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Theoretical Aspects of Optimization using FACTS Devices

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***Abstract-* This paper presents the theoretical aspects of the optimization using FACTS devices. Various FACTS devices such as the voltage source converter types were considered. The conventional compensation technique such as the use of capacitor banks in series and parallel were treated in this paper. Their modes of operation as well as short comings were investigated. Finally, various model equations showing the operation of the FACTS devices especially in power transfer and voltage improvement in the receiving end of the transmission line were presented.**

Keywords: Optimization, FACTS Devices, Power Transfer, Voltage Improvement.

I. INTRODUCTION

Generally, the main objectives of FACTS are to increase the use able transmission capacity of lines and control the power flow over designated transmission routes. There are two generations for realization of power electronics-based facts controllers: the first generation employs conventional Thyristor-switched capacitors and reactors, and quadrature tap-changing transformers, the second generation employs gate turn-off (GTO) thyristor-switched converters as voltage source converters (VSCS).The first generation has resulted in the Static VAr Compensator (SVC), the Thyristor- controlled series capacitor(TCSC), and the Thyristor-controlled phase shifter (TCPS)[**1**][**2**].The second generation has produced the static Synchronous Compensator (STATCOM), the Static Synchronous Series Compensator (SSSC), the Unified Power Flow Controller (UPFC), and the Interline Power Flow Controller (IPFC) [**3**].

The number of publications discussing facts applications to different power system studies has been recorded. The results of the survey are shown in Fig.1.0. It is clear that the applications of facts to different power system studies have been drastically increased in years 2000-2004. Generally, both generations of FACTS have been applied to different areas in power system studies including economic power dispatch, voltage stability, power system security and power quality [**3**].

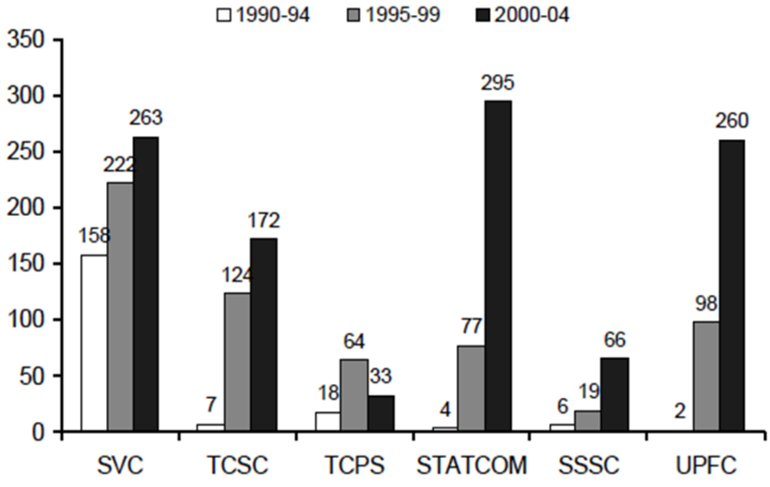

Fig. 1.0 Statistics for FACTS Applications to different Power System Studies Source:[**3**]

Flexible AC Transmission Systems, called FACTS, became in the recent years a well-known term for higher controllability in power systems by means of power electronic devices [**4**]. Several FACTS devices have been introduced for various applications worldwide. The concept of using series/shunt capacitors/inductors to control the line power flow and to support the load bus voltage derived from the fundamental equations of power transfer has been used for long to control and optimize power flow in transmission systems, mechanically switched devices (phase shifters, series and shunt VArs compensators) have been implemented. These devices have been successfully used, but proved to be very slow [**5**].

Another problem with the mechanically switched devices is that control cannot be initiated frequently, because switches tend to wear out quickly.

FACTS-devices are usually perceived as new technology, but hundreds of installations worldwide, especially of SVC since early 1970s with a total installed power of 90000 MVA, show the acceptance of this kind of technology [**4**]. Table 1.0 shows the estimated number of worldwide installed FACTS devices and the estimated total installed power.

TABLE 1.0 Estimated number of worldwide installed FACTS-devices and their estimated total installed power.

S/NO	**TYPE**	**NUMBER**	**TOTAL POWER INSTALLED (MVA)**
1	SVC	600	90000
2	STATCOM	15	1200
3	SERIES COMPENSATION	700	350000
4	TCSC	10	2000
5	HVDC B2B	41	14000
6	HVDC VSC B2B	1+(7 WITH CABLE)	900
7	UPFC	2-3	250

Source:[4]

II. CLASSIFICATION OF FACTS CONTROLLERS

The three main ways of categorizing the FACTS controllers according to the connection of the devices within a transmission system are **[6]:**

A. ***Series Devices***

Series devices have been further developed from fixed or mechanically switched.Compensations to the thyristor controlled series compensation (TCSC) or even Voltage source converter based devices. The main applications are:

- Reduction of series voltage decline in magnitude and angle over a power line
- Reduction of voltage fluctuations within defined limits during changing power t.ransmissions.
- Limitation of short circuit currents in networks or substations.
- Avoidance of loop flows. Power flow adjustments.

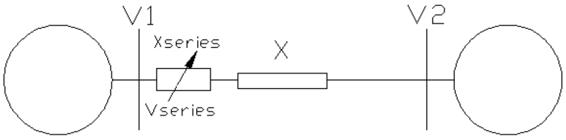

Fig. 2.0 A series controlled power system.

According to **[6],** the power transferred in the network of Fig. 2.0 is

$$P=\frac{V_1V_2\,Sin\,\delta}{X - X_{series}} \quad \ldots\ldots 1.0$$

Where V_1 and V_2 are the bus voltages, X series is the reactance of the series device; X is the reactance of the line. ‘P’ is the transferred power along the transmission line.

Series compensation is used in order to decrease the transfer reactance of a power line at rated frequency. A series capacitor installation generates reactive power that in a self-regulating manner balances a fraction of the line's transfer reactance. The result is that the line is electrically shortened, which improves angular stability, voltage stability and power sharing between parallel lines **[7].**

B. Shunt devices

Their main applications in transmission, distribution and industrial networks are **[7]**:

- Reduction of unwanted reactive power flows and therefore reduced network losses.
- Keeping of contractual power exchanges with balanced reactive power.
- Compensation of consumers and improvement of power quality especially with huge demand fluctuations like

industrial machines, metal melting plants, railway or underground train systems,

- Compensation of thyristor converters e.g. In conventional HVDC lines
- Improvement of static or transient stability.

Industrial, commercial and domestic groups of users require good power quality. Flickering lamps are no longer accepted, nor are interruptions of industrial processes due to insufficient power quality.

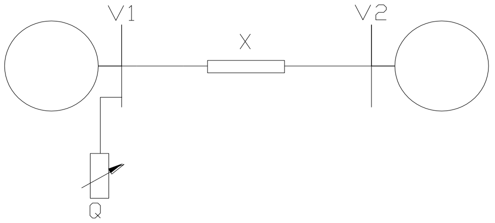

Fig. 3.0 A shunt controlled power system

According to **[6],** the power transfer equation for Fig. 3.0 is represented thus;

$$P=\frac{V_1V_2Sin\delta}{X} \quad \ldots\ldots\ldots\ldots\ldots\ldots 2.0$$

Where V_1 and V_2 are the bus voltages, X is the reactance of the line and δ is the power angle. P is the transferred power along the transmission line.

C. Hybrid devices

These devices combine the features of both shunt and series converters. Classification is according to the concept of operation, that is, the function and operating principles of the power electronics implemented in the FACTS controllers. There are two distinctly different approaches to the realization of power electronics based FACTS controllers, each resulting in a comprehensive group of controllers able to address specific transmission problems**.**

1 *.Thyristor Controlled FACTS devices*

This group employs reactive impedances or tap-changing transformer with thyristor switches working as the control elements. This group includes the Static Var Compensator (SVC), Thyristor Controlled Series Compensator-Switched capacitor (TCSC) and Thyristor controlled phase shifter (TCPS). They employ conventional thyristors in circuit arrangements which allow fast control response compared to the corresponding mechanical system **[8].** Each device can control one of the three power transmission control variables (bus voltage, transmission impedance and phase angle).

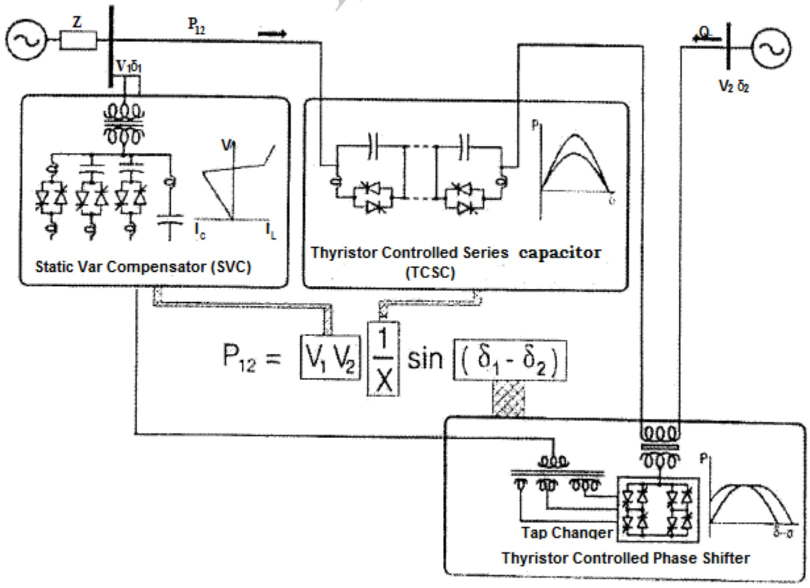

Fig. 4.0 Thyristor controlled FACTS devices

2. StacticVAr Compensator (SVC)

The SVC is effectively a variable shunt reactance which is able to produce a compensating reactive current. The device is operated to regulate the voltage at a selected terminal of the transmission system by a proper coordination of the capacitor switching and reactor phase angle control **[8].** It may be controlled to improve the transient and dynamic stability of the transmission system **[9].** SVC may be controlled to damp power oscillation by adjusting its output between appropriate capacitive and inductive values to oppose the angular acceleration and deceleration of the involved synchronous machine**.**

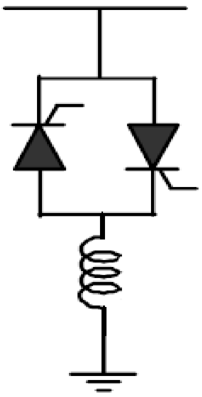

Fig. 5.0a Thyristor Controlled reactor

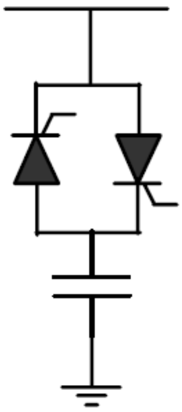

Fig. 5.0b Thyristor Switched Capacitor

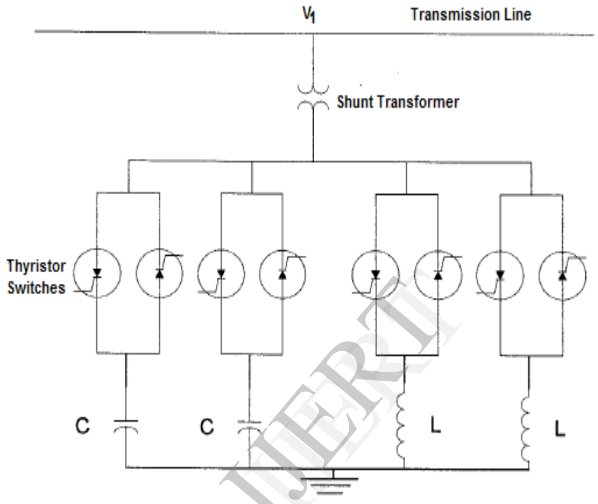

Fig. 6.0 Static VAr Compensator.

3. Thyristor Controlled Series Compensator (TCSC).

The TCSC is used to control the voltage across the series impedance of a given transmission line that ultimately determines the line current and transmitted power **[8].** Many different techniques have been reported in the literature pertaining to investigating the effect of TCSC on power system stability **[10-13].**

Several approaches based on modern control theory have been applied to TCSC controller design. A state feedback controller for TCSC was presented by using a pole placement technique**.** However, the controller requires all system states which reduce its applicability **[4].** A control scheme of TCSC for power flow control has been proposed **[14].**

III.Modelling of the Conventional Compensators.

The circuit diagram for an uncompensated line is shown in Fig. 7.0.

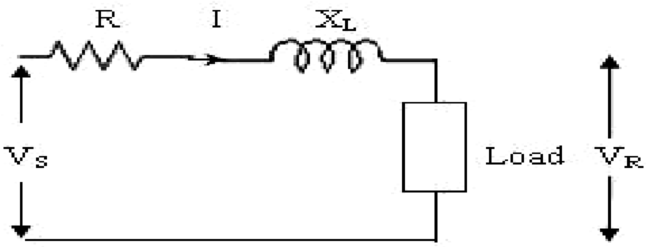

Fig .7.0 Circuit diagram for an uncompensated line.

The phasor diagram of the circuit is shown in Fig. 8.0.

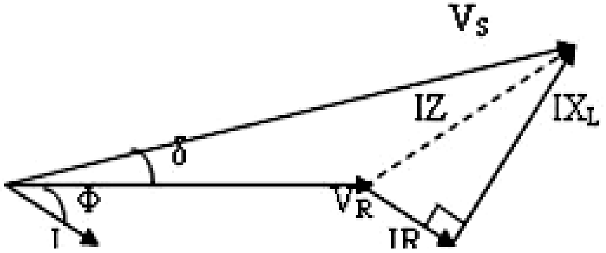

Fig. 8.0 Phasor diagram for an uncompensated line.

Where Vs is the voltage at the sending end, V_R is the voltage at the receiving bus, δ is the phase angle between the voltage at the sending bus and the voltage at the receiving bus.Voltage drop in the line with lagging power factor can be approximated as

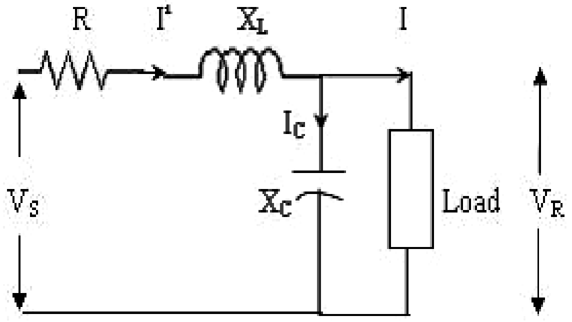

Fig. 9.0 Line with Shunt compensator.

The phasor diagram for the shunt compensation is shown in Fig. 10.0.

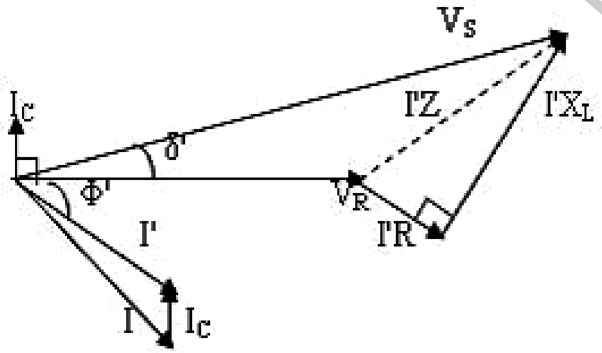

Fig. 10.0 Phasor diagram for a shunt compensated line

The voltage drop can be approximated as

$$V_D = I^1R + I^1X_L - I_CX_C \quad 4.0$$

The difference between the voltage drops is the voltage rise due to the installation of the shunt capacitor.

$$V_R = I_CX_L. \quad 5.0$$

For the series compensation, the capacitor is connected in series to the line resistance and line inductive reactance. Fig. 11.0 shows the circuit diagram for the series compensation.

$$V_D=I_RR + I_XX_L \quad 3.0$$

For a shunt compensated line with capacitors, a capacitor bank is connected in parallel to the receiving bus. Fig. 9.0 shows a shunt compensated line.

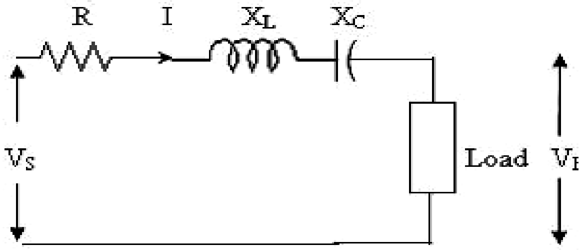

Fig. 11.0 Circuit diagram for series compensation

The phasor diagram is shown in Fig. 12.0.

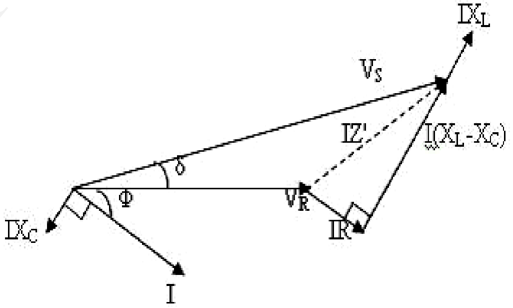

Fig. 12.0 Phasor diagram

When a load with lagging power factor is connected at the end, voltage drop (V_d) in the line is

$$V_d=I(R\cos\O+X_L\sin\O) \quad 6.0$$

If a capacitance 'C' with reactance Xc is connected in series with the line, then the reactance will be reduced to (X_L-X_C) and hence the voltage drop is reduced.

It can be observed from the phasor diagram that the line voltage drop is

$$V_d=I(R\cos\O+(X_L-X_C)\sin\O) \quad 7.0$$

Thus the use of series capacitors is to reduce the voltage drop in the lines with low power factor and improve the voltage at the receiving end particularly with low power factor loads.

For variable load conditions, the voltage can be controlled by switching in suitable series capacitors in the line.

IV.Modelling Of STATCOM.

According to [7] an equivalent circuit of a STATCOM model is as shown in Fig. 13.0.

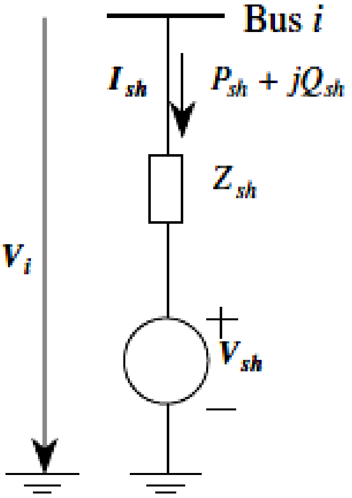

Fig. 13.0 Equivalent circuit diagram of the STATCOM model.

The equivalent circuit of the STATCOM is now shown in Fig. 13.0. Suppose

$V_{sh}= V_{sh}\angle\theta_{sh}, V_i= V_i\angle\theta_i$, then the power flow constraints of the STATCOM are to be specified.

The operating constraint of the STATCOM is the active
)=0.
power exchange via the DC-link as described by:

$PE=\mathrm{Re}(\boldsymbol{V}_{sh}\boldsymbol{I}_{sh}{}^{*}$

8.0

For the bus voltage control, the control constraint is as follows:

$ViVi^{spec}=0$

9.0

where Vi^{spec} is the bus voltage control reference.

V.CONCLUSION

The theoretical aspects of FACTS devices have been considered in this paper. Different FACTS devices were presented and discussed. The conventional compensation technique such as the use of capacitor banks in series and parallel were treated in this work. Their modes of operation as well as short comings were highlighted. Various model equations showing the operation of the FACTS devices especially in relation to power transfer and voltage improvement in the receiving end of the transmission line were also presented. The application of FACTS devices in a physical power system will be handled in an accompanying paper.

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