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THE DESIGN OF LOW-VOLTAGE STATIC VAR GENERATOR BASED ON RBF NEURAL NETWORK AND LINEAR CANCELLATION PRINCIPLE

Wenge Ma[1], Lin Wang[1,2] and Ang Li[1]

[1]College of Electrical Engineering
Liaoning University of Technology
No. 169, Shiying Street, Guta District, Jinzhou 121001, P. R. China
{ horseprofessor; wanglinteacher; 18341698807 }@163.com

[2]College of Engineering and Technology
Tieling Normal College
No. 45, Heilongjiang Road, Fanhe New District, Tieling 112008, P. R. China

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Abstract. *In recent years, the study on how to improve power quality and achieve high-efficiency reactive power compensation has gained much attention from researchers. Therefore, many researchers have focused on the investigation of the Static Var Generator (SVG). In this paper, the design method of low-voltage SVG is developed. The basic principle and structure of SVG are introduced, and the direct control method of currents is used as the strategy of the main circuit. Based on Radial Basis Function (RBF) neural network and linear cancellation principle, a current detection method is used to establish the SVG. Finally, a simulation experiment through MATLAB/SIMULINK software is provided to verify the effectiveness and reliability of the proposed design method.*
Keywords: Reactive power compensation, RBF neural network, Linear cancellation principle, MATLAB

1. **Introduction.** With the development of power electronic technology, power electronic devices are widely used. However, power electronic devices have some disadvantages, which include the effect on the reactive component of the power grid and unnecessary harmonic generation. Traditional reactive power compensation methods had distinct disadvantages and were unable to meet the requirements of the power factor of the power grid. In [1-3], Static Var Compensator (SVC) device can meet the requirements of the reactive power compensation of the modern power grid, but it also can always cause harmonics and bring electrical pollution. In [4,5], SVG device is a new compensation method, it can not only meet the requirements of the reactive power compensation, but also have good performance of harmonic suppression. However, the timeliness and the rate of compensation of SVG device lack sophistication, so SVG is designed in this paper in order to solve these problems.

In this paper, the basic principle and structure of SVG is introduced. A bridge voltage-type main circuit is used, and current detection link is researched. An RBF neural network detection method [6] based on the principle of linear cancellation is proposed, and it is very intelligent. The constant-frequency triangular wave comparison method is used as the direct control method of currents. A Proportional Resonant (PR) regulator is added into the control circuit in order to get better harmonic suppression. Finally, a simulation experiment through MATLAB/SIMULINK software is provided to verify the effectiveness and reliability of the proposed design method. SVG can effectively compensate both active and reactive power, and it has a good performance in adjusting power factor and improving power quality.

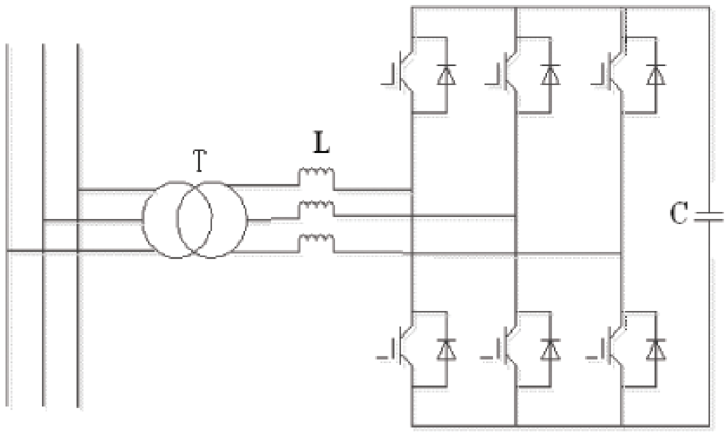


Figure 1. The main circuit of the voltage-type SVG device

2. **Main Circuit and Working Principle of SVG Device.** There are two kinds of main circuits: current-type and voltage-type. Current-type main circuit needs better hardware, so this paper uses a bridge voltage-type main circuit. This circuit is made up of an energy storage capacitor, an inverter, a reactor, etc.

As shown in Figure 1, the capacitor on the DC side provides the necessary voltage support for the circuit as an energy storage element, and it has the function of stabilizing voltage. Inverter is made up of high power switching devices IGBT, and diodes are connected in parallel with each of IGBT devices in order to prevent commutation failure. Pulse Width Modulation (PWM) signal output by control circuit controls the on-off of power switching devices, and modulates DC side voltage into required AC voltage. The reactor connects the DC side and the AC side, it can not only prevent interference of harmonics in the grid, but also filter out the high order harmonic generation from inverter.

The basic principle of SVG is using the bridge circuit to control the AC side current for the realization of dynamic reactive power compensation. Without considering the harmonic, SVG can be regarded as the voltagetype inverter and its single-phase equivalent circuit [7] is shown in Figure 2.

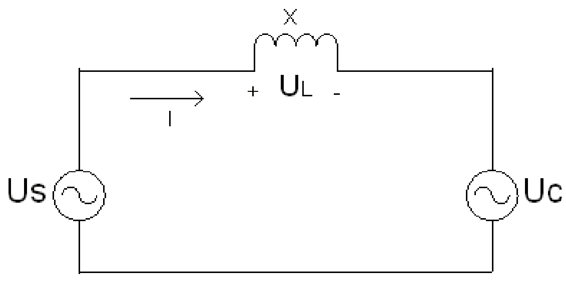


Figure 2. The single-phase equivalent circuit of SVG

As shown in Figure 2, there are three parts: the ratio of voltage U_S, the output voltage of inverter U_C, the voltage of reactor U_L. Their relation can be expressed by the equation below:

$$U_L = U_S - U_C \tag{1}$$

From Formula (1), while the reactance of inverter $X = jwL$, the current I in Figure 2 can be calculated as follows:

$$I = U_L/j\omega L = (U_S - U_C)/j\omega L \tag{2}$$

From Formula (2), except U_C, other parameters are invariant. Therefore, it only needs to change U_C in order to change the phase and amplitude of current I, namely, to choose to compensate inductive or capacitive reactive power. To be specific, when $|\dot{U}_C| > |\dot{U}_S|$, as shown in Figure 3(a), SVG offers inductive reactive power; when $|\dot{U}_C| < |\dot{U}_S|$ as shown in Figure 3(b), SVG offers capacitive reactive power; when $|\dot{U}_C| = |\dot{U}_S|$, as shown in Figure 3(c), SVG does not offer reactive power. So SVG is a kind of advanced equipment, which compensates not only inductive but also capacitive reactive power.

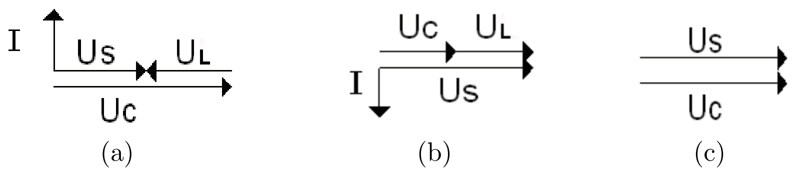


FIGURE 3. The voltage vector digram of the single-phase equivalent circuit

3. **An RBF Neural Network Detection Approach of Current Based on Linear Cancellation Principle.** Current detection is the first link of the whole SVG device; the detection method with high precision, fast speed and strong integration is generally selected. RBF neural network detection approach has been used, but it also needs to be further improved. An RBF neural network detection approach of current based on linear cancellation principle is developed in this paper.

3.1. **The structure of RBF neural network.** As shown in Figure 4, RBF neural network is feed-forward and has three layers. The first layer is input layer, and the input vector of the network is $x = (x_1, x_2, \ldots, x_d)^T$. The second layer is hidden layer, the input vector of the network passes through each of the hidden layers and outputs different values compared with the weight. The weight is 1 steady while the bias term is 0 steady. The values close to the weight enter the output layer. The number of hidden layer nodes is M, k is $(1, 2, \ldots, M)$ while the number of output layer nodes is N, j is $(1, 2, \ldots, N)$, and their connection weights are donated by ω_{kj}. The output of nodes is calculated by basic RBF function and Gaussion RBF function in Formulae (3) and (4).

$$h_j(x) = \phi_j(\|x - c_j\|) \tag{3}$$

$$\phi(\|x - c_j\|) = e^{-\frac{\|x-c_j\|^2}{2\sigma^2}} \tag{4}$$

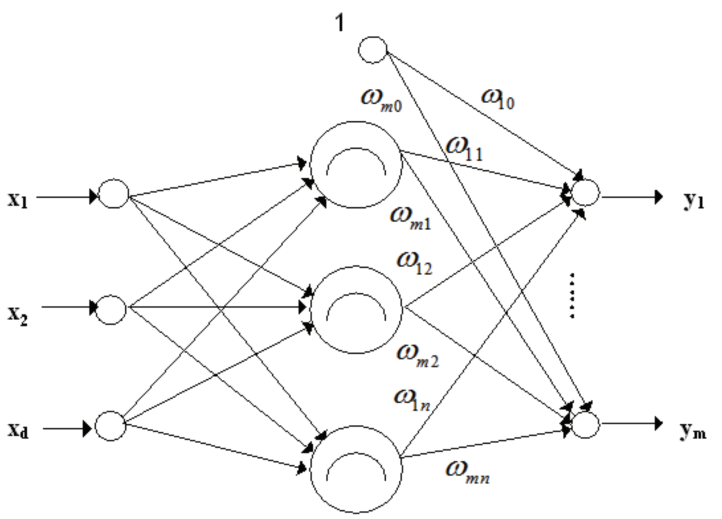


FIGURE 4. The structure of Gaussion RBF neural network

From formulae (3) and (4), the output of nodes about the vector x is y_k, and it is calculated in Formula (5).

$$y_k(x) = \sum_{j=1}^{n} \omega_{kj} h_j(x) + \omega_{k0} = \sum_{j=1}^{n} \omega_{kj} e^{-\frac{\left\|x-c_j\right\|^2}{2\sigma^2}} + \omega_{k0} \tag{5}$$

3.2. **An RBF neural network based on linear cancellation principle.** Let nonsinusoidal current be i_L, and it can be expressed with fourier series.

$$\begin{aligned} i_L(t) &= I_1 \sin(\omega t + \varphi_1) + \sum_{n=2}^{\infty} I_n(n\omega t + \varphi_n) = i_1(t) + \sum_{n=2}^{\infty} i_n(t) \\ &= I_1 \cos\varphi_1 \sin(\omega t) + I_1 \sin\varphi_1 \cos(\omega t) = i_{1p}(t) + i_{1q}(t) \end{aligned} \tag{6}$$

In Formula (6), $i_{1p}(t)$ is fundamental active current, and $i_{1q}(t)$ is fundamental reactive current. The principle of the detection approach of currents based on RBF neural network is shown in Figure 5.

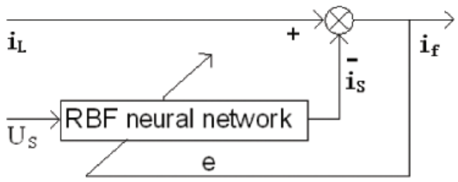


FIGURE 5. The principle of the detection approach of currents

U_S is reference input, and i_L is original input, they have the same frequency, phase and similar amplitudes. As U_S passes through the RBF neural network and produces a similar current signal i_S, and then i_f is obtained by subtracting i_S from i_L. i_f is an undetected harmonic current, and it is taken as an error signal e. e can change the neural network module to make i_S more closely to $i_{1p}(t)$. The smaller the error is, and the more accurate the result is. This is known as the linear cancellation principle. It is better to determine the accuracy of this algorithm by adding the linear cancellation principle into the RBF neural network.

4. **The Direct Control Method of Currents Based on Triangular Wave Comparison.** After the current detection link is developed, triangular wave comparison method is chosen for the direct control method of currents. A constant-frequency triangular wave comparison method for single phase diagram is shown in Figure 6.

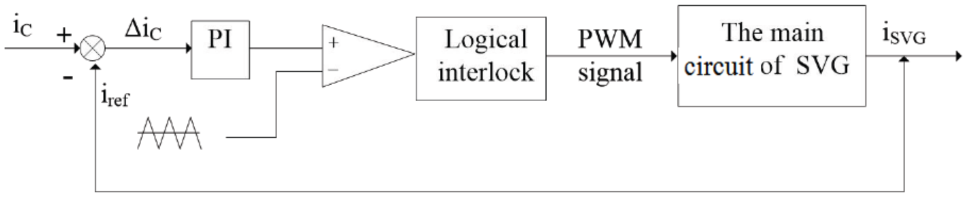


FIGURE 6. Constant-frequency triangular wave comparison method

In Figure 6, i_C is a single phase current detected at the detection link, and i_{ref} is a feedback current generated by inverter, $\triangle i_C$ is generated by subtracting i_C and i_{ref}. $\triangle i_C$ enters Proportional Integral (PI) controller and for amplifying the signal. The amplified signal and the constant frequency triangular wave input onto the comparison link, and the result inputs onto logic interlock link. Then PWM signal is generated in order to control the IGBT in the main circuit, and thus the output current of SVG i_{SVG} is controlled.

The use of three-phase PI causes a delay, and then causes system shaking [8]. In fact, harmonic contents in SVG need to be considered, so this paper adds a PR controller. After PR regulator is used, the good optimal impact is gained, namely tracking current signals well and making up for shortcomings of abc coordinate. Besides, it has a good effect on harmonic control. So adding the module can solve many problems, and it is very efficient. The whole process of control link is shown in Figure 7.

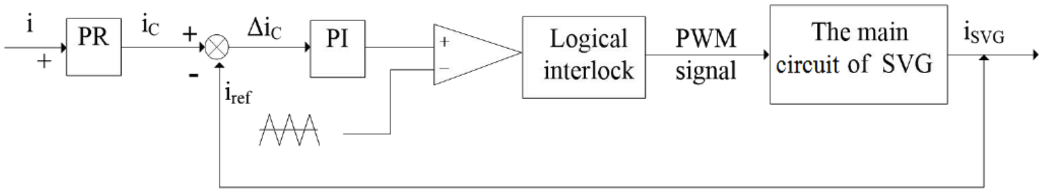


Figure 7. The whole process of control link

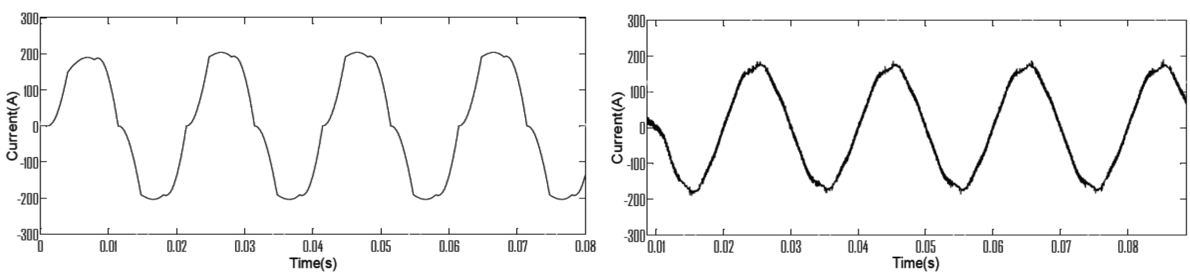
5. Simulation Experiment.

5.1. The establishment of simulation model. A three-phase AC power source model is used as power supply, and the voltage amplitude is 220V and the frequency is 50Hz. Three-phase full controlled rectifier bridge with resistance-inductance load harmonic source is used as the load model that the resistance is 6Ω, the inductance is 20mH, and harmonic content is replaced by diode. Detection circuit is modeled by RBF neural network algorithm. Control circuit is modeled by triangular wave comparison method in abc coordinate. Take the actual compensation current and instruction current through the RELAY module. Eventually, a trigger signal g needed by PWM module is generated. DC voltage of PWM needs to be controlled in about 800V.

5.2. The simulation results. The current waveforms before and after compensation are respectively shown in Figure 8(a) and Figure 8(b). The active power before and after compensation are respectively shown in Figure 9(a) and Figure 9(b). The reactive power before and after compensation are respectively shown in Figure 10(a) and Figure 10(b).

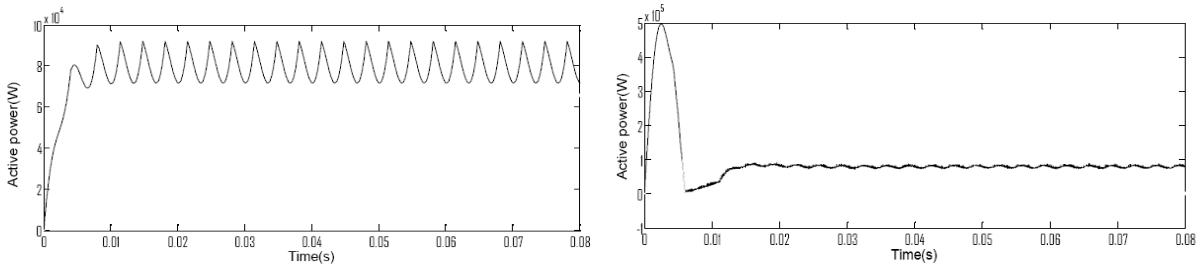
In Figure 8, the current waveform after compensation is closer to sine wave; therefore, SVG device designed in this article can restrain harmonics. In Figure 9 and Figure 10, it can be seen that SVG has a good effect on both active and reactive power compensation. What is more, it can avoid delay and system shaking.

6. Conclusions. In this paper, a novel research and design method of low-voltage SVG was proposed. An RBF neural network detection method based on the principle of linear cancellation was introduced. After the current detection link was developed, triangular wave comparison method was chosen for the direct control method of currents while a PR



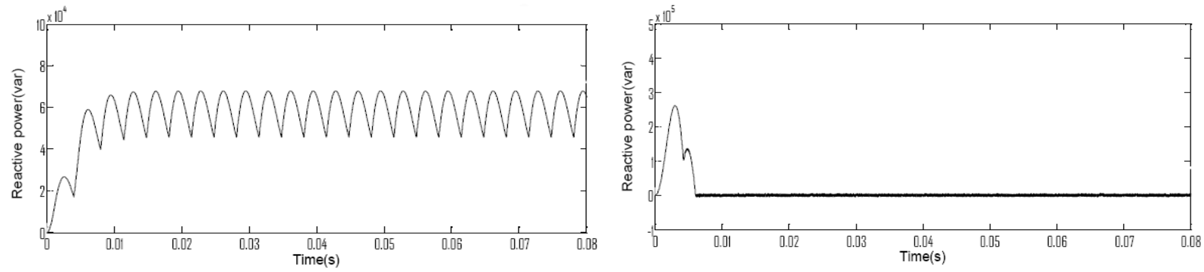
(a) (b)

Figure 8. The current waveforms before and after compensation



(a) (b)

FIGURE 9. The active power before and after compensation



(a) (b)

FIGURE 10. The reactive power before and after compensation

regulator was added in order to get better harmonic suppression. The simulation study demonstrated that SVG can effectively compensate both active and reactive power, and it has a good performance in adjusting power factor and improving power quality. However, there are also many imperfect aspects to be studied and many problems to be solved. In the future research, the combination of RBF neural network and linear cancellation principle will be a hot research direction.

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