

# Design and Simulation for Three-Level Static Synchronous Compensator

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**Abstract.** It adopts three-level inverter as the main circuit of Static Synchronous Compensator (STATCOM), making the output waveform of main circuit more close to sine waveform and the contents of harmonic reduced a lot. Space voltage vector modulate technology (SVPWM) is widely used for control algorithm of three-level main circuit because its digital realize easily, and few current harmonic wave components etc. Design single-phase drive circuit with level clamp using IR2110. Theory analysis and simulation experiment results indicate that the designed STATCOM system of three-level main circuit can send out inductive or capacitive reactive power smoothly, has good dynamic compensation characteristic, it can meet the needs of reactive power compensation.

## Introduction

In electric power system, the harmfulness to system because of lack of reactive power can not be ignored. STATCOM is an important member of Flexible AC Transmission System[1][2], compared with traditional reactive power compensation device, it not only decrease the volume and cost of the device, but also has faster response speed and more smooth regulating property. This paper introduces a STATCOM which adopts three-level inverter as its main circuit, and mainly introduces its structure, fundamental principal, and simulation results.

## Principle of the STATCOM

STATCOM produces a three phase voltage source which has internal reactance, and its amplitude and phase angle controlled. When output alternating voltage of inverter is higher than (lower than) the bus voltage, the inverter will generate leading (lag) current, the difference of the two voltage amplitude had decided the magnitude of current, so it can control the reactive power from this[3].

**Main Diagram of STATCOM System.** The device is mainly comprised of voltage signal condition, current signal condition, controller, impulsator and three-level main circuit. Its diagram is shown in Fig.1.

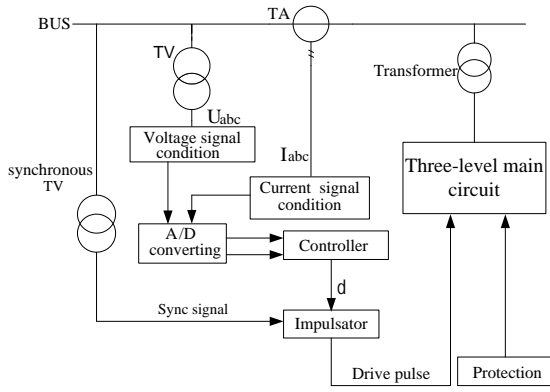


Fig. 1. STATCOM system block diagram

In Fig.1, *TV* is voltage transformer, *TA* is current transformer, and they are used to measure three-phase voltage and three-phase current signal of system. Voltage signal  $U_{abc}$  and current signal  $I_{abc}$  passes through the voltage condition circuit and current condition circuit respectively, they are converting to analog signal that A/D can accept. These analog signals enter into controller after A/D converting. The controller completes the STATCOM output reactive power and control direct voltage of inventor, its output is the STATCOM output voltage and

systemic voltage's phase difference  $\delta$ , the impulsator produces multiplex drive pulse that its phase and pulse width change along with  $\delta$ , these pulses are sent into each power switch, causing the device produces the reactive power that the power network needs.

**Three-level Main Circuit.** From Fig.2 we can see the main circuit is use of neutral-point clamping method to divide the inverter circuit into positive, negative and zero three levels, so that each component subject to the maximum voltage reduced to half of the traditional inverter circuit[4].

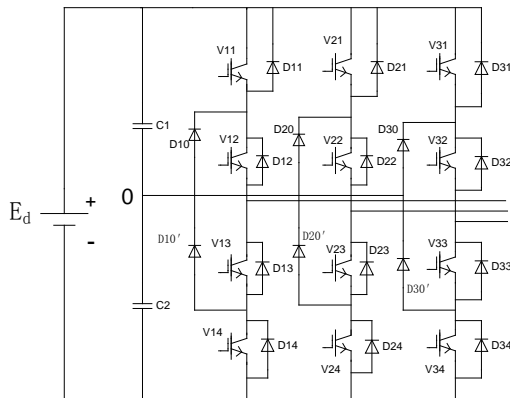


Fig.2 Three-level main circuit

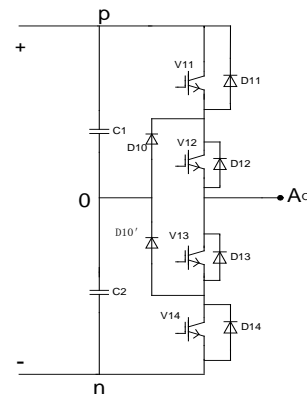


Fig.3 Circuit diagram of A phase

Fig.3 is the circuit diagram of A phase, we can analysis the working process of output voltage.

(1) When give conduction trigger pulse for *V11*、*V12* and shut off *V13*、*V14*: if the load current is inflow direction (relative to the load), and then power supply for charging capacitor *C1*, current flows through *V11*、*V12*, ignoring the tube voltage drop and the output voltage of A phase is  $U = E_d/2$ ;

(2) When give conduction trigger pulse for *V12*、*V13* and shut off *V11*、*V14*: if the load current is inflow direction (relative to the load), and then power supply for charging capacitor *C1*, current flows through *D10*、*V12*, ignoring the tube voltage drop and the output voltage of A phase is  $U = 0$ ;

(3) When give conduction trigger pulse for *V13*、*V14* and shut off *V11*、*V12*: if the load current is inflow direction (relative to the load), and then power supply for charging capacitor *C2*, current flows through *V13*、*V14*, ignoring the tube voltage drop and the output voltage of A phase is  $U = -E_d/2$ ;

Although such a three-level main circuit increases the voltage drop in the conducting state due to an increase component witch the current flowing through, but as of the cut-off state the component withstand voltage is only half of the three-phase bridge inverter. So on the one hand, it can reduce the voltage requirements for IGBT components; On the other hand the output waveform of the three-level inverter can be closer to a sine wave due to increased the third voltage value.

Fig.4 to Fig.7 are voltage waveforms between A、B、C and O. Fig.7 is the output line-to-line voltage waveform of  $U_{AB}$ , it is a five levels step wave.

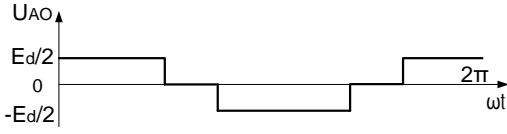


Fig.4  $U_{AO}$  waveform of three-level inverter

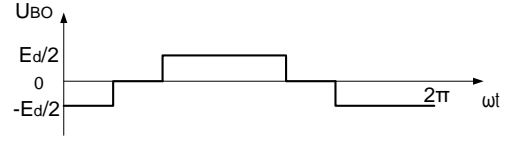


Fig.5  $U_{BO}$  waveform of three-level inverter

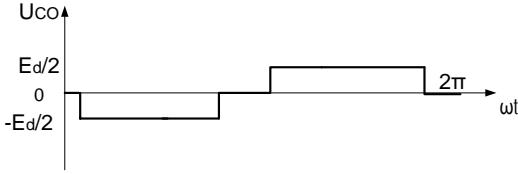


Fig.6  $U_{CO}$  waveform of three-level inverter

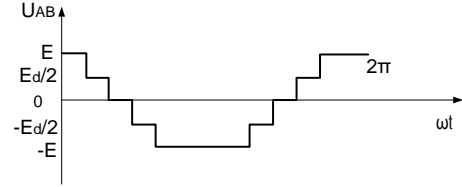


Fig.7  $U_{AB}$  waveform of three-level inverter

From Fig.7 it shows that comparing with two-level inverter, the line-to-line voltage waveform of three-level is more closer to sine wave, so the output voltage waveform harmonic of the device with three-level is smaller and higher reliability.

**Control Algorithm of Three-level Main Circuit.** The output performance of voltage inverter mainly depends on modulating algorithm. Space voltage vector modulate technology (SVPWM) is widely used because its digital realize easily, direct current utilization ratio to be high, and few current harmonic wave components etc[5]. The principle of SVPWM is use balanced three-phase reference voltage to structure a space vector as the reference voltage vector at the vector space, and then use the latest three switch state vector to structure the expected reference voltage vector. The voltage vector of three-level inverter is:

$$\mathbf{V} = V_A + e^{j\frac{2\pi}{3}} V_B + e^{-j\frac{2\pi}{3}} V_C. \quad (1)$$

It can introduct switching function  $S_A$ 、 $S_B$ 、 $S_C$  instead of  $V_A$ 、 $V_B$ 、 $V_C$ , and then:

$$\mathbf{V}(S_A, S_B, S_C) = \frac{V_d}{2} [S_A + S_B e^{j\frac{2\pi}{3}} + S_C e^{j\frac{4\pi}{3}}]. \quad (2)$$

$S_A$ 、 $S_B$ 、 $S_C$  is the voltage value of  $E_d/2$ 、 $0$ 、 $-E_d/2$  respectively.

**Design of IGBT Driving Circuit.** In the process of the use of IGBT, the correctness of selecting

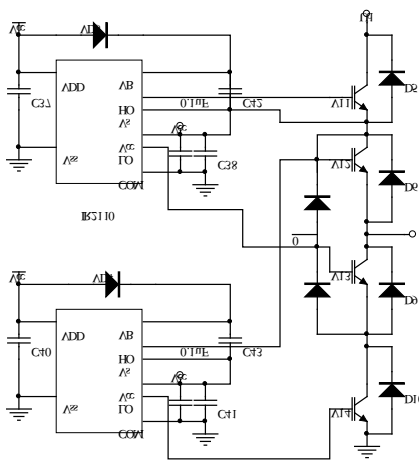


Fig.8 Driving circuit diagram of IGBT  
between the  $V_{cc}$  and  $COM$ .

the driving circuit is extremely important to the realization of the IGBT function. IR2110 is a dual-channel high-voltage, high-speed voltage power switching device gate driver with floating bootstrap power supply, the drive circuit is very simple, which with only one power supply can drive up leg and down leg, it can reduce system costs greatly, and simplify the structure of system hardware[6]. The design of single-phase drive circuit with level clamp using IR2110 as shown in Fig.8, in which a diode in parallel on the grid, the drive level of the grid will clamp to zero level during the period of shut off the gate, and then the burr on the gate drive can be reduced greatly. In order to provide transient current to capacitive load, it should be connection two bypass capacitors

## Simulation Experiment

In order to verify the compensate performance of STATCOM, it has done simulation experiment under MATLAB/simulink.

**Simulation Experiment Under Inductive Load.** When inductive load, the system switching in  $R=70\Omega$ ,  $L=0.2H$  inductive load. Voltage and current waveform of A phase before switching in STATCOM are show in Fig.9.

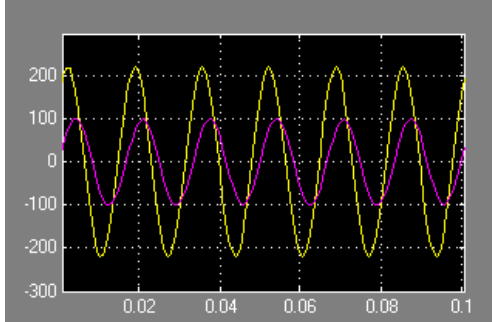


Fig.9. Voltage and current waveform of A phase Before STATCOM compensation

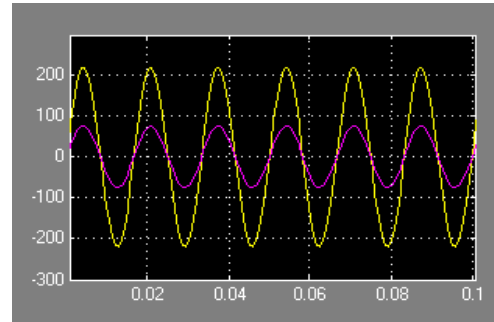


Fig.10. Voltage and current waveform of A phase after STATCOM compensation

From Fig.9 we can see because the load has inductive part, the current waveform lag behind voltage waveform a certain angle, and there is a phase difference between the current and the voltage, the electric circuit's power factor is not equal to 1, it indicates that the power network side both provides active component and reactive component, therefore, it needs carry on the reactive compensation to the electric circuit.

Fig.10 is the voltage and the current waveform of A phase after switching in STATCOM, comparing Fig.9 and Fig.10 we can see that the voltage and current waveform of A phase are basic in-phase after compensation, it shows that the power network side only transports active component after compensation, and the reactive component is provided by STATCOM. This has met the requirement of reactive compensation, and realized the reactive component's on-site compensation.

**Simulation Experiment for Dynamic Adjustment Characteristic of STATCOM.** In the natural environment, the power system suffer a small perturbation is unavoidable, and usually the small disturbance are instantaneous disturbance, it may cause small fluctuations within the scope of the stable operation, and does not cause any major fault that endanger the system security. In the fixed load of the simulation model in parallel the same load, the load and the three-phase circuit breaker series connected to the electricity grid, simulation the impact load in system. It will cause system disturbance with a sudden impact load when the system operation in stable. The simulation waveforms of system three-phase voltage and three-phase current after disturbance are shown in Fig.11 and Fig.12

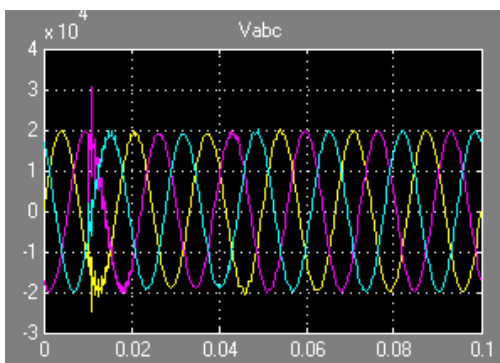


Fig.11 Three-phase voltage waveform after disturbance

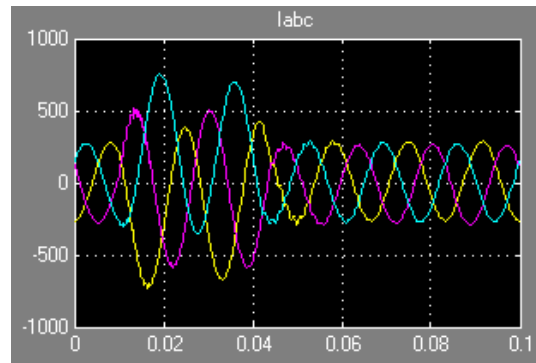


Fig.12 Three phase current waveform after disturbance

It can be seen from Fig.11 and Fig.12 that after the impact load put into the system, the amplitude of three-phase voltage and three-phase current are all increased, it is because reactive power load of the system increased, and the compensation angle  $\delta$  is increased also. But after a short process, the voltage and current waveforms have returned to their original state, this is because the STATCOM calculate the new compensation angle value real-time based on the change of reactive load, and adjustment the phase of output pulse immediately, so it can realize the dynamic reactive power compensation, this suggesting that the STATCOM device has good dynamic compensation characteristic.

## Conclusion

Comparing with two-level inverter, the device with three-level inverter has smaller harmonic wave and higher reliability. The advantages of SVPWM is digital realize easily, direct current utilization ratio to be high, and few current harmonic wave components etc. Theory analysis and simulation experiment results indicate that STATCOM can send out inductive or capacitive reactive power smoothly, it also has good dynamic compensation characteristic. It is an effective measure to enhance the stability of power system, the power factor, and improve the quality of electrical energy.

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