THEIMPACTOFSTATICVARCOMPENSATOR(SVC)ONPOWERSYSTEM
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THE IMPACT OF STATIC VAR COMPENSATOR (SVC) ON POWER SYSTEM STABILITY

A Project

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Department of Electrical and Electronic Engineering
Abstract

of

THE IMPACT OF STATIC VAR COMPENSATOR (SVC) ON POWER SYSTEM STABILITY

by

Shuchuang Tang

This project investigates the application of static VAR compensator (SVC) to improve power system stability. A static VAR compensator is a set of electrical devices that can be used to provide fast acting reactive power on high-voltage electricity transmission networks. SVCs can be used to regulate voltage, power factor, harmonics, and stabilize the system. Unlike a synchronous condenser which is a rotating electrical machine, a static VAR compensator has no significant moving parts (other than the internal switch gear). There are two types of SVCs: Thyristor Controlled Reactor (TCR) and Thyristor Switched Capacitor (TSC). Both types are discussed in this report, where the application of SVC in single and multi-machine system is carried out and discussed in details. Simulink is used to study the characteristics of SVC and its impact on power system stability. Results show the effectiveness of SVCs in maintaining power system stability.

_______________________, Committee Chair
Dr. Fethi Belkhouche

_______________________
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1. BACKGROUND INFORMATION OF THE PROJECT

Introduction

The stability of an interconnected power system is related to its ability to return to normal or stable operation after being subjected to some form of disturbance. Conversely, a condition denoting loss of synchronism means instability. Power system stability has been recognized as an essential part of power system planning for a long time. With interconnected systems continually growing in size and extending over vast geographical regions, it is becoming increasingly more difficult to maintain synchronism between the various parts of a large power system.

Small disturbances are continually occurring in power systems. In a dynamically unstable system, the oscillation amplitude is large and persists for a long time. This constitutes a serious threat to system security and creates undesirable operating conditions. Following a sudden disturbance on the power system, the rotor speed, rotor angular differences and the power transfer undergo fast changes in which the magnitudes depend on the severity of the disturbance. For a large disturbance, changes in angular differences may be large enough to make the machines out of step.

Static VAR Compensator (SVC) is currently widely used in power systems. By adjusting the firing angle, it can smoothly and rapidly provide reactive power control and therefore provide effective control to the bus voltage [1]. In addition, SVC can enhance the transient stability [2] and provide additional damping to the power system as well [3].

In transmission applications, SVCs are used to regulate the grid voltage. If the power system's reactive load is capacitive (leading), the SVC will use TCR to consume
reactive power from the system, lowering the system voltage. Under inductive (lagging) conditions, the capacitor banks are automatically connected, thus providing a higher system voltage. By connecting the thyristor controlled reactor, which is continuously variable, along with a capacitor bank step, the result is continuously variable and could provide leading or lagging power.

In general, SVCs are cheaper, faster and more reliable than dynamic compensation schemes such as synchronous condensers [4]. However, static VAR compensators are more expensive than mechanically switched capacitors, so many system operators use a combination of the two technologies (sometimes in the same installation), the static VAR compensators provide support for fast changes of the mechanically switched capacitors. It also can provide steady-state VARs.

**Research Status on SVC**

Static reactive power compensation devices have been developed in the 1970s. The early compensators were synchronous condensers and parallel capacitors, mostly used for centralized compensation in the high-pressure side of the system. One traditional approach is to connect the inductive load with the capacitor, which is a method of reactive power compensation. It has a wide range of applications. The parallel capacitor reactive power compensator has many advantages, such as low cool, convenient and simple structure [5]. But its impedance is immutable, it cannot change along with the load, which means it cannot achieve dynamic reactive power compensation. For today’s power system, synchronous condensers are specifically designed for generating reactive power.
In the case of over-excitation, it can generate the dynamic reactive power. It can also generate the inductive reactive power at the under-excitation state [6]. Based on the rotation of the synchronous motor, the loss in the operation and noise could not be avoided. The response speed is slow and the operation and maintenance is complex. It is difficult to meet the requirements of fast dynamic response [7].

In the last 20 years or so, new technologies of static VAR compensator have been introduced. Before FACTS were introduced, this approach has been successfully applied and widely used around the world. Static VAR compensator is defined as switching (on and off) reactors or capacitors through different static switches. Therefore it has the ability to emit or absorb the reactive current. This approach could maintain system voltage and improve power system factor [8]. This is mainly divided into two types: electronic switches and circuit breakers. Because a circuit breaker is a contact device, its switching speed is relatively slow. Therefore it is impossible to achieve fast response when the load reactive power change rapidly. Also it will come with some serious side effects, such as severe surge current and over-voltage operation [9].

Power electronic devices have seen important development, the speed of SCR, GTR, and GTO has improved rapidly. No matter what the parameters of the system are, the reactive compensation can be done in one period and realize the single-phase regulation. For now, the technology of SCR is widely used in power systems.
2. THE CHARACTERISTIC OF TWO DIFFERENT COMPENSATORS

SVC devices can be divided into two types: Thyristor Controlled Reactor (TCR) and Thyristor Switched Capacitor (TSC). In this chapter, we discuss the characteristics of these compensators. Simulink is used to build models to analyze the effect of the two different compensators on the power system.

**Thyristor Controlled Reactor (TCR)**

A thyristor controlled reactor is a static VAR compensator device that consists of a reactance connected in series with a bidirectional thyristor valve. A TCR is usually a three-phase connection, normally connected in a delta arrangement to provide partial cancellation of harmonics. Figure 1 shows the TCR circuit diagram.

![TCR circuit diagram](image)

**Figure 1** – TCR circuit diagram

In order to assess the effect of TCR, a Simulink model is constructed as shown in figures 2 and 3. We build a simple system: a 424.3kv ac voltage source, a RL series
branch, using a transformer to reduce the voltage. One RL branch is connected on the secondary of the transformer. We use two anti-parallel thyristors to build the TCR and the pulses are used to trigger the thyristors. In figure 3, the TCR is removed. The data pertaining to the system are shown in table 1.

**Figure 2** – System with TCR model

**Figure 3** – System without TCR model

We monitor the primary current and the thyristor voltage and current. The results are shown in the following figures.
From the figures above, it can be concluded that when TCR is used, the primary current is changing according to the thyristors on-off switch, which is consistent with the control law of TCR.
Thyristor Switched Capacitors (TSC)

A thyristor switched capacitor (TSC) is a static VAR compensator used for compensating the reactive power in electrical power systems. It consists of a power capacitor connected in series with a bidirectional thyristor valve and, usually, a current limiting reactor (inductor).

A TSC is usually a three-phase connection, connected either in a delta or a star arrangement. Unlike the TCR, a TSC generates no harmonics and therefore does not require filtering. For this reason, most SVCs have been built with TSC. Typically, the TSC is usually connected in a delta arrangement as shown in Figure 6.

![TSC circuit diagram](image)

**Figure 6** – TSC circuit diagram

A Simulink model of the TSC is shown in figure 7. The system includes: a 424.3kv ac voltage source, a RL series branch, using a transformer to reduce the voltage. One RL branch is connected on the secondary of the transformer. We use two anti-parallel thyristors to build the TSC and the step pulses are used to trigger thyristors. The model’s data are shown in table 2.
Because of the characteristics of TSC, the pre-state of the capacitor should be considered. We compare between two different states: pre-charged and no-charge, and we observe the capacitor voltage and primary current in the two states.

**Figure 7** - System with TSC model

**Figure 8** - Comparison of capacitor voltage in the two states
From figures 8 and 9, it can be concluded that when TSC is applied, the primary current is changing according to the thyristors on-off switch. Because of the different states of the capacitor, the voltage and the current are different, which is consistent with the control law of TSC.

**Figure 9**  Comparison of primary current in the two states
3. ANALYSIS OF SINGLE-LOAD SYSTEM WITH SVC

Characteristic of SVC

The SVC can operate in two different modes [10]: In voltage regulation mode (the voltage is regulated within limits as explained below) and in VAR control mode (the SVC susceptance is kept constant). When the SVC is operating in voltage regulation mode, it implements the V-I characteristic shown in figure 10.

![V-I characteristic of SVC in voltage regulation mode](image)

**Figure 10** – V-I characteristic of SVC in voltage regulation mode [10]

As long as the SVC susceptance $B$ stays between the maximum and minimum susceptance values imposed by the total reactive power of the capacitor banks ($B_{c_{\text{max}}}$) and reactor banks ($B_{l_{\text{max}}}$), the voltage is regulated at the reference voltage $V_{\text{ref}}$. However, a voltage droop is normally used (usually between 1% and 4% at maximum reactive power output), and the V-I characteristic has the slope indicated in figure 10. The V-I characteristic is described by the following three equations:
Model of Single-Load System

Using a 200MVA/-100MVA (capacitor and inductor), Xs=0.03/200MVA, the pu of capacitor and inductor is 1/-0.5. The SVC is set to Voltage Regulation mode with a reference voltage Vref=1.0pu. The voltage droop reactance is 0.03pu/200MVA, therefore the voltage varies form 0.97 pu to 1.015 pu when the SVC current goes from fully capacitive to fully inductive. This is shown in the following equations:

For the capacitor: \( V_{cpu} = \frac{200MVA}{200MVA} = 1pu \)

For the inductor: \( V_{ipu} = \frac{-100MVA}{200MVA} = -0.5pu \)

For fully capacitive operation: \( V = V_{ref} - 0.03*V_{cpu} = 0.97pu \)

For fully inductive operation: \( V = V_{ref} - 0.03*V_{ipu} = 1.015pu \)

A simple system is used to discuss the influence of SVC and shown in figure 11. The model’s data are shown in table 3. The system consists of a three-phase voltage source, a three-phase RL series branch and a load. We use a V-I measurement block to detect the current and voltage to get the actual susceptance: \( B = \frac{I}{V} \theta = \frac{I}{V} (\theta_i - \theta_v) \)
and a SVC (phasor type) block to control the voltage and susceptance. The results of the experiments are discussed below.

![Diagram of a power system with SVC](image)

**Figure 11** – The power system with SVC

**Results Analysis**

In order to illustrate the results, we compare between the actual voltage and the voltage after the addition of SVC, and also between the actual susceptance and the susceptance with SVC. The three-phase voltage source block value varies as follows: at time 0s, the amplitude value is 1pu; at time 0.2s, it is 0.95pu; at time 0.4s, it goes up to 1.02pu; at time 0.8s, it goes back to 1pu.
From figure 12, it can be seen that without SVC, at time 0.2s, the voltage goes down to 0.95pu and it stays at 0.95pu during the time interval [0.2s 0.4s]. At time 0.4s, it changes to 1.02pu and stays the same for 0.4s then goes back to 1pu. However, with the SVC control, at 0.2s, when the voltage goes down, it increases to 1pu quickly. At 0.4s, the voltage goes up, under the control of SVC, the voltage goes back to the reference voltage rapidly. From the figure above, it can be concluded that the SVC can regulate the voltage effectively and quickly.
4. ANALYSIS OF SINGLE-MACHINE SYSTEM WITH SVC

The Control Theory of SVC

The SVC regulates the voltage at its terminals by controlling the amount of reactive power absorbed or injected into the power system. When the system voltage is low, the SVC generates reactive power (SVC capacitive). When the system voltage is high, it absorbs the reactive power (SVC inductive). The variation of reactive power is performed by switching three-phase capacitor and inductor banks connected on the secondary side of a coupling transformer. Each capacitor bank is switched on and off by three thyristor switches (Thyrister Switched Capacitor or TSC). Reactors are either switched on-off (Thyrister Switched Reactor or TSR) or phase-controlled (Thyrister Controlled Reactor or TCR).

![The control diagram of single-machine system](image)

**Figure 13** – The control diagram of single-machine system

The control procedure using the SVC is shown in figure 13. It has four parts:

1. Voltage measurement: it collects the primary voltage to control.
(2) Voltage regulator: for this part, it regulates the error of the primary voltage and reference voltage to determine the SVC susceptance B needed to keep the system voltage constant.

(3) Distribution unit: this part determines the control signal of TCRs and TSCs

(4) Synchronizing unit: it generates the signal to control the secondary voltage.

Model building

Based on the control procedure discussed above, we build the system shown in figure 14. We use a three-phase voltage source, RL branch, a three-phase load and a transformer to build the system. Two V-I measurement blocks are used to observe the primary and secondary voltage and current. One TCR and four TSCs are connected on the secondary side. The system’s data are shown in table 4.

![Diagram](image-url)

**Figure 14** – Single-machine system
We use one TCR/102Mvar and four TSCs/75Mvar (The calculations are shown in appendix I). The TCR and TSC blocks are connected in delta so that during normal balanced operation, the zero-sequence triple harmonics (3rd, 9th, ...) remain trapped inside the delta, thus reducing harmonic injection into the power system (as shown in figures 15 and 16).

Figure 15 – TCR block

For the TSC block, we use a parallel RL branch to reduce the surge current. The voltage measurement block is shown in figure 17.
Figure 17 – Voltage measurement block

The voltage measurement block is used to resolve the primary voltage to magnitude and phase so that the $V_{mes}$ (voltage measured) can be obtained. The voltage regulator block is shown in figure 18.

Figure 18 – Voltage regulator block

We set the reference voltage equal to 1pu, this block realizes the V-I characteristic of equation (1). The voltage regulator uses a PI regulator to regulate the primary voltage at the reference voltage (1.0 pu specified in the SVC controller block menu). The voltage droop is incorporated with a slope (0.01 pu). Since $V_{mes}$ is the magnitude of the primary voltage, we can get the susceptance ($B_{svc}$) of system.
Results Analysis

In order to illustrate the working principle, we monitor the primary reactive power $Q$, the number of switch-on TSCs, the primary voltage and the angle of TCR. The results are shown in figure 19.

![Simulink results: the reactive power (Q), the numbers of switch-on TSCs, the V/Vref, the angle of TCR](image)

**Figure 19** – Simulink results: the reactive power ($Q$), the numbers of switch-on TSCs, the $V/V_{ref}$, the angle of TCR

We set the voltage value at time $0s$ equal to $1pu$; at $0.2s$, equal to $1.05pu$; at $0.6s$ equal to $0.87pu$; at $0.8s$, $1pu$. From figure 20, it can be observed that:

1. At time $0.2s$, the voltage goes up to $1.05pu$. To make the voltage go back to the reference voltage $1pu$, the TCR is turned on and thus absorb reactive power ($-100Mvar$), all TSCs are off.
(2) At time 0.6s, the voltage goes down to 0.87pu, to make the voltage increase to 1pu, it can be seen that all TSCs are in service and also the TCR is switched on from figure 19. With the interaction of TCR and TSC, the SVC applies about 300 Mvar reactive power to make the voltage go back to 1pu.

(3) Each time a TSC is switched on, the firing angle $\alpha$ of the TCR changes from 180 degrees (no conduction) to 90 degrees (full conduction).

From figure 19, we can see that the voltage and power of the system can be regulated effectively by switching on and off the TCR and TCS. The device can compensate for the reactive power effectively.
5. ANALYSIS OF MULTI-MACHINE SYSTEM WITH SVC

Model building

In order to analyze the impact of SVC on a multi-machine system, we build a two-machine system as shown in figure 20. A 1000MW hydraulic generator is connected with 750km transmission line, two transformers, a 3000MW resistive load and one 3000MW generator. The system’s data are shown in table 5.

![Figure 20 – The model of two-machines system](image)

The hydraulic generator is controlled by a subsystem as shown in the figure 21.
We obtain the stator voltages $V_d$ (pu) and $V_q$ (pu), the rotor angle deviation (rad), the rotor speed $w_m$ (pu), the rotor speed deviation $d_w$ (pu), the output active power $P_{eo}$ (pu), the electromagnetic torque $T_e$ (pu) and the electrical power $P_e$ (pu) of the generator.

**Figure 21** – The control block for the hydraulic generator

**Figure 22** – Subsystem of the control block
From figure 22 above, the “Hydraulic Turbine and Governor” block implements a nonlinear hydraulic turbine model, a PID governor system, and a servomotor [11]. The “Excitation System” block provides excitation for synchronous machine and regulates its terminal voltage in generating mode. The two blocks are combined to realize the control system for the generator.

**State Equations for Multi-Machine System**

The state equations for a multi-machine system can be written similarly to one-machine system by making the following assumptions:

1. Each synchronous machine is represented by a constant voltage $E$ behind $X_d$.
2. Input power remains constant.
3. Using pre-fault bus voltages, all loads are in equivalent admittances to ground.
4. Damping and asynchronous effects are ignored.
5. $\delta_{\text{mech}} = \delta$ (mechanical power angle = electrical power angle).
6. Machines belonging to the same station swing together and are said to be coherent, coherent machines can equivalent to one machine.

Before any disturbance, the machine current can be calculated as follows.

$$I_i = \frac{S_i^*}{V_i^*} = \frac{P_i - jQ_i}{V_i^*} \quad i=1, 2, 3, \ldots, n$$  \hspace{1cm} (2)

where:
(1) \( V_i \) is terminal voltage of ith generator

(2) \( P_i \) is real power

(3) \( Q_i \) is reactive power

(4) \( N \) is the total number of generators

If we neglect the generator armature resistance, we can write

\[
E_i = V_i + jX_i I_i \quad i=1, 2, 3, \ldots n \quad (3)
\]

The loads can be converted to an equivalent admittance:

\[
Y_{io} = \frac{S_i^*}{V_i^*} = \frac{P_i - jQ_i}{|V_i|^2} \quad i=1, 2, 3, \ldots n \quad (4)
\]

By taking node 0 as a reference, the node voltage equation can be calculated:

\[
\begin{bmatrix}
0 \\
I_m
\end{bmatrix} =
\begin{bmatrix}
Y_{mm} & Y_{mn} \\
Y_{nm} & Y_{nn}
\end{bmatrix}
\begin{bmatrix}
V_n \\
E_m
\end{bmatrix} \quad (5)
\]

where:

(1) \( I_m \) is the generator current

(2) \( E_m \) is the generator voltage

(3) \( V_n \) is the load voltage

From the equation (6), it can be concluded that

\[
I_m = [Y_{mm} - Y_{mn} Y_{nn}^{-1} Y_{nm}] E_m \quad (7)
\]
The equivalent admittance matrix is

$$Y_{newbus} = Y_{mm} - Y_{mn} Y_{nm}^{-1} Y_{mn}$$  \hspace{0.5cm} (8)

Based on the machine’s internal voltages, the output power of the machines can be concluded as follows:

$$S_i^* = E_i^* I_i$$  \hspace{0.5cm} (9)

The active power:

$$P_i = \text{Re}(E_i^* I_i)$$  \hspace{0.5cm} (10)

where

$$I_i = \sum_{j=1}^{m} E_j Y_{ij}$$

So:

$$P_i = \sum_{j=1}^{m} |E_i| |E_j| Y_{ij} \cos(\theta_{ij} - \delta_i + \delta_j)$$  \hspace{0.5cm} (11)

When a three-phase fault occurs at bus k, the voltage of this bus will go to zero. The electrical power of the $i^{th}$ generator after fault can be obtained from equation (11).

**Results Analysis**

In power system operations, the transmission lines are the most prone to fault. Short circuit fault is the most serious. When it occurs, the operating point of the system will change suddenly. In all short circuit faults, the worst is the three-phase ground fault. Therefore we add a three-phase fault to the transmission line, and study the effects of SVC on sustaining the system stability.
The fault occurs from 0.1s to 0.2s, the simulation run time is 10s. The fault occurs at bus 1 near machine 1. The load is located near machine 2. Initially the SVC is out of service. We analyze the two machines’ electromagnetic torque, electrical power, the voltage and the line power of bus 1 and bus 4 (near the load), and also the machines’ stator voltage and rotor speed. The results are shown in figures 23, 24 and 25.

Figure 23 – The electromagnetic torque and electrical power of the two machines without SVC

Figure 23 shows the machines electromagnetic torque (Te) and electrical power (Pe). At 0.1s, the fault occurs, the electromagnetic torque begins oscillating rapidly. After removing the fault at 0.2s, the system keep fluctuating. The system is unstable. Figure 24 shows the machines rotor speed and stator speed without SVC.
Figure 24 - The rotor speed and stator voltage of the two machines without SVC

From figure 24, we can see that when the fault occurs during 0.1s to 0.2s, after 1s, the machine speed goes up and the stator voltage begins fluctuating from 1s to 1.5s. It is clear that the system is unstable after three-phase to ground fault.

Figure 25 - The voltage and line power of bus 1 and bus 4 without SVC
Figure 25 shows the bus voltage and line power without SVC. From figure 25, it can be seen that when the fault occurs, the bus voltages go to zero suddenly; after the fault is removed, the voltages go back to the reference value for a brief amount of time and then begin oscillating. For the fault line, at 0.1s, the power goes down to zero. At 0.2s, when the fault is removed, the power goes back to 1000MW rapidly. However, it only stays stable for about 0.3s. After 0.5s, the power begins to fluctuate. The system only operates for about 1.5s (the total simulate time is 10s). The system becomes unstable.

Now, we consider the effect of SVC. The SVC is in service, which means that Bref=1. The results are shown in the following figures.

Figure 26 represents the electromagnetic torque and electrical power of two machines with SVC and figure 27 represents the rotor speed and stator voltage. Figure 28 shows the bus voltage and line power.

![Figure 26](image)

**Figure 26** - The electromagnetic torque and electrical power of two machines with SVC
It can be clearly seen that the results of figure 26 are different from those of figure 23. After removing the fault, it only takes about 1.8s for the system to stabilize and remain at the stable operating point for the whole operating time.

Figure 27 – The rotor speed and stator voltage of two machines with SVC

Figure 28 – The voltage and line power of bus 1 and bus 4 with SVC
From figures 27 and 28, we can see that the rotor speed and stator voltage go to the reference value in a few seconds after the fault is removed. After 1.8s, the voltages of the load line and fault line go back to 1pu. For the power of both lines, although it has serious changes after fault occurs, it goes back to the normal state. The SVC is effective in stabilizing the system.

From the figures above, it can be concluded that when the short circuit fault occurs in the system, SVC can decrease the time of system recovery greatly to prevent system crashes and also reduce the voltage fluctuation. The SVC plays an important role in maintaining the system stability.
6. CONCLUSIONS

Static VAR compensators are widely used in power systems. They can be used to regulate the system voltage through compensating the reactive power, and thus stabilize the power system. To study the effect of SVC on power system, we discussed the characteristics of the two different compensators (TCR and TCS) in this report. We also built the Simulink models for both single and multi-machine system to discuss the applications of SVC. Through comparisons and analysis, it can be shown that the static VAR compensator can enhance power system stability and power quality. The main results of this project are as follows:

(1) Building the models of the two types of SVC (TCR and TSC) to discuss the characteristics of the two compensators. The basic features of the two compensators are explained in detail through simulation results.

(2) We discussed the two operation modes of the SVC and also the V-I characteristic. Building the single-load system, through comparing the system’s voltage and susceptance between with SVC and without SVC, it is clearly shown that the SVC can regulate the voltage effectively.

(3) Building single-machine and multi-machine system, details are discussed in the report. We compare the simulation results before and after adding compensation and analyze the simulation waveforms to study the effects of SVC on power systems. From the two different systems’ models, it can be concluded that the SVC can regulate voltage and compensate reactive power quickly and effectively. In this report, we consider three-
phase ground fault. The analysis of the three-phase ground fault shows that the system goes back to stability when SVC is used.

In conclusion, Static Var Compensator has a significant effect on improving the dynamic stability of power system.
Appendix A: the M-file of calculating the capacity of TCR and TSC

For TCR block, there has two anti-parallel diodes, a small resistor and inductor.

\[
\begin{align*}
\omega &= 2\pi \cdot 60; \quad \text{\% the frequency} \\
L &= 20 \cdot 10^{-3}; \\
V &= 20 \cdot 10^{3}; \quad \text{\% the secondary voltage} \\
L_1 &= j \omega L; \\
Q_l &= |3V \cdot \text{conj}(V/L_1)| \quad \% \text{the capacity of TCR}
\end{align*}
\]

For TSC block, there has two anti-parallel diodes, one anti-parallel inductor and resistor to reduce the harmonic waveform, a serial inductor and capacitor.

\[
\begin{align*}
C &= 308.4 \cdot 10^{-6}; \quad \% \text{the serial capacitor value} \\
R_p &= 191.7/2; \quad \% \text{the paralleled resistor value} \\
R_s &= 4.26 \cdot 10^{-3} \cdot 2; \quad \% \text{the serial resistor value} \\
L_s &= 1.13 \cdot 10^{-3}; \quad \% \text{the serial inductor value} \\
C_1 &= (R_p \cdot j \omega L_s)/(R_p + j \omega L_s) + R_s + 1/(j \omega C); \\
Q_c &= |3V \cdot \text{conj}(V/C_1)| \quad \% \text{the capacity of TSC}
\end{align*}
\]
### Appendix B: The Data of TCR Models

<table>
<thead>
<tr>
<th>Power (VA)</th>
<th>Frequency (Hz)</th>
<th>Windings 1 parameters (V1/R1/L1)</th>
<th>Windings 2 parameters (V2/R2/L2)</th>
<th>Voltage (V)</th>
<th>Resistance (Ohms)</th>
<th>Inductance (H)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC Source</td>
<td></td>
<td></td>
<td></td>
<td>424.4e3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL Line 1</td>
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<td></td>
<td></td>
<td>2.7</td>
<td>71.65e-3</td>
<td></td>
</tr>
<tr>
<td>RL Line 2</td>
<td></td>
<td></td>
<td></td>
<td>70.5e-3</td>
<td>18.7e-3</td>
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<tr>
<td>Transformer</td>
<td>250e6</td>
<td>60</td>
<td>424.4e3</td>
<td>16e3/0.002/0.08</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 1** - The data of TCR model

The Data of TSC Model
<table>
<thead>
<tr>
<th></th>
<th>Power(VA)</th>
<th>Freq.(Hz)</th>
<th>Winding 1 parameters(V1/R1/L1)</th>
<th>Winding 2 parameters(V2/R2/L2)</th>
<th>Voltage(V)</th>
<th>Resistance(Ohms)</th>
<th>Inductance(H)</th>
<th>Capacitance(F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC Source</td>
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<td></td>
<td></td>
<td></td>
<td>424.4e3</td>
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<td></td>
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<tr>
<td>RL Line 1</td>
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<td></td>
<td></td>
<td></td>
<td>2.7</td>
<td>71.65e-3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL Line 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.5e-3</td>
<td>1.13e-3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transformer</td>
<td>250e6</td>
<td>60</td>
<td>424.4e3/0.002/0.08</td>
<td>16e3/0.002/0.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capacitor</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>308.4e-6</td>
</tr>
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</table>

**Table 2** – The data of TSC model

The Data of Single-Load System Model
<table>
<thead>
<tr>
<th></th>
<th>Power (W)</th>
<th>Ph-Ph voltage (V)</th>
<th>Freq. (Hz)</th>
<th>Resistance (Ohms)</th>
<th>Inductance (H)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three-phase voltage source</td>
<td></td>
<td>500e3</td>
<td>60</td>
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</tr>
<tr>
<td>Three-phase RLC branch</td>
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<td></td>
<td></td>
<td>0.05</td>
<td>1.33e-3</td>
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<tr>
<td>Three-phase Load</td>
<td>10e6</td>
<td>500e3</td>
<td>60</td>
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**Table 3 – The data of single-load system model**

**The Data of Single-Machine System Model**

<table>
<thead>
<tr>
<th></th>
<th>Power (W)</th>
<th>Ph-Ph voltage (V)</th>
<th>Freq. (Hz)</th>
<th>Resistance (Ohms)</th>
<th>Inductance (H)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three-phase voltage source</td>
<td></td>
<td>1.005* 750e3</td>
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<td>Three-phase RLC branch</td>
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<td>0.25</td>
<td>0.66e-3</td>
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<tr>
<td>Load</td>
<td>150e6</td>
<td>750e3</td>
<td>60</td>
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</table>
## Table 4 – The data of single-machine system model

<table>
<thead>
<tr>
<th></th>
<th>Inductance</th>
<th>Thyristor snubber(R/C)</th>
<th>Capacitance</th>
<th>Rs/Rseries/Rparallel</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCR</td>
<td>20e-3</td>
<td>500/250e-9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TSC</td>
<td>1.13e-3</td>
<td>500/250e-9</td>
<td>250e-6</td>
<td>4.26e-6/95.85</td>
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</tbody>
</table>

## The Data of Multi-Machine System Model

<table>
<thead>
<tr>
<th>Nominal power</th>
<th>Line-to-Line voltage</th>
<th>Freq.</th>
<th>Winding 1 parameters(V1/R1/L1)</th>
<th>Winding 2 parameters(V2/R2/L2)</th>
<th>Line length(Km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine 1</td>
<td>1000e6</td>
<td>13800</td>
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</tr>
<tr>
<td>Machine 2</td>
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<td>13800</td>
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<tr>
<td>Transformer 1</td>
<td>1000e6</td>
<td>60</td>
<td>13.8e3/0.002/0.002/0.12</td>
<td>500e3/0.002/0.12</td>
<td></td>
</tr>
<tr>
<td>Transformer</td>
<td>3000e6</td>
<td>60</td>
<td>13.8e3/0.002/0.002/0.12</td>
<td>500e3/0.002/0.12</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
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<td>002/0</td>
<td>002/0.12</td>
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<td>-------</td>
<td>---------</td>
<td></td>
</tr>
<tr>
<td>er 2</td>
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<td></td>
</tr>
<tr>
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<td>Line 23</td>
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<td>Line 34</td>
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<td>250</td>
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**Table 5** – The data of multi-machine system model
References


