence current.

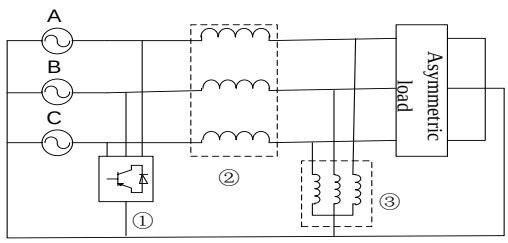

Figure 1. System's basic structure

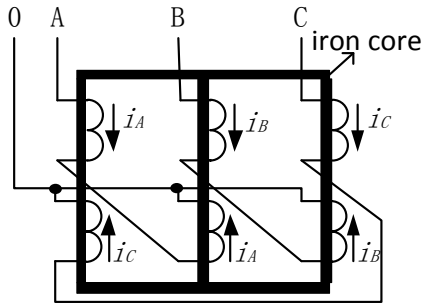

Figure 4. Structure of Zig-Zag TR

Three phase unbalance current can be divided into positive-sequence fundamental current component, negative-sequence fundamental current component, zero-sequence fundamental current component, positive-sequence secondary harmonic current component, negative-sequence secondary harmonic current component, zero-sequence secondary harmonic current component, and so on [10]. With the exception of positive-sequence fundamental current component, others need to filter out. Equivalent circuit of system is shown in figure 2 for zero-sequence current. X_0 is short circuit impedance of system. As a general rule, X_0 is far less than X_1 and can be ignored. X_1 is zero-sequence impedance of ZSBT. X_2 is short circuit impedance of Zig-Zag TR. The figure 2 can be seen that system filter efficiency is . Choose impedance of ZSBT to meet the requirements of zero-sequence filter. Equivalent circuit of system is shown in figure 3 for positive-sequence and negative-sequence current. i_h is the current to be compensated. i_f is positive-sequence fundamental current. The figure 3 can be seen that only i_f is retained.

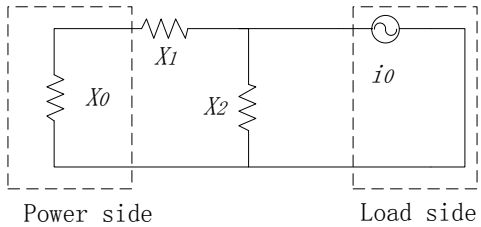

Figure 2. Equivalent circuit for zero-sequence current

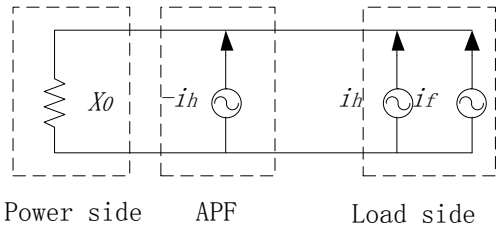

Figure 3. Equivalent circuit for positive - sequence current

3. The principle and the design of reactor

3.1 The principle and the design of Zig-Zag TR

Zig-Zag TR only has one side of the winding. It's a special reactor. In each phase, there are two of the same winding, which roll on iron core column，as shown in figure 4.

Flux linkage of iron core column can reflect the reactance according to definition of inductance [11]. Assuming that the flux linkage Ψ_A, Ψ_B, Ψ_C respectively is generated by the phase current i_A, i_B, i_C. Ψ_{Ae}, Ψ_{Be}, Ψ_{Ce} respectively is total flux linkage in iron core column A,B,C. Total flux linkage of iron core column that is generated by positive-sequence current is three-phase symmetrical, as shown in figure 5. The sizes of Ψ_A, Ψ_B and Ψ_C are equal. Zig-Zag TR has big impedance to positive-sequence current. Leakage current is about 0.01A and can be ignored. Total flux linkage of iron core column

that is generated by negative-sequence current is similar to that of positive-sequence current. So Zig-Zag TR is equivalent to open circuit for positive-sequence and negative-sequence current. Total flux linkage of iron core column that is generated by zero-sequence current is 0 Wb because the sizes of Ψ_A, Ψ_B, Ψ_C are equal, as shown in figure 6. Ignore leakage flux, Zig-Zag TR is equivalent to short circuit for zero-sequence current. Design of Zig-Zag TR can use the traditional design method of transformer [12].

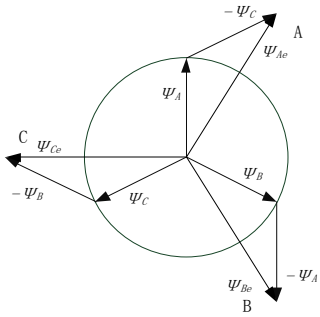

Figure 5. Flux linkage of iron core column for positive-sequence current

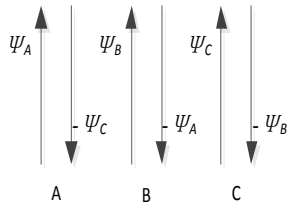

Figure 6. Flux linkage of iron core column for zero-sequence current

3.2 The principle and the design of ZSBT

ZSBT is a special reactor. Three identical windings of ZSBT roll on the same iron core column [8], as shown in figure 7.

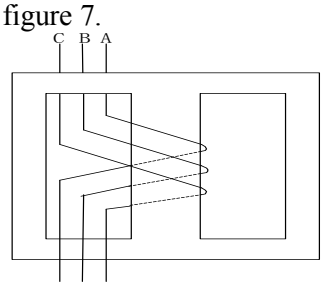

Figure 7. Structure of ZSBT

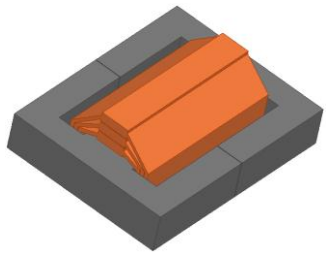

Figure 10. 3D model of ZSBT

Total flux linkage of iron core column that is generated by positive-sequence current is 0 Wb, as shown in figure 8. Ignore leakage flux, ZSBT is equivalent to short circuit for positive-sequence current. Total flux linkage of iron core column that is generated by negative-sequence current is similar to that of positive-sequence current. So ZSBT is equivalent to short circuit for positive-sequence and negative-sequence current. Total flux linkage of iron core column that is generated by zero-sequence current is a sum of Ψ_A, Ψ_B and Ψ_C, as shown in figure 8. Because the sizes of Ψ_A, Ψ_B, Ψ_C are equal, it is 3 times as single phase flux linkage. So impedance of ZSBT is 3 times as single phase impedance.

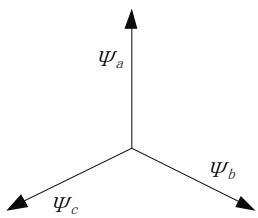

Figure 8. Flux linkage of ZSBT for positive-sequence current

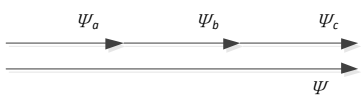

Figure 9. Flux linkage of ZSBT for zero-sequence current

There is a big error by traditional design method for special structure of ZSBT. The paper design ZSBT by the magnetic coupling method. Core cross-sectional area, turns of winding, Wire diameter and estimate of air gap are defined by traditional design method. 3D model of ZSBT is set up in Ansoft, as shown in figure 10. Air gap is defined by simulation with different air gap length. electromagnetic properties of ZSBT can be analyze in Ansoft.

4. Design of APF

In three-phase four-wire system, a sum of positive-sequence and negative-sequence phase current is 0 A; a sum of zero-sequence phase current is 3 times of zero-sequence phase current. So output current of DC side is 0 A when APF compensates positive-sequence and negative-sequence phase current; it's 3 times of zero-sequence phase current when APF compensates zero-sequence current. Therefore, fluctuation of DC side voltage is increased when APF compensates zero-sequence current, which astricts the ability of APF compensation.

In this paper, main circuit of APF uses diode-clamped three-level inverter [13] that is the most widely used at present; harmonic detection uses instantaneous reactive power theory [14],[15]; current regulator uses VR (vector resonant regulator) [16]-[18]. Control chart is shown in figure 11. Directive current i_C* is composed of current of voltage regulator i_u and harmonic current ih. Output current of APF i_C follows i_C*.

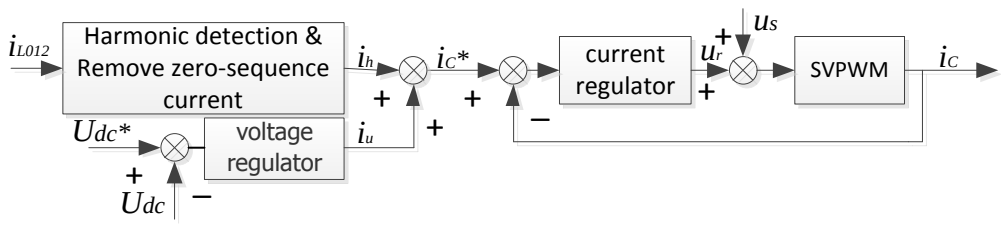

Figure 11. Control chart of APF

5. Simulation experiment

In Simulink, the model was set up to prove the feasibility of this method, as shown in figure 12. The load is shown in table 1. System currents are shown in figure 13 when the load access to the system. It shows the phase current is not balanced and neutral current is mainly fundamental current. A little harmonic current of neutral line is generated by Single-phase uncontrollable rectifier of A-phase. Parameters of mixed mode are shown in table 2.

Table 1. Compositions of the system load

the load in parallel	Phase of load	Structure of load	R(Ω)/L(mH)
1	A&B&C	three-phase uncontrolled rectifier	5.0/2.0
2	A	Single-phase uncontrollable rectifier	1.5/1.0
	B	resistance-inductance load	5.0/1.0
	C	resistance-inductance load	10.0/1.0

Table 2. Parameters of mixed mode

Parameters	value	Parameters	value
zero-sequence impedance of ZSBT	0.03140Ω	Voltage of DC side	800V
short-circuit impedance of zag-zig TR	0.00628Ω	system voltage	220V
inlet wire inductance of APF	1.0mH	Capacitor of DC side	3300uF

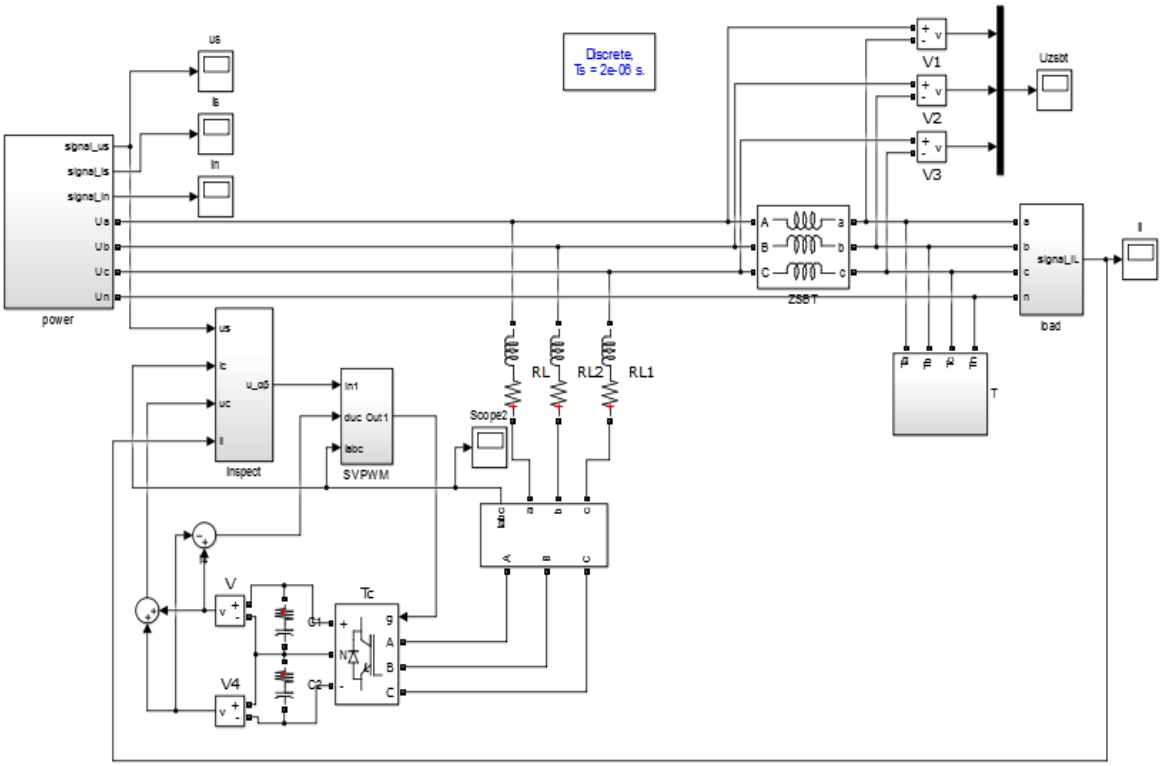

Figure 12. Mode of three-phase hybrid power balancing technique

After using methods of this paper, THD (distortion rate) of phase current respectively drop to 2.3%, 2.3%, 2.3%, 2.3% from 14.3%, 15.6%, 17.8%; neutral current drop to 2.26A from 115.26A; three-phase unbalance degree drop to 1.4% from 51.28%; system currents are shown in figure 14. Output current of APF and current that is filtered by Zag-Zig TR are shown in figure 15. A sum of APF output phase current is 0 A and Zag-Zig TR can filter out neutral current of each time. The contrast of capacitor voltage fluctuations that the system only uses APF to governance unbalanced three-phase current and that it uses mixed mode is shown in figure 16. Capacitor voltage is more volatile with APF. Voltages of two capacitors aren't equal, which has big effects on performance of APF.

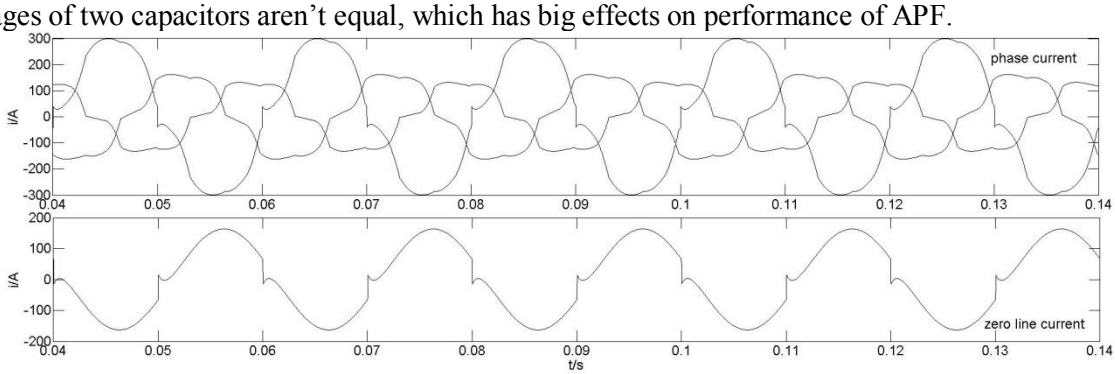

Figure 13. System currents without three-phase balancer

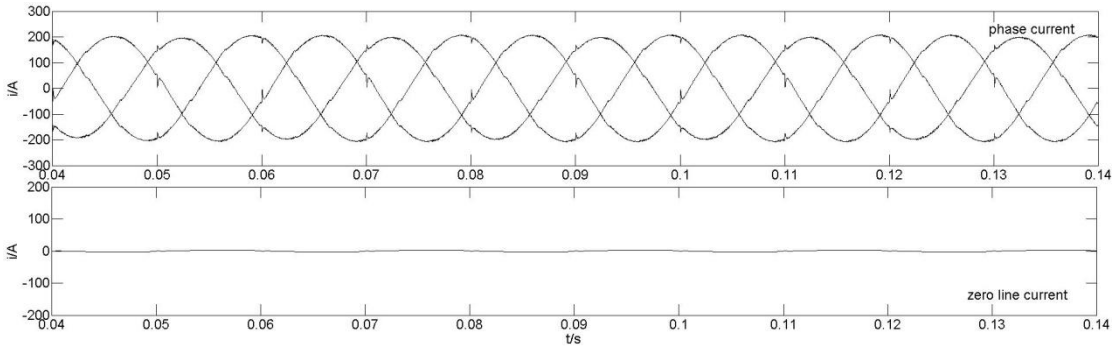

Figure 14. System currents with three-phase balancer

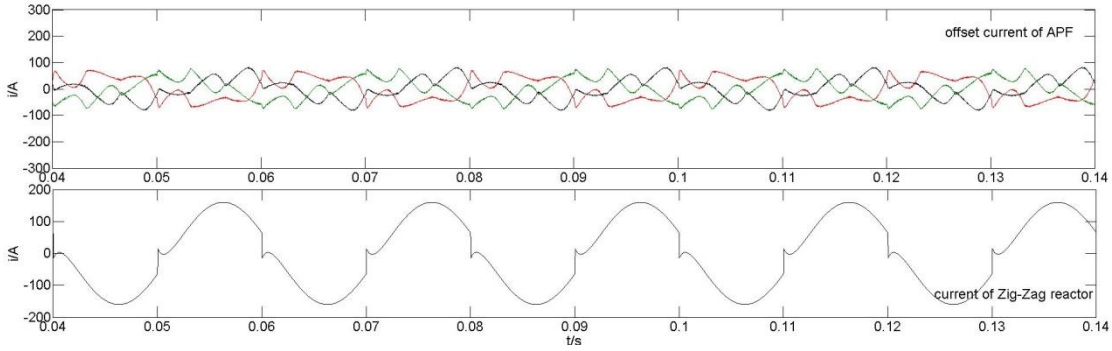

Figure 15. Output current of APF and current that is filtered by Zag-Zig TR

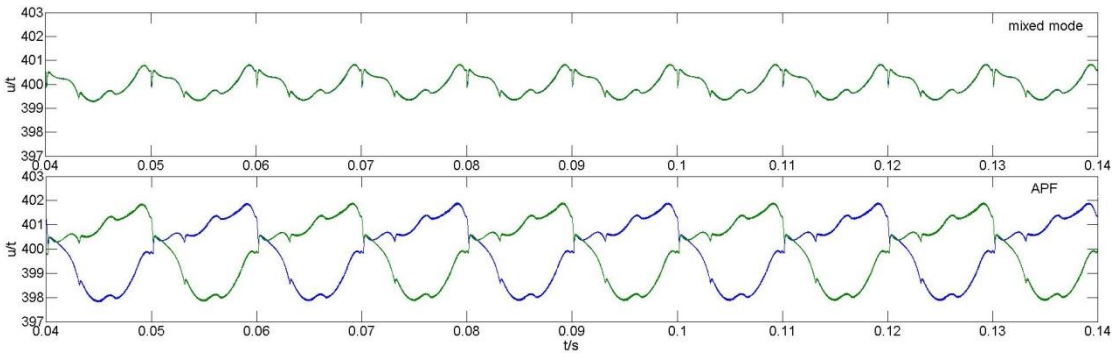

Figure 16. Contrast of capacitor voltage fluctuations with two modes

6. Conclusion

The technology of hybrid three-phase current balance that is researched by this paper is suitable for three-phase four-wire system. Compared with traditional technology of three-phase current balance, it can better play the advantage of PPF and APF. With the deepening of research, it will have a public concern in the building voltage power distribution system.

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