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Three-Phase Static Var Generator Based on Z-Source Network

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Abstract

In order to improve the work reliability of three-phase static var generator and reduce requirements of its inverter circuits on the DC-side voltage, the three-phase static var generator combined with Z-source network is designed based on the Z-source network topology theory. Through analyzing the working state of the main circuit, system simulation model is built by using simulation software Simplorer. Simulation results show that static var generator based on the Z-source network has lower requirements of capacitance and voltage of the inverter circuit on DC-side and better voltage and current compensation waveforms than the traditional static var generator. The results further support that the three-phase static var generator based on Z-source network has higher reliability and better compensation effect.

Keywords: *var generator; Z-source network; reactive power compensation; Simplorer*

1. Introduction

With the rapid development of Chinese modern industry, quality of power supply causes attention extensively to the power departments and power users. Currently, the majority of power distribution and electrical equipment work on the principle of electromagnetic induction, such as transformers, excitation of the motors and leakage reactance of the windings, etc. These devices not only consume the necessary active power, but also consume or occupy a lot of reactive power [1]. Therefore, in order to maintain the balance of reactive power of the grid, a variety of reactive power compensation device comes into being used. At present, the most advanced reactive power compensation device uses the self-commutated inverter circuit—Static Var Generator (SVG), which has the advantages of flexibility for controlling, fast response, less components of harmonic current [2]. With increasing in the ability of voltage and current withstand of the switching devices, and the application of multiple and multi-level technologies, SVG device is growing in perfect [3]. However, it still exists some problems on traditional SVG. The DC-side voltage of SVG directly affects the size of the output reactive power of compensation devices, thereby affects the reactive power compensation effect [4].

Z-source network topology, which is a new theory of the inverter circuit topology [5], was proposed by the Michigan State University's F.Z.Peng in 2002. It overcomes some shortages in traditional inverter circuit. For example, the range of output voltage is limited [6], voltage and current type of main circuit can not exchange each other, and it is easy to damage when the bridge arms turn to be open circuit or short circuit caused by transient electromagnetic

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interference [7]. Due to the unique structure of Z-source network, it has the following advantages of SVG device combined with Z-source network:

(1) The usage of X-type LC networks can achieve single-stage voltage-up/down.

(2) Don't need a dead zone. It is able to eliminate traditional inverter output noise brought by dead-time.

(3) The straight bridge arm becomes the normalcy, which enhances the anti-interference ability of the inverter.

Therefore, this paper puts forward applying Z-source network topology to SVG device. Through analysis of the working state of SVG main circuit combined with Z-source network, SVG system simulation model based on Z-source network is designed in Simplorer 9.0.

2. Working State of SVG based on Z-source Network

The main circuit of traditional SVG has eight working state, including two traditional zero state and six effective state. Traditional zero state refers to that the load is short circuit by above or below three bridge arms of the main circuit. Six effective state means that when the DC source is applied across the load, the inverter circuit has six non-zero vectors [8]. Combining traditional SVG with Z-source network, the main circuit has nine working status, which have one more short-circuit zero state than traditional SVG. At short-circuit zero state, DC source supplies for Z-source network to make a unique lifting characteristic for DC-side, and there won't be device damage caused by short circuit problem of above and below bridge [9]. At short-circuit zero state, the equivalent circuit from DC-side observation is shown in Figure 1. At other eight traditional situations, equivalent circuit is shown in Figure 2. The value of current source can be thought as zero at traditional zero state, which equals to the open circuit.

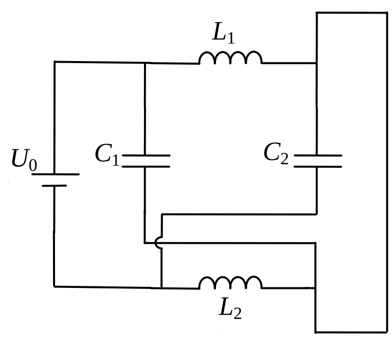

Figure 1. Equivalent circuit at short-circuit zero state

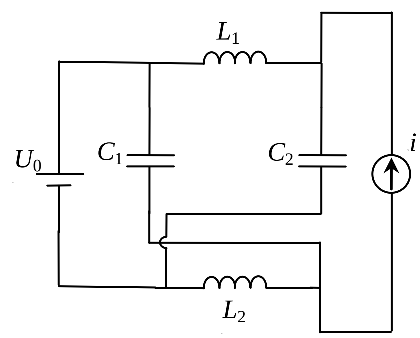

Figure 2. Equivalent circuit at traditional state

Assuming C_1=C_2=C, L_1=L_2=L in the Z-source network. The time of short-circuit zero state is T_0 in one work cycle. The time of traditional state is T_1 and one work cycle time is T.

Because of symmetry Z-source network, Figure 1 at short-circuit zero state T_0 shows:

$$U_{C1} = U_{C2} = U_C. \tag{1}$$

$$u_{L1} = u_{L2} = u_L. \tag{2}$$

$$u_L = U_C, U_0 = 2U_C, u_i = 0. \tag{3}$$

At traditional state T_1, Figure 2 shows:

$$u_L = U_0 - U_C. \tag{4}$$

$$u_i = U_C - u_L = 2U_C - U_0, \tag{5}$$

where U_0 is the DC supply voltage.

When Z-source network is in steady state, the inductor voltage value is zero on average. Equations (3) and (4) get:

$$U_L = \overline{u_L} = \frac{T_0 U_C + T_1 \cdot (U_0 - U_C)}{T} = 0. \tag{6}$$

$$\frac{U_C}{U_0} = \frac{T_1}{T_1 - T_0}. \tag{7}$$

Peak voltage at the ends of the inverter bridge is:

$$\hat{u}_i = U_C - u_L = 2U_C - U_0 = \frac{T}{T_1 - T_0} U_0 = BU_0, \tag{8}$$

where B means the step-up factor.

$$B = \frac{T}{T_1 - T_0} \geq 1. \tag{9}$$

Equation (9) is produced by the short-circuit zero state.

On the other hand, the peak value of output phase voltage can be expressed as:

$$\hat{u}_{ac} = M \cdot \frac{\hat{u}_i}{2} = M \cdot B \cdot \frac{U_0}{2} = G \frac{U_0}{2}, \tag{10}$$

where M is the modulation factor, and G is the lift coefficient.

Equations (1), (5) and (7) can obtain:

$$U_{C1} = U_{C2} = U_C = \frac{1 - \frac{T_0}{T}}{1 - 2\frac{T_0}{T}} T_0. \tag{11}$$

The modulation factor M and lift coefficient G can be adjusted by changing the time T_0 of short-circuit zero state. The short-circuit zero state only takes the time of traditional zero state, and does not affect other effective state. However, the time of traditional zero state is limited by modulation factor M, and the work time of short-circuit zero state is not beyond the time of traditional zero state.

From the derivation and analysis, the DC-side voltage-up/down characteristics of SVG can be controlled after adding Z-source network. And the dead zone condition becomes a working state of the main circuit. Thus the work reliability of SVG is increased.

3. Total Design of SVG System

The composition of the SVG system is relatively complicated. The overall control system needs reasonable configuration to complete a given task. The whole system block diagram is shown in Figure 3. According to the actual situation, the system is divided into the following core components:

(1) Three-phase bridge inverter circuit. The main circuit of inverter part of SVG is paralleled with the grid system. Its main task is to receive the PWM pulse control signal from the controller part, which is used to drive three-phase switching tube. The main circuit also sends out reactive current that is needed by the grid to compensate the power system network [10]. By increasing the Z-source network in the traditional main circuit, it makes the output voltage range of the circuit wider and the compensation effect better.

(2) Detecting circuit and conditioning circuit. These two circuits are the front-end of the part that SVG connects with grid, aiming at transforming the strong electricity signal which needs to be collected into feeble electricity signal on the grid side and inverter, and then transforming it into electrical signal that is within the limits permitted by conditioning circuit as controller input requested.

(3) Controller. This part is the brain of SVG. Namely, controller is the central unit of the control system, whose main task is to transform the receiving single into PWM driving signal by operation and make the inverter work reasonably [11]. At the same time, the main circuit is controlled by controlling circuit to create appropriate current component, and then the compensation can be realized.

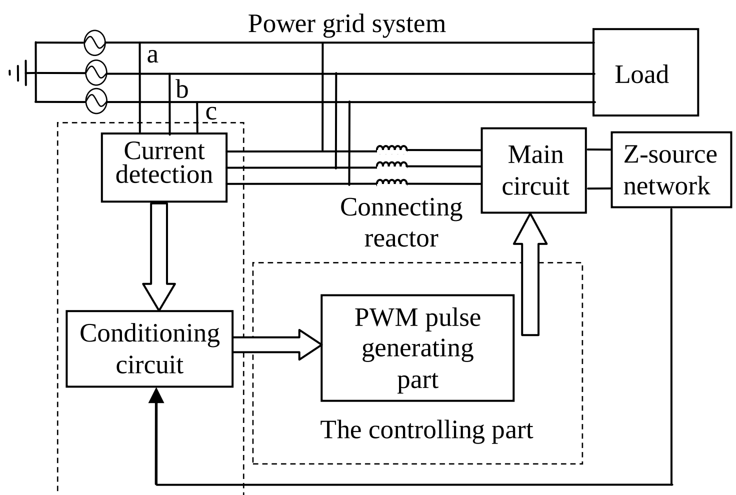

Figure 3. Diagram of the SVG

4. Establishment of Simulation Model

This paper chooses Simplorer 9.0 as the simulation experiment platform. Simplorer is a powerful software in various fields like electromechanical system design and simulation. It is used to the complex and multidisciplinary system, such as electronics, magnetism, thermodynamics, mechanics and hydraulic, for high precision modeling, simulation and optimization. It is widely used in automobiles, electric power industry, national defense, aerospace and industrial automation so on.

When building simulation model, the system parameters and simulation parameters of simulation software Simplorer 9.0 are needed to set up firstly. System parameters are set up as a model for environment and criterion of simulation algorithm; simulation parameters are set according to the hardware conditions of laboratory. Due to the low voltage under the condition of experiment, the RMS values of grid voltage is 12V. The load side of grid chooses the symmetric resistance-inductance load, R=5Ω, L=10mH. The switch devices of main circuit choose MOSFET and diode reverse in parallel. The specific parameters of SVG system simulation model are shown in Table 1.

Table 1. Parameters of SVG simulation model

System Parameters		Simulation Parameters	
Simulation algorithm	Euler	Freq.of grid(Hz)	50
Truncation error	0.1	RMS voltage of grid(V)	12
Maximum number of iterations	20	On-Res.of MOSFET(Ω)	0.001
Simulation time(ms)	150	Freq.of carrier wave(kHz)	5

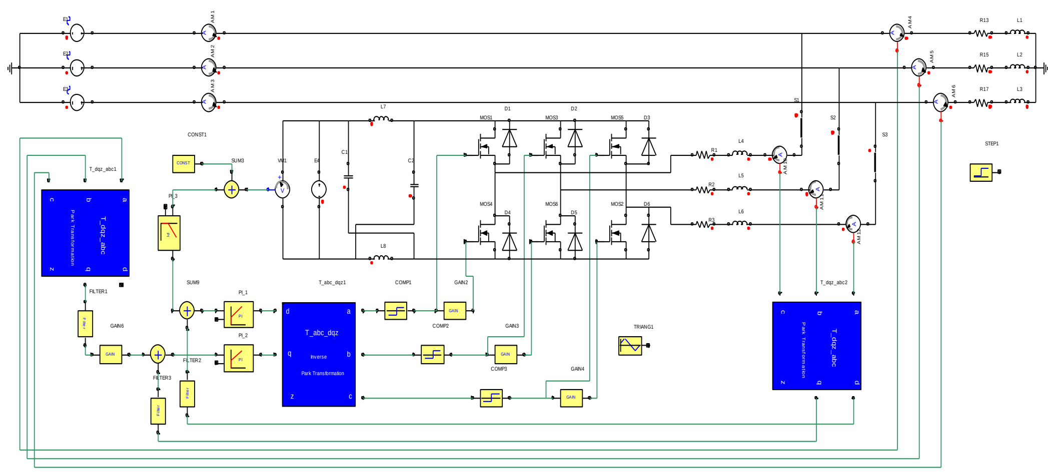

Figure 4. Simulation model of the SVG system

After analyzing the working state and setting the system parameters and simulation parameters, simulation model of SVG based Z-source network is built in Simplorer 9.0, which is shown in Figure 4. It mainly includes: a grid side, the control circuit, and main circuit.

The grid side is composed of three-phase power supply and three-phase resistance-inductance load, as a compensation object of SVG. The control circuit is mainly composed of dq0 transformation and dq0 inverse transformation, which converts the detected signal into PWM drive signal through the operation. The main circuit of SVG, which is in parallel with the grid, receives PWM pulse signal produced from control circuit to drive the MOSFET, and generates reactive power compensation current for need. In this paper, the main circuit increases Z-source network in the DC-side, so that it has a wider output voltage range and better compensation effect.

5. Simulation Results and Analysis

There are two main solutions of the voltage support problem for the DC-side of reactive power compensation device. One is only supported by large capacitor, and the other is supported by DC source. The former is provided by the grid and the latter is provided by the DC power supply. According to these two cases, the simulation models are set up respectively. The voltage and current waveforms of a phase are chosen for contrasting with the simulation results of the simulation model of SVG based on Z-source network.

When the voltage of DC-side is only supported by capacitor, which is C=200μF, the compensation waveforms are shown in Figure 5. In this Figure, 1 and 2 represent the voltage waveform and current waveform of the grid respectively. When the simulation time is 50ms, SVG device is put into the system. As shown from the Figure 5, only part of grid reactive power is compensated, but the grid voltage and current still exist phase difference. Thus the purpose of reactive power compensation cannot be reached. Through the simulation experiment for many times, there is a good simulation result only when the capacitance reaches $C \geq 1500$μF.

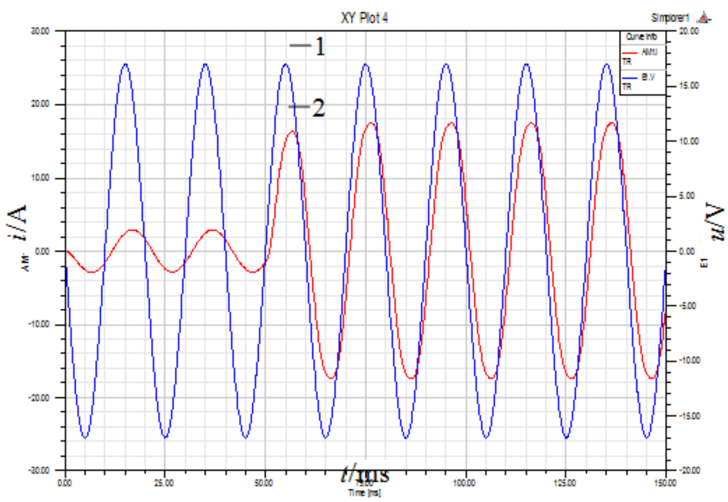

Figure 5. Voltage and current compensation waveforms under 200μF capacitor supply

When the voltage of DC-side is only supported by DC source which is 12V, the compensation waveforms are shown in Figure 6. In this Figure, 1 and 2 represent the voltage waveform and current waveform of the grid respectively. As shown from the Figure 6, the compensation effect is a little better than the capacitor situation, but it still cannot meet the required compensation effect. If we want to get a better compensation effect, the amplitude of DC source must be greater than $\sqrt{3}$ times of the grid voltage peak.

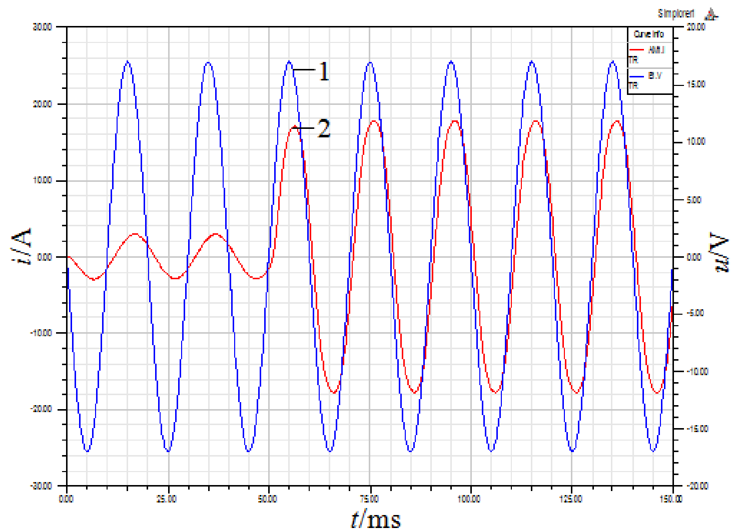

Figure 6. Voltage and current compensation waveforms under 12V DC source supply

This paper introduces Z-source topology to the main circuit of SVG, and sets up the parameters of Z-source network according to the simulation model in Figure 4, which are C_1=C_2=20μF, L_7=L_8=30μH, DC source E_4=5V. When the simulation time is 50ms, SVG device is put into the system. The voltage and current compensation waveforms are shown in Figure 7. In this Figure, 1 and 2 represent the voltage waveform and current waveform of the grid respectively. It can be seen that voltage and current exist a large phase difference before 50ms. However, after putting the compensation device, voltage and current have the same phase, and there is a better compensation effect.

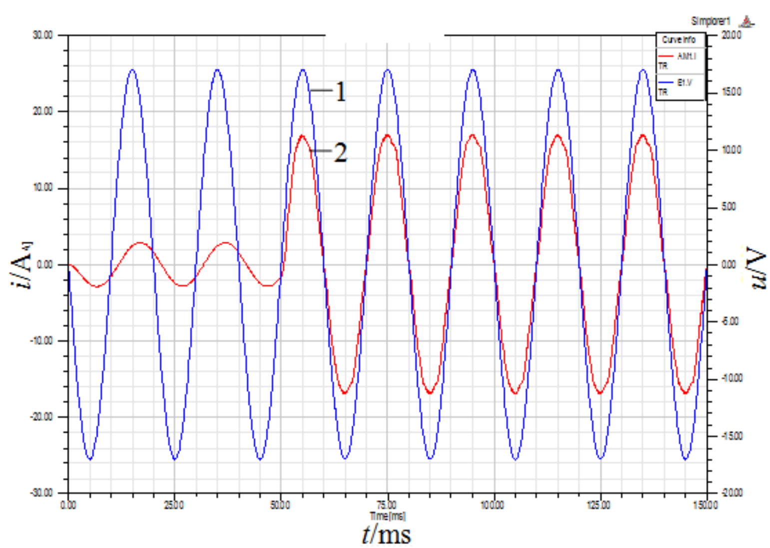

Figure 7. Voltage and current compensation waveforms under Z-source network supply

Through analysing and comparing with the compensation waveforms of traditional SVG and the SVG based on Z-source network, it can be seen that SVG based on Z-source has better voltage and current compensation effect when the capacitance and voltage amplitude are on equal terms. Thus it can reduce the cost of compensation device, and make SVG device more extensive applicability.

6. Conclusions

After analyzing the working state of main circuit, this paper designs the simulation model of SVG based on Z-source network in Simplorer 9.0, and carries on the simulation research. Simulation results prove that the SVG device based on Z-source network has lower requirements on capacitance and voltage of the inverter circuit and better voltage and current compensation waveforms than those of traditional SVG. The Z-source network makes the main circuit more adaptable, and the scope of reactive power compensation wider. It has greatly improved the work reliability of SVG device.

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