

Simulation Model of Thyristor Controlled Reactor

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Abstract—Controlled power is a fundamental pre-requisite of various sectors. This paper discuss one of the FACT device i.e. Thyristor Controlled Reactor which is used to compensate the reactive power and controls the voltage profile of the power transmission line. Firing control scheme for triggering Thyristor is performed in MATLAB SIMULINK software. This paper deals with the Simulink model of TCR and results of Thyristor controlled reactor (TCR) system. Generation of harmonics in TCR system, operation of TCR under different conditions are also discussed.

Keywords—Thyristor Controlled Reactor, SVC, Flexible AC Transmission System, Variable Shunt Compensation, Ferranti Effect.

I. INTRODUCTION

A temporary over voltage is an oscillatory phase to ground or phase to phase over voltage that is relatively long duration and is undamped or only weakly damped. Temporary over voltages usually originate from faults, sudden change of load, Ferranti effect. The steady-state voltage at the open end of an uncompensated transmission line is always higher than the voltage at the sending end. This phenomenon is known as the Ferranti effect.

Fixed shunt reactors used in EHV & UHV lines to compensate for increase in voltage at receiving end due to Ferranti effect. They have following disadvantages,

- Loaded power lines continuously absorb rated reactive power and thus limit steady state power transfer capacity of the lines.
- Reduce bus voltage during steady state peak load condition and during recovery voltage.
- Reduce surge impedance loading (SIL) level.

In order to overcome the disadvantages associated with permanently connected fixed shunt reactors, one approach to solve this problem is the application of "Flexible AC Transmission Systems" (FACTS) technologies. Flexible AC transmission system (FACTS) is based on power electronic devices, used to enhance the existing transmission capabilities in order to make the transmission system flexible operation, such as the static var compensator (SVC) consist thyristor controlled reactor (TCR) and the thyristor-switched capacitor (TSC) [1]. Thyristor controlled reactor (TCR) is one of the most important building blocks of thyristor-based SVCs. The first industrial TCR based SVC was installed by ABB (former ASEA Co.) in 1972. It was connected to 20kV with a total reactive power capacity of 60 MVar. Siemens

built their first TCR in 1974. The first TCR standard was published by IEEE in 1991. The IEEE 1031 offers a guide to the standardization process of TCR design and implementation.

II. PRINCIPLE OF USING SVC

The SVC behaves like a shunt-connected variable reactance, which either generates or absorbs reactive power in order to regulate the point of common coupling voltage magnitude. In its simplest form, the SVC consists of a TCR in parallel with a bank of capacitors. The SVC regulates voltage at its terminals by controlling the amount of reactive power injected into or absorbed from the power system. When system voltage is low, the SVC generates reactive power (SVC capacitive). When system voltage is high, it absorbs reactive power (SVC inductive). SVC principle is supplying a varying amount of leading or lagging VAR to the lagging or leading system. By phase angle control of thyristor, the flow of current through the reactor is varied. Hence, by varying the firing angle ' α ' from 90° to 180° the conduction interval is reduced from maximum to zero. Generally, by changing the firing angle ' α ' the fundamental reactance X_L of the reactor is changed [3].

$$X_L = V / I_{FL1} (1)$$

III. OPERATION OF THYRISTOR CONTROLLED REACTOR

The basic principle of TCR is to control the reactive power by using a thyristor valve by means of firing angle control. The controlled element is the reactor and the controlling element is the thyristor controller consisting of two oppositely poled thyristors which conduct every alternate half cycles of the supply frequency. An elementary of single-phase thyristor-controlled reactor consists of a fixed (usually air-core) reactor of inductance L , and two anti-parallel thyristor switch "sw" is shown in Fig. 1(a). The closure of the thyristor valve is delayed with respect to the peak of the applied voltage in each half-cycle shown in Fig. 1(b). The current lags the voltage across the reactor by 90° . So, a firing angle of 90° results in maximum current through the reactor, that is, continuous reactor current. For a firing angle of 180° , the reactor current will be zero. Therefore, the firing angle can be in the range of $90^\circ \leq \alpha \leq 180^\circ$ to vary the TCR current from zero to its maximum with respect to the crest of the voltage by phase angle control of the thyristors. The current in the reactor can be expressed in equation (2) with $V(t) = V \cos \omega t$ as follows:

$$i_L(t) = 1/L \int_{\alpha}^{\omega t} V(t)dt = \frac{V_m}{\omega L} (\sin\omega t - \sin\alpha) \quad (2)$$

That is, the delay angle α defines the prevailing conduction angle σ : $\sigma = \pi - 2\alpha$. Thus, as the delay angle α increases, the correspondingly increasing offset results in the reduction of the conduction angle σ of the valve and the consequent reduction of the reactor current. It is evident that the magnitude of the current in the reactor can be varied continuously by this method of delay angle control from maximum ($\alpha = 0$) to zero ($\alpha = \pi/2$), as illustrated in Fig. 1(c)[2]-[3].

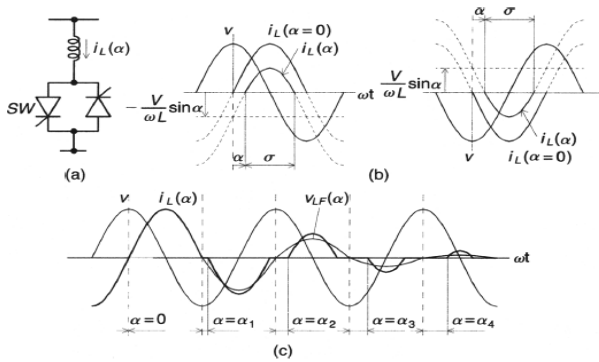


Fig. 1 Basic thyristor-controlled reactor (a), firing delay angle control (b) and operating waveforms (c).

IV. SIMULINK MODEL OF THYRISTOR CONTROLLED REACTOR

A. SIMULINK Model of Single Phase TCR

The SIMULINK model of single phase thyristor controlled reactor is shown in Fig 2.1. In this model current through the reactor is controlled with triggering the thyristor at different firing angle α (i.e. from 90° to 180°) [5]. Triggering pulses to the thyristor is also simulated in MATLAB.

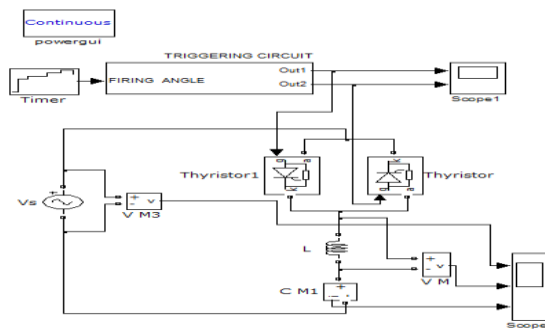


Fig. 2.1 Simulink model of single-phase TCR

B. Simulation Result of Single Phase TCR

Fig. 2.2 shows the output result of Simulink model of single phase TCR. Timer Block provides different firing angle at different specified time. For this firing angle different current through the TCR is obtained.

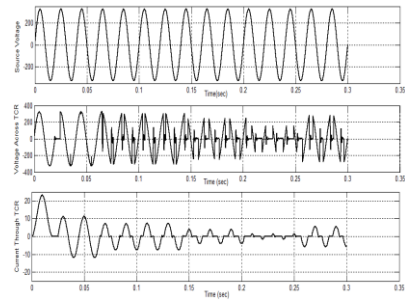


Fig. 2.2 Single phase thyristor controlled reactor for different firing angle ' α '

C. Three Phase Thyristor Controlled Reactor

In a three-phase system, three single-phase thyristor-controlled reactors are used, usually in delta connection as show in Fig. 3.1. Under balanced conditions, the triple-n harmonic currents (3rd, 9th, 15th, etc.) circulate in the delta connected TCRs and do not enter the power system. The magnitudes of the other harmonics generated by the thyristor-controlled reactors can be reduced by various methods [2]. One TIMER block is used to provide different firing angle to the thyristor at specified time which gives continuous change in current flowing through the reactor.

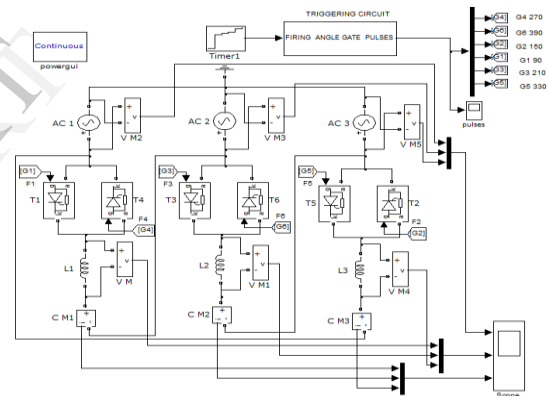


Fig. 3.1 SIMULINK model of three phase TCR

Fig. 3.2 shows Simulink model of pulse generation, gives triggering pulses for three phase TCR which require six pulses in one cycle. These triggering pulses are given to the three single phase delta connected TCR. In this Fig. the subsystem block having SIMULINK Model for generation of triggering pulses. This model is build using different blocks that is, Compare to zero which work as zero crossing detector, discrete edge detector, discrete time integrator and relational operator.

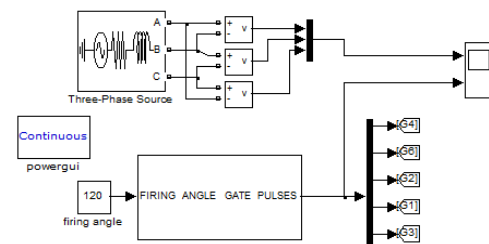


Fig. 3.2 Pulse generation circuit

D. Simulation Result of Three-Phase TCR

Fig. 3.3 shows the triggering pulses for the firing angle $\alpha=120^\circ$. These triggering pulses are applied to three phase supply which gives six pulses in one cycle.

Fig. 3.4 shows the output result of Simulink model of three phase TCR. Timer Block provides different firing angle at different specified time. For this firing angle different voltage across the reactor is obtained and corresponding to this voltage, current through the reactor is obtained.

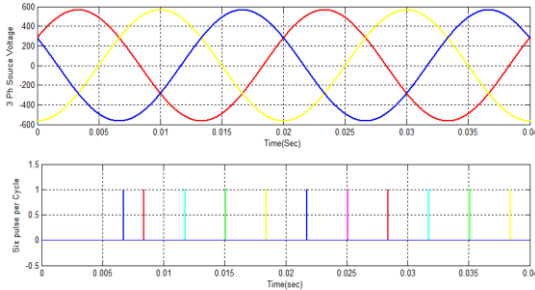


Fig. 3.3 Output waveforms with triggering pulses

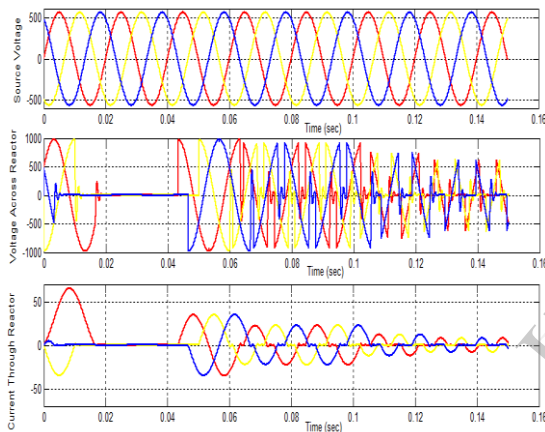


Fig. 3.4 Output waveform of three phase TCR

V. PRODUCTION OF HARMONICS IN TCR

A. Harmonics Generation in TCR

Increasing the gating angle has two other important effects. First, the power losses decrease in both the thyristor controller and the reactor. Second, the current waveform becomes less sinusoidal. In other words, the TCR generates harmonic currents. If the gating angles are balanced, all odd order harmonics are generated. By varying firing angle α , admittance changes and consequently fundamental current component which in turn gives rise to variation of reactive power absorbed by reactor. Hence if $\alpha = 85.5^\circ$ continuous conduction of current takes place. However, if firing angle is

increased beyond this, non-sinusoidal currents are generated and hence harmonics get introduced. TCR is the heart of typical static VAR compensator and problem of harmonics is very severe.

The firing angle ranges between 85.5° to 130° degrees which gives very satisfactory performance with regard to harmonics, real and reactive powers, D.C. components and other variables [4].

B. TCR Under Balance Condition

For three phase balance system, with all the thyristors are fired symmetrically with equal firing angles in each phase then symmetrical current pulses result in both positive and negative half cycle generate only odd harmonics (3^{rd} , 5^{th} , 7^{th} , 9^{th}). Under balance condition, triplen harmonic current i.e. multiple of 3^{rd} order harmonic (3, 9, 15, etc.) circulate in delta connected TCR and do not enter the power system.

C. Effect of Unbalance Voltage on TCR

For unbalance condition where voltages or phase angle of each phase is not equal, the triplen harmonics are flow into the system as well as positive and negative sequence harmonic is flow into the system. This is due to unequal firing of thyristor in positive and negative half cycles which results in DC component.

VI. CONCLUSION

For generating different phase delay, thyristor controlled reactor can absorb reactive power which maintains the system voltage under lightly loaded condition and provide stable conditions as per the system requirement.

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