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A Review on Reactive Power Compensation Techniques using FACTS Devices

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ABSTRACT

The paper describes a study of various techniques of reactive power compensation needed by any power system network using FACTS device. It is better solution to any power transmission related problems in today's world to implement FACTS device for either lagging or leading behavior of power system network. In this paper we study the shunt operation of FACTS controller, the STATCOM and how it helps in the better utilization of a network operating under normal conditions. Firstly, a literature review of many papers related to FACTS and STATCOM, along with reactive power control are to be considered and analyze. The study of STATCOM and its principles of operation and control, including phase angle control and PWM techniques, are carried out. However, these are very useful in determining the behavior of the system under a fault condition.

***Keywords* -** STATCOM, Reactive Compensation, SVC, Vcomp, Shunt Compensation and Series Compensation

I. INTRODUCTION

When integrated to the power system, large wind farms pose stability and control issues. A through study is needed to identify the potential problems and to develop. This thesis investigates the use of a Static Synchronous Compensator (STATCOM) along with wind farms for the purpose of stabilizing the grid voltage after grid-side disturbances such as a three phase short circuit fault, temporary trip of a wind turbine and sudden load changes. The strategy focuses on a fundamental grid operational requirement to maintain proper voltages at the point of common coupling by regulating voltage. The DC voltage at individual wind turbine (WT) inverters is also stabilized to facilitate continuous operation of wind turbines during disturbances.

From the past towards the future the supply of electrical energy developed from separated utilities to large interconnected systems. In former times distributed power generation supplied load centers within a limited supply area. These smaller systemswere operated at lower voltage levels. Nowadays there is increased power exchange over larger distances at highest system voltages allowing reserve sharing and competition. Electrical energy shall be made available at most locations at minimum cost and at highest reliability.

Following problems have been observed in three phase-systems:

1. Voltage control at various load conditions
2. Reactive power balance (voltage, transmission losses)
3. Stability problems at energy transfer over long distances
4. Increase of short circuit power in meshed systems
5. Coupling of asynchronous systems
6. Coupling of systems with different system frequencies

The upper ones can be solved by proper use of reactive power compensation based on FACTS devices and the last two problems can be solved using HVDC technology.

An electric power system is never in equilibrium for very long time. Frequent occurrences of unwanted situation disturb the equilibrium so that system is almost always in transition between equilibrium or steady state conditions. In this paper we are concerned with such dynamic transition which affects the controlling and stabilizing influence of compensating such as shunt and series capacitor and especially FACT devices like STATCOM (static compensator).To maintain the stability of synchronous machines, it is essential to control the voltage by reactive power compensation that can have a positive stabilizing influence on the system during disturbance. The compensating device like STATCOM also presents unnecessary flows of reactive power on transmission line.

1.1 *Concept of Reactive power*

Reactive power is the power that supplies the stored energy in reactive elements. Power, as we know consists of two components, active and reactive power. The total sum of active and reactive power is called as apparent power. In AC circuits, energy is stored temporarily in inductive and capacitive elements, which results in the periodic reversal of the direction of flow of energy between the source and the load.

Explanation for reactive power says that in an alternating current system, when the voltage and current go up and down at the same time, only real power is transmitted and when there is a time shift between voltage and current both active and reactive power are transmitted. But, when the average in time is calculated, the average active power exists causing a net flow of energy from one point to another, whereas average reactive power is zero, irrespective of the network or state of the system. In the case of reactive power, the amount of energy flowing in one direction is equal to the amount of energy flowing in the opposite direction .That means reactive power is neither produced nor consumed. But, in reality we measure reactive power losses, introduce so many equipments for reactive power compensation to reduce electricity consumption and cost. Capacitors are said to generate reactive power, because they store energy in the form of an electric field.

Therefore when current passes through the capacitor, a charge is built up to produce the full voltage difference over a certain period of time. Thus in an AC network the voltage across the capacitor is always charging. Since, the capacitor tends oppose this change; it causes the voltage to lag behind current in phase. In an inductive circuit, we know the instantaneous power to be:

$$P = \frac{V_{max} I_{max}}{2} \cos\theta\,(1+\cos\omega t) + \frac{V_{max} I_{max}}{2} \sin\theta . \sin 2\omega t$$

Where: P = instantaneous power

V_{max} = Peak value of the voltage waveform

ω = Angular frequency

$= 2\pi f$

f = frequency of the waveform.

t = Time period.

θ = Angle by which the current lags the voltage in phase.

1.2 *Need for Reactive power compensation*

The main reason for reactive power compensation in a system is;

1) The voltage Regulation.
2) Increased system stability.
3) Better utilization of machines connected to the system.
4) Reducing losses associated with the system.

The impedance of transmission lines and the need for lagging VAR by most machines in a generating system results in the consumption of reactive power, thus affecting the stability limits of the system as well as transmission lines.

Unnecessary voltage drops lead to increased losses which needs to be supplied by the source and in turn leading to outages in the line due to increased stress on the system to carry this imaginary power. Thus we can infer that the compensation of reactive power not only mitigates all these effects but also helps in better transient response to faults and disturbances. In recent times there has been an increased focus on the techniques used for the compensation and with better devices included in the technology, the compensation is made more effective. It is very much required that the lines be relieved of the obligation to carry the reactive power, which is better provided near the generators or the loads. Shunt compensation can be installed near the load, in a distribution substation or transmission substation.

1.3 *Concept of FACTS Devices*

A power electronic-based system and other static equipment that provide control of one or more AC transmission system parameters. As new technology for power transmission system, FACTS and FACTS controllers not only provide the same benefits as conventional compensators with mechanically-controlled switches in steady state but also improve the dynamic and transient performance of the power system.

The power electronics-based switches in the functional blocks of FACTS can usually be operated repeatedly and the switching time is a portion of a periodic cycle, which is much shorter than the conventional mechanical switches. The advance of semiconductors increases the switching frequency and voltage-ampere ratings of the solid switches and facilitates the applications.

The Flexible AC transmission system or FACTS used are:

1) VAR generators.

a) Fixed or mechanically switched capacitors.

b) Synchronous condensers.

c) Thyristorized VAR compensators

(i) Thyristors switched capacitors (TSCs).

(ii) Thyristor controlled reactor (TCRs).

(iii) Combined TSC and TCR.

(iv)Thyristor controlled series capacitor (TCSC).

2) Self Commutated VAR compensators.

a) Static synchronous compensators (STATCOMs).

b) Static synchronous series compensators (SSSCs).

c) Unified power flow controllers (UPFCs).

d) Dynamic voltage restorers (DVRs).

II. MODELLING OF FACTS CONTROLLERS

Compared to the dynamic controllers, this generation of FACTs controllers can be easily installed at any place we want. Although the capacitor bank can also achieve this advantage, it cannot be controlled to get the continuous value of the capacitance like the devices included in the second generation. Instead of analyzing their complex mathematical voltage-current expression, I paid my effort on comparing their topologies, shunt-series types and their effects on the existing power grid.

2.1 Thyristor-controlled Reactor (TCR)

In 1982, Miller et al. proposed TCR in [1], the configuration of a typical TCR is shown in the Figure 2.1. The controller is an antiparallel thyristor pair. Each of them conducts on alternate half cycles of the supply frequency. The other important sub-device of TCR is the inductance L. The TCR mainly acts as a controllable susceptance. TCR is also the fundamental component of the SVC and TCSC. When talked about TCR, people always use this device as a shunt compensator.

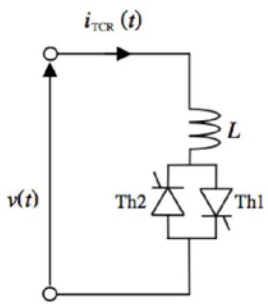


Figure 2.1: Thyristor-based circuit

2.2 Static VAR Compensator (SVC)

SVC is the most popular FACTs devices in the recent years.

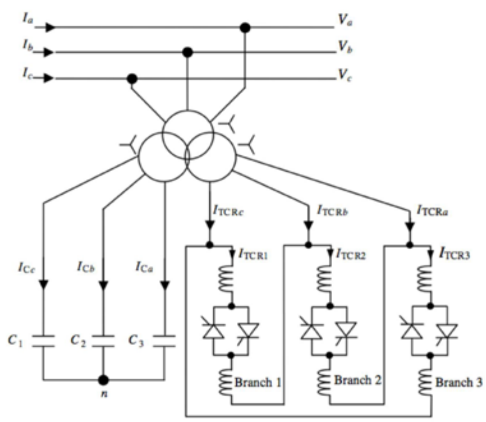


Figure 2.2: A three-phase SVC

It typically consists of a TCR in parallel with a capacitor bank. From the operational viewpoint, the SVC acts as a shunt connected variable reactance. Compared to the TCR that can only generate reactive power, SVC cannot only generate but also absorb reactive power. SVC is also a shunt connected device, and is always modeled into three phase form as shown in the Figure 2.2.

2.3 Thyristor - controlled Series Compensator (TCSC)

Kinney et al. proposed the concept of the TCSC in 1994in [3]. A TCSC is made up of a TCR in parallel with a fixed capacitor. Compared to TCR and SVC, TCSC is a series connected controller instead of a shunt-connected device. Therefore, TCSC is always represented in single-phase form instead of three-phase form and is always comprised of one or more sub-modules. The basic structure of a TCSC is shown in the Figure 2.3.

TCSC changes the electrical length of the existing transmission line with negligible delay. This characteristic makes TSCS be used to perform the fast active power flow regulation. But adding TCSC into the existing system will change the phase angle of the buses. This trait is not the same as that of the SVC.

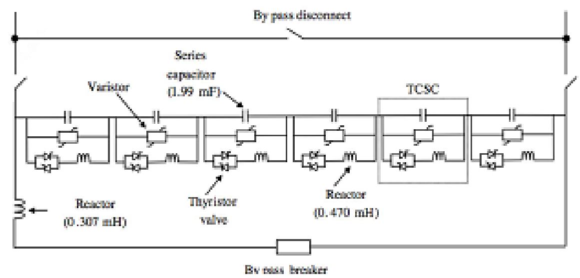


Figure 2.3: Basic Structure of TCSC

The three types of FACTs devices are introduced in the topic 2.1~2.3 which are all based on thyristor, a half controlled devices. However, the following FACTs controllers are mainly based on multiple kinds of fully controlled devices.

2.4 Static Compensator (STATCOM)

The concept of STATCOM is proposed in [2]. A STATCOM is mainly consists of a voltage source controller and the corresponding shunt-connected transformer. Although it acts like a static part of the rotating synchronous device, its absence of moving parts makes it owns faster speed than the older dynamic compensators. The basic structure of the STATCOM is shown in the Figure 2.4. The STATCOM performs the same voltage regulation function as the SVC introduced before and it is also a shunt connected device.

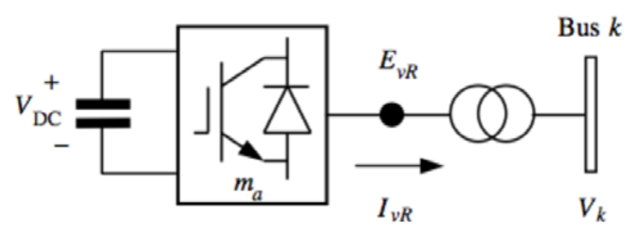


Figure 2.4: Basic Structure of the STATCOM

III. SYSTEM IMPLEMENTATION USING STATCOM

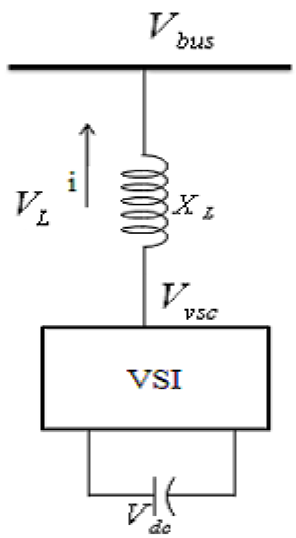


Figure 3.1: Single line Diagram of STACOM

A STATCOM is a regulating device which can be used to regulate the flow of reactive power in the system independent of other system parameters. STATCOM has no long term energy support on the d.c side and it cannot exchange real power with the a.c system. In the transmission systems, STATCOMs primarily handle only fundamental reactive power exchange and provide voltage support to buses by modulating bus voltages during dynamic disturbances in order to provide better transient characteristics, improve the transient stability margins and to damp out the system oscillations due to these disturbances. So it is necessary to invest in power plants and transmission facilities. Therefore, the control for reactive power is essential in order to stabilize system voltage. With the progress of power electronics, FACTS (flexible a.c. transmission system) devices make it possible to maximize the transmission efficiency and can be widely applied for the voltage control. In Korea, beginning with the installation of FACTS devices has been expanding into other areas. STATCOM (Static Synchronous Compensator) can perform voltage regulation function in a robust manner because it generates or absorbs reactive power at a fast rate. The control of reactive power with FACTS devices can greatly contribute to stabilizing the voltage. The FACTS devices are very effective to maintain the voltage stability during systematic accident and the proper voltage level for both heavy and light load.

3.1 Reactive Power Compensation Techniques

i) Shunt compensation

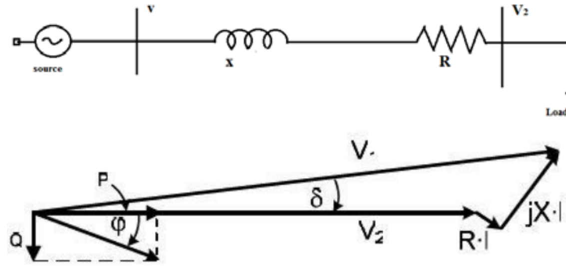


Figure 3.2: Before Compensation

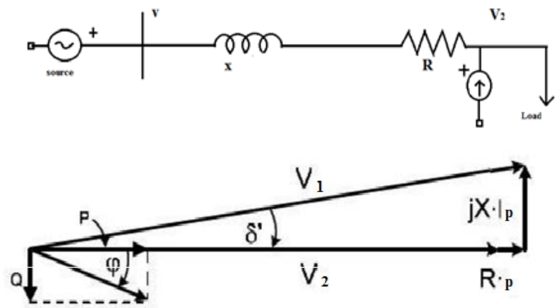
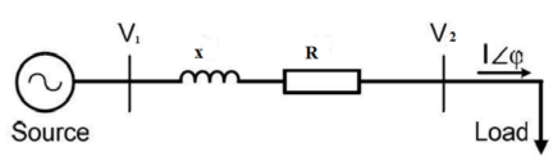


Figure 3.3: After compensation

Above figure 3.2 shows the system without any type of compensation. It includes the voltage source V_1 with an inductive load and a power line. Here the active current I_p is in phase with a load voltage V_2. As the load is an inductive therefore it requires reactive power for suitable operation. Thus, by increasing the current from the generator side and thus through power lines, it is desirable to regulate the reactive power that can be supplied near the load, the line current can be minimized, reducing the power losses and improving the voltage regulation at the load terminals. This can be done in three ways: 1) A voltage source. 2) A current source. 3) A capacitor. Therefore we can see that, a current source or a voltage source can be used for both leading and lagging shunt compensation, the main advantages being the reactive power generated is independent of the voltage at the point of connection.

ii) Series Compensation

Below figure 4 shows the series compensation which can be implemented like the shunt compensations, i.e.; with a current or a voltage source. However, series compensation techniques are different from the shunt compensation technique as here capacitors are used mostly in the series compensation technique.



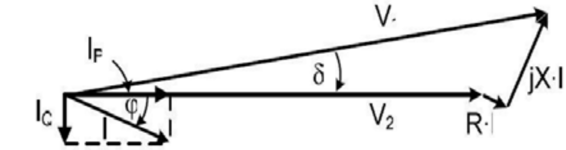


Figure 4: Before Compensation

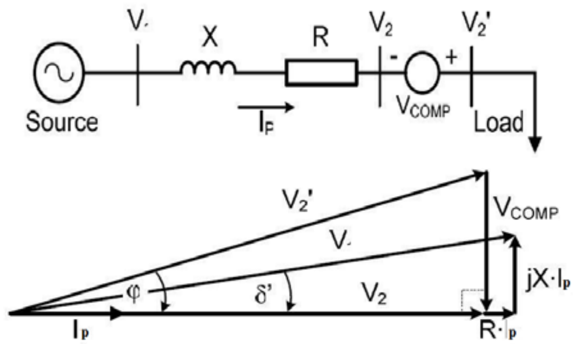


Figure 5: After compensation

We can see the result which are obtained by the series compensation through a voltage source and maintained till the unity power factor obtained at the voltage V_2. In this case, the voltage compensator V_{comp} has been added between the line and the load to change the angle V_2. Now this is the voltage at the load side. Hence from this unity power factor can be maintained with the proper magnitude of V_2.

IV. CONCLUSION

We have seen that the reactive power of the system can be compensated by using the STATCOM or using the FACTS devices, i.e. by using this above compensation techniques the flow of reactive power and the power factor of the system can be maintained at unity power factor and hence the system can be maintained at balanced condition with the proper magnitude of voltage V_{comp}.

Under light load condition, a flat voltage profile is achieved by inductive shunt compensation. Under heavy load condition, a flat voltage can be achieved by adding shunt capacitive compensation.

Series capacitive compensation may theoretically be used instead of shunt compensation to give a flat voltage profile, under heavy loading. As practically, lumped series capacitors are not suitable for obtaining a smooth voltage profile along the line. Thus, it is obvious that we get step a change in voltage occurs at points where the series capacitors are applied. However, with use of series capacitors improved voltage regulation at any point can be obtained.

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