

THE ROLE OF STATIC VAR COMPENSATOR AT REACTIVE POWER COMPENSATION

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As the need for electricity has increased and the cost of energy generation has arised. For this reason, it is important to use the generated energy in good quality, safely and efficiently. Reactive power compensation is one of the most effective application to reduce transmission losses, prevent voltage drops, prevent consumers from paying for reactive energy, facilitate operating, increase efficiency and save energy in energy systems. However, due to improvements in semiconductor technology, reactive power compensation systems have gained a new dimension. The power compensation made by the use of semiconductor power elements is called Static VAR Compensation. This compensation is used for the compensation of loads such as arc furnaces, elevators, automotive; paper packaging, food and textile, point welding machines, port cranes, flat welds. Transient events are minimized, losses are reduced, back uped possibility,controled flexibility and reliability are ensured by using Static VAR Compensation systems in power network. In this study, thyristor triggering angles and power factor values of a system, that contains reactive loads and controlled by Static VAR Compensation, were obtained by using the computer software developed by Microsoft C Sharp (C#) programming language. The results were discussed in terms of importance of using such controlling structures in power networks.


Key words: *Energy efficiency, Reactive power, Static VAR compensation*

1. Introduction

Due to the fact that operating costs are high in energy generating units, the efficiency of renewable energy sources is in the development process, the leakage losses in the transmission and distribution system are large, the state does not have enough resources to reduce losses and the demand for electricity increases day by day, need of more quality and reliable energy has appeared[1].

For this reason, reactive reactive power compensation has become compulsory and the prospect has begun to increase day by day to use the produced energy better and more efficiently, to reduce transmission losses, to prevent voltage drops, and to pay the price of reactive energy that causes financial burden on consumers[2]. Because reactive power compensation is one of the most effective measurements to facilitate operation in power systems, it increase efficiency and ensure energy saving.

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According to the "Procedures and Principles Regarding Tariff Applications of Distribution Licensee Legal Entities and Supply Companies" accepted by the Energy Market Regulatory Authority at its meeting dated 30.12.2015, For customers with a power of less than 50 kVA, the inductive reactive power consumption exceeds 33% of the active power, the capacitive reactive energy to the system exceeds 20%; Inductive reactive power consumption exceeding 50 kVA and over 20% of active power users are obliged to pay reactive power rating in case of capacitive reactive energy supply to the system exceeding 15%. For this reason, when the reactive power limits are exceeded, reactive power consumption fee is applied. While different methods are being developed for the production of electricity every day, various techniques and methods are being investigated in order to use the produced energy in the most efficient way.

Reactive power can be controlled by switching shunt capacitors and reactors. If thyristors are used as a switch, these use for the current control within capacitors and /or shunt reactors. These can provide fast and stepless control of reactive power. In recent years, with the developing technology, power electronics components can be manufactured with greater power. In addition, the performance of the control elements has also been improved[3]. The Flexible AC Transmission System (FACTS) implementation is predominantly for dynamic issues, this design proves the point that there are mainly three main variables whose direct control in the power system might have an impact on performance. They are voltage, angle, impedance. FACTS Controllers use for Power Systems' Controllability[4].

In general terms FACTS devices, especially SVCs have become fundamental components in planning, operation and control stages of power systems[5].

There are different types FACTS Controllers. These are; Thyristor Controlled Series Compensation (TCSC), Static Synchronous Series Controller (SSSC), Thyristor-switched series capacitor (TSSC), Static Synchronous Compensator (STATCOM), Static VAR Compensator (SVC) and Unified Power Flow Controller (UPFC). Research focuses on the impact of compensation of the SVC and STATCOM controllers, especially on the steady-state analysis and for first-swing stability enhancement [6-8]. Comparison for different FACTS Controllers given by Table 1.

Table 1. Comparison for different FACTS Controllers [9]

Control Attributes	FACTS Controllers					
	TCSC	SSSC	TSSC	STATCOM	SVC	UPFC
Power flow control	x	x	x			x
Voltage profile improvement				x	x	x
Line commutated	x		x		x	
Forced commutated		x		x		x
Voltage source converter		x		x		x
Current source converter	x	x	x	x	x	
Transient and dynamic converter	x	x	x		x	x
Damping oscillation	x	x	x	x	x	x
Fault current limiting	x		x			x
Voltage stability	x	x	x	x	x	x

2. Classification of Reactive Power Compensation

In practice, compensation is provided by controlling reactive power by using contactor and semiconductor power elements. The compensation made using the contactor is called conventional compensation and the compensation made using semiconductor power elements is called Static VAR Compensation.

2.1. Conventional compensation

Most of the electrical loads used in the industry are inductive reactive power from the electric grid. In order to compensate this inductive reactive power, capacitors groups with different capacity values are used after the meters in the plant.

Devices called reactive power control relays determine the reactive power needed by the system and either activate or deactivate groups of capacitors that will provide the capacity value to compensate for this power[10].

When reactive power compensation is required, the capacitor groups are only activated within 5 to 10 seconds in the conventional compensation systems. Such a long time causes overloads and major losses in the electric grid. The total loss that occurs when losses are taken into account by thousands of end-users is reaching levels of reparability for power distribution companies.

In addition, these systems cause transient voltages, arcs, sudden voltage increases and electrical noise during switching because the power factor correction process takes the capacitor blocks out of contact by means of contactors[11]. Along with that, this system tries to supply capacitive reactive energy to the system through reactive power control relay and contactor.

However, it can not respond to loads that powerful and quickly enter and exit the circuit. To be able to perform a complete compensation, a large number of single-phase grades must be used. In addition, entering and leaving a large number of circuits in a short time has an adverse effect on the capacitor and arcing occurs in the contacts of the contactors[12].

The In order to compensate the reactive power when the loads are switched on and off fast, a instantaneous start current as shown in Figure 1. on capacitors when capacitors switched on contactors.

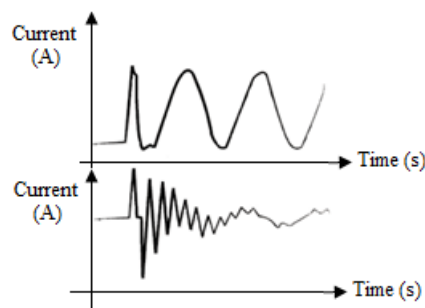


Figure 1. Instantaneous start current change

As the loading and unloading operations of the loads become more frequent, instantaneous start current and arc effect cause deformation of the contactor contacts and after a while the contacts stick.

In many cases, this situation, which occurs in contactors, can cause the contactors to burn. This also causes shortening of life due to continuous current draw of the capacitors. The disadvantages of conventional compensation systems and the development of semiconductor technology have brought reactive power compensation systems to a new dimension.

It is not possible to respond to fast variable loads by switching with mechanical contactors in conventional systems. Such workings can only be answered by switching with a thyristor. In thyristor systems, since capacitors are activated at zero crossings, the obligation to wait for discharge times is eliminated. In addition, when the capacitors are switched on for the first time, it is possible to switch them on and off at a high speed since the current drawn is minimum. Thus, the life and power quality of capacitors and switching elements are also positively affected. In addition, panel maintenance costs are minimized. For this reason, using static VAR compensator at reactive power compensation is important.

2.2. Static VAR Compensation

The static VAR compensators (SVCs) are traditionally used to dynamically compensate reactive power[13]. SVC systems, which are implemented as thyristor-switched compensation systems, are one of the most effective methods of ensuring energy efficiency. The basic types of reactive power control elements that bring the whole or a part of a SVC system into play are; thyristor controlled reactor (TCR), thyristor switched reactor (TSR) ve thyristor switched capacitor (TSC)[14- 15]. SVCs increases the quality of power in many respects. There are many functional benefits of the SVC. Such as flicker reduction, Voltage stabilisation, reactive power compensation, reduction of harmonics, energy savings, increase in productivity. It has the ability to provide maximum capacitive and inductive power limits and every value between these limits. In general, the SVC circuit diagram is given in Figure 2.

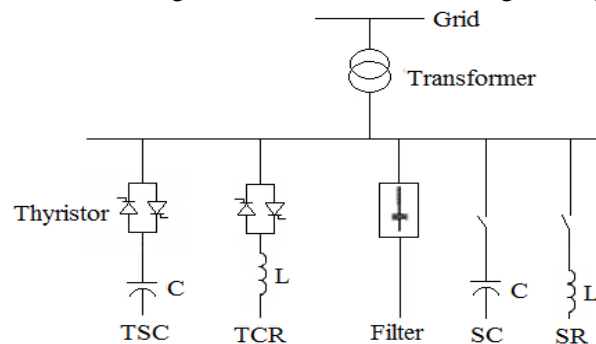


Figure 2. SVC circuit diagram

It is provided the capacitors to be switched on in less than 10 ms by using thyristor modules. In addition, a high instantaneous starting current generated during the switching of the capacitors is prevented and only the normal capacitor current flows, as shown in Figure 3. In this way, rapidly varying loads can be easily compensated, the compensation response time can be adjusted between 20 and 500 ms.

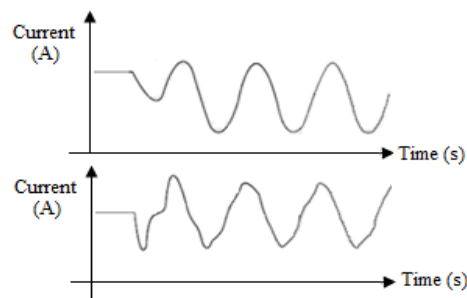


Figure 3. The capacitor's own nominal current change

Static VAR compensation systems have advantages such as minimizing transient events, reducing losses, providing redundancy, control flexibility and high reliability. However, it is an important question that causes harmonics that affect energy quality. This compensation is used compensation of loads such as especially in the fields of arc furnaces, elevators, automotive, paper, packaging, food, textile, glass, cement sectors, point welding machine, harbor cranes, flat welds, where power factor coming in and out very frequently and in short period shows frequent and big changes. The implementation diagram for a three-phase Static VAR Compensation implemented as a thyristor-switched compensation system shown in Figure 4.

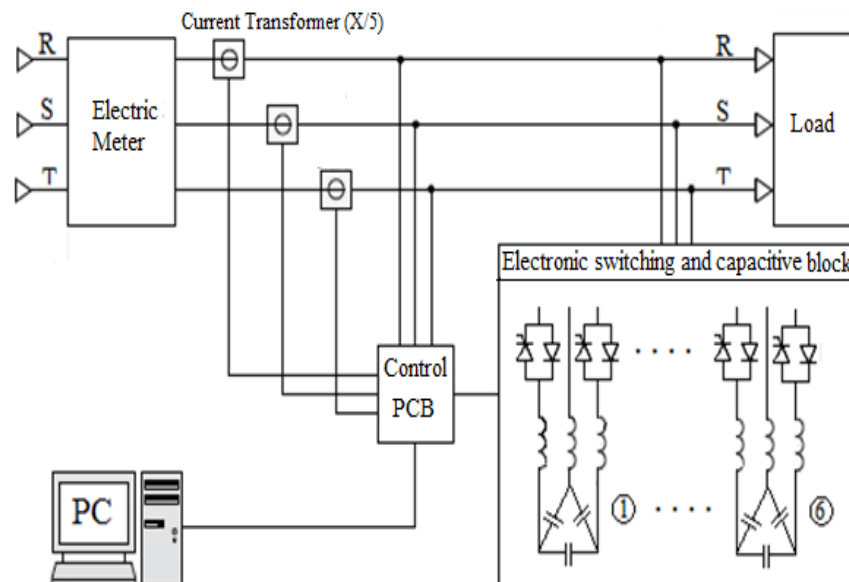


Figure 4. Three-phase SVC application scheme[4]

3. Static VAR Compensation Application

In a fixed-capacitor thyristor controlled reactor (FC-TCR), the fixed capacitors generate reactive power while the TCR will consume power. Since the reactive power generation of the capacitor group is fixed at a certain voltage level, the reactive power generation of the system provided by the reactor is determined by changing the triggering angle of the thyristors.

Changing the triggering angle of the thyristor will control the main component of the reactor current, thus controlling the magnitude of the reactive power[16].

An facility has been selected for such a static VAR compensation system application. The maximum power of the selected facility is 292 kW and the maximum current drawn from the network is 738 A. When all loads in the system are activated, the power factor $\cos \varphi = 0.6$, ie the largest phase difference is 53° . In this facility, FC-TCR compensation method is used to raise the power factor to nearly 1. The fixed capacitor value used in the system has been selected to be $8,817 \mu\text{F}$, the power 400 kVAr and the reactor value $X_L = 1.1 \text{ mH}$. The principle connection diagram of the compensation system is given in Figure 5[11].

System includes a control and measurement unit as shown in Fig.5. This structure is the most important component of overall system. Because triggering angles are being adjusted by this unit. This adjustment can be summarized as given below;

- . Measure grid current and terminal voltage

- . Measure phase angle
- . Calculate active power
- . Calculate reactive power
- . Obtain difference of fixed capacitor power value and calculated reactive power
- . Calculate triggering angle by using from Equation 1 to Equation 8
- . Output calculated triggering angle value

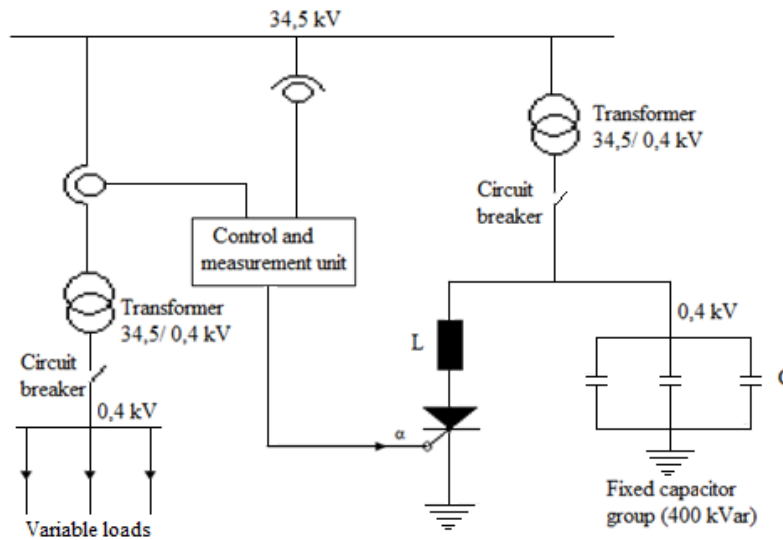


Figure 5. Principle connection diagram of the compensation system

The power factor is reduced when dissimilar loads in the system enter the operation at different times. The fixed capacitor group will remain active after compensating the reactive load to bring the power factor closer to 1.

For this power compensation, this increased capacitive reactive power will be compensated by producing an inductive reactive power, depending on the α angle of trigger of the thyristor [17].

In order to find the reactive power generated on the reactor depending on the angle of trigger of α thyristor, it is necessary to calculate the effective values of the current and the voltage depending on the trigger angle of the Equation 1.

$$QB(\alpha) = V_{\text{eff}}(\alpha) \cdot I_{\text{eff}}(\alpha) \tag{1}$$

The time-dependent variation of the current and voltage at the α triggering angle of the thyristor-connected reactor circuit is given in Figure 6.

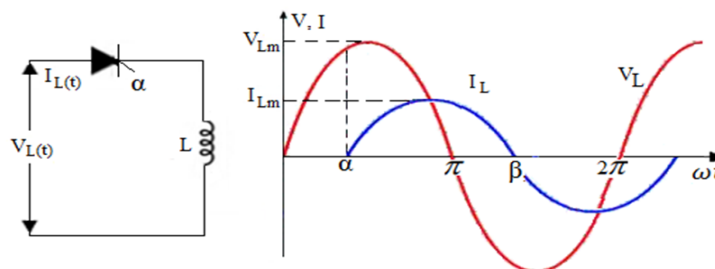


Figure 6. Time-dependent change of current and voltage

$$I_{L(t)} = \frac{1}{L} \cdot \int VL(t)dt + I_0 \tag{2}$$

$$I_{L(t)} = \frac{Vm}{\omega L} \text{Sin}(\omega t - 90^\circ) + I_0 \tag{3}$$

$$I_0 = -\frac{Vm}{\omega L} \text{Sin}(\alpha - 90^\circ) \tag{4}$$

If Equation (4) is written in place of Equation (3), Equation (5) is obtained.

$$I_{L(t)} = \frac{Vm}{\omega L} \text{Sin}(\omega t - 90^\circ) + (-\frac{Vm}{\omega L}) \text{Sin}(\alpha - 90^\circ) \tag{5}$$

As shown in Figure 6., in the cases of $\omega t = \alpha$ and $\omega t = \beta$, $I_L(t) = 0$ and $\beta = 2\pi - \alpha$.

$$I_{eff}(\alpha) = \frac{1}{2\pi} \int_{\alpha}^{\beta=2\pi-\alpha} I^2(t) dt \tag{6}$$

The effective value of the current passing through the reactor after integration in Equation (6) depends on the α trigger angle is calculated by Equation (7).

$$I_{eff}(\alpha) = \frac{Vm}{\omega L} \sqrt{\frac{(\pi-2\alpha)(1-0.5\text{Cos}2\alpha)-1.5\text{Sin}2\alpha}{\pi}} \tag{7}$$

Similarly, the effective value of the voltage, depending on the α trigger angle, is calculated from Equation (8).

$$V_{eff}(\alpha) = \frac{Vm}{\sqrt{2}} \sqrt{\frac{\pi-2\alpha-\text{Sin}\alpha}{\pi}} \tag{8}$$

According to the information described above, the flow chart of the overall system includes thyristors and other components is given in Figure 7.

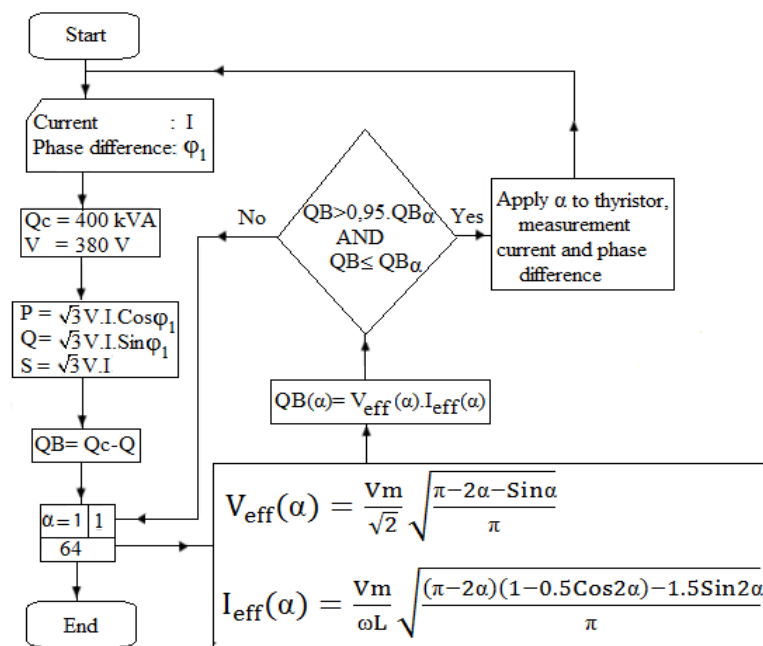


Figure 7. Flow chart of the SVC system

As shown in Figure 7, the current and phase difference obtained from the network is measured. Grid voltage and fixed capacitor power are known. Active, reactive and apparent powers are calculated from these values. A loop was created to see which of the triggering angles of the thyristor of the inductive reactive power compensating capacitive reactive power remaining from the reactive power difference with the fixed capacitor power.

The inductive reactive power generated on the reactor due to the α triggering angle of the thyristor is calculated according to Equations. (1), (7) and (8). These calculate has been provided by the computer software developed by Microsoft C Sharp (C#) programming language. If the power factor is close to 1 or 1, the program will start to measure new values for the load changes after having found the α trigger angle of the thyristor. The state of the computer program that computes the angle of trigger α and the after compensation power factor according to the different load cases in facility with the program are given by Table 2-5.

Table 2. Algorithm result for case 1

Case 1	Value
Power factor before compensation	0,65
Measured current value	654 A
Measured phase angle	49°
Active power	282073 W
Fixed capacitor power	400 kVAr
Residual capacitive power after compensating reactive power in the system	75,53 kVAr
Thyristor controlled reactive power	78,8 kVAr
Angle of thyristor trigger	37°
Power factor after compensation	1

Table 3. Algorithm result for case 2

Case 2	Value
Power factor before compensation	0,70
Measured current value	595 A
Measured phase angle	45°
Active power	276593 W
Fixed capacitor power	400 kVAr
Residual capacitive power after compensating reactive power in the system	123,419 kVAr
Thyristor controlled reactive power	125,178 kVAr
Angle of thyristor trigger	29°
Power factor after compensation	1

Table 4. Algorithm result for case 3

Case 3	Value
Power factor before compensation	0,84
Measured current value	345 A
Measured phase angle	32°
Active power	192341 W
Fixed capacitor power	400 kVAr
Residual capacitive power after compensating reactive power in the system	279,8 kVAr
Thyristor controlled reactive power	287 kVAr
Angle of thyristor trigger	10°
Power factor after compensation	0,99

Table 5. Algorithm result for case 4

Case 4	Value
Power factor before compensation	0,94
Measured current value	312 A
Measured phase angle	19°
Active power	193934 W
Fixed capacitor power	400 kVAr
Residual capacitive power after compensating reactive power in the system	333,2 kVAr
Thyristor controlled reactive power	341,5 kVAr
Angle of thyristor trigger	5°
Power factor after compensation	0,99

5. Conclusion

The energy used in industrial facilities must be uninterrupted and of good quality. Therefore, the important of the continuity and quality of the electric energy transmitted is increasing day by day. It has become imperative to reduce energy quality deficiencies resulting from reactive power change and voltage fluctuations. Conventional compensation systems cause disruptive effects in the network and cause overcurrents and voltages. SVC systems eliminate such negative effects.

SVC application is the most suitable solution for medium voltage installations where disturbing effects are present in the grid. Voltage stability is ensured with reactive power compensation by this application, harmonic and flicker levels are reduced to the values according to the standards. Thus, in addition to saving energy, production time is also shortened. SVC systems; it is the ideal solution for the compaction of loadings coming and going fast in the circuit. These systems, requirements provide a great advantage over conventional reactive power compensation systems because they provide precise and complete compensation against unbalanced loads.

For this reason, SVC systems are provide a lot of benefits to facilities as an alternative to conventional compensation systems. With the development of technology, the prices of power electronic components will be reduced and SVC systems will be an economical solution within small businesses.

In this respect, the role of SVC in reactive power compensation at power plants is large. With the computer program developed, the α trigger angle of the thyristor is calculated according to the different load conditions in operation and the states on the application are given. As the loads change, the reactive power is compensated by changing the α trigger angle of the thyristor with programme.

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