Operation and Control of STATCOM

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Abstract--- The Static Synchronous Compensator (STATCOM) as the shunt Voltage-Source Converter-Based FACTS (VSC-FACTS) device is introduced in this paper. In this paper the basic operation and control strategy of the STATCOM is presented. The control of VSC-FACTS is based on d-q transformation and decoupled control. Therefore the concept of direct and quadrature axes and Park Transformation is presented. The basic component of VSC-FACTS is a converter capable of generating a three phase, almost sinusoidal voltage. Shunt compensation is well-known concept in AC power systems to control the reactive power flow and hence regulate the bus voltage. When the real power demand of the load increases the amount of the required reactive power also increases and shunt compensation is required to provide this additional reactive power demand. The main objective of any AC transmission or distribution line compensation is to increase the steady state and short term power transfer capability of the existing transmission systems. This paper describes the general concept of AC transmission system compensation using tools such as shunt capacitive or reactive compensation and then the new concept of solid - state, converter-based Flexible AC Transmission Systems (FACTS) is introduced. The paper reviews the previous works on FACTS schemes.
Keywords: STATCOM, Shunt compensation, d-q transformation

I. INTRODUCTION

The IEEE definition of the STATCOM is:
STATCOM: A static synchronous generator operated as a shunt-connected static Var compensator whose capacitive or inductive output current can be controlled independent of the AC voltage system.

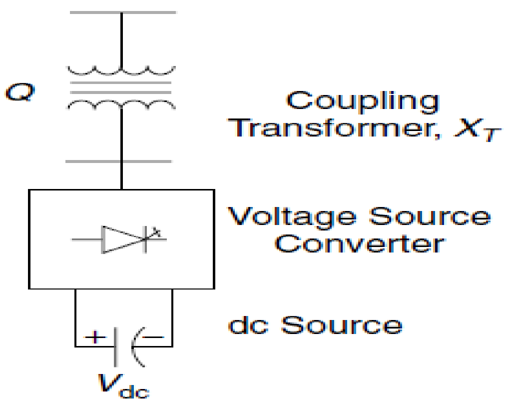

Fig. 1: basic diagram of the STATCOM (static synchronous compensator).

Fig.1 shows the basic diagram of the STATCOM. Basically, the STATCOM is a Synchronous Voltage Generator (SVG) that generates a three phase voltage from a dc source in synchronism with the line voltage [1].

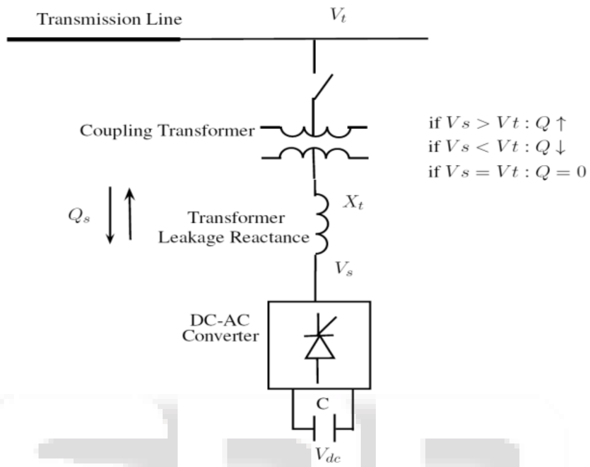

Fig. 2: STATCOM reactive power exchange

Fig.2 shows STATCOM reactive power exchange. If Vs > Vt, the STATCOM operates in capacitive mode and supplies reactive power into the transmission system and if Vs < Vt , the STATCOM operates in inductive mode and consumes reactive power from the transmission system. The power rating of the STATCOM depends on the required reactive power compensation at the point of connections. The load flow calculations determine the unregulated bus voltage and how much reactive power is needed to regulate the bus voltage. By knowing the STATCOM power and voltage ratings, the voltage and current ratings of the GTO's can also be determined.

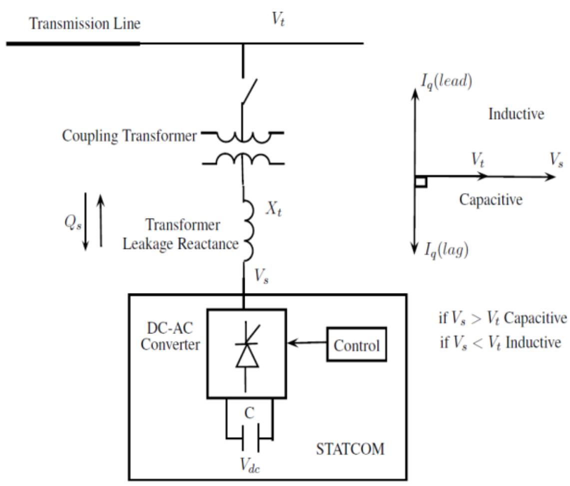

Fig. 3: STATCOM operation

The magnitude of the STATCOM voltage can be controlled in order to adjust the amount of reactive power exchange between the STATCOM and the controlled transmission system. Therefore in Fig.3, Vs is in phase with Vt and there is no real power exchange between the STATCOM and the transmission system.
There is usually a small amount of converter switching and coupling transformer losses that should be supplied by the transmission system. Since Vs and Vt are in phase, the STATCOM current is essentially in quadrature with bus voltage, Vt , and the STATCOM voltage, Vs ,and therefore it is a reactive current, Iq. The magnitude of Iq and the corresponding reactive power exchange between the STATCOM and the transmission system in per unit are:

$$I_q = \frac{V_s - V_t}{X_t} \quad (1.1)$$

$$Q_s = V_s I_q = \frac{V_s^{\,2}}{X_t}\left(1 - \frac{V_t}{V_s}\right) \quad (1.2)$$

II. VOLTAGE-SOURCE CONVERTER OPERATION

The basic building block of the STATCOM is converter that generates a synchronous sinusoidal voltage. For operational, control and economic reasons Voltage-Source Converters (VSC) are currently employed in FACTS applications. The most practical and economical configuration that is currently used and recommended in High power utility applications are multiphase converters. If the converter is operated to supply only reactive power, the real power provided by dc capacitor is zero.
Furthermore since reactive power at zero frequency i.e., capacitor voltage is by definition zero, the dc capacitor plays no part in the reactive power generation. In other words, the reactive power is generated only due to interconnection of the AC phases by the converter in such a way that the reactive current of the AC system can flow freely between the phases. However, although reactive power is internally generated by the action of solid-state switches, it is still necessary to have some relatively small dc capacitor across the terminals of the converter. The need for the dc capacitor is primarily required to satisfy the equality of the instantaneous input and output powers of the converter. The output voltage waveform of the converter is not a perfect sine wave. However the multipulse converter injects a smooth almost sinusoidal current through the tie reactance to the transmission system. As a result the net three phase instantaneous power (VA) at the output terminals of the converter has reduced ripple content[2]. Thus in order not to violate the equality of the instantaneous powers, the converter must draw a fluctuating current.
From the dc capacitor, The presence of the input ripple current components is thus entirely due to the ripple components of the output voltage, which are a function of the output wave form fabrication technique. In a high power converter, using sufficiently high pulse number, the output voltage distortion and capacitor current can be theoretically reduced to any desired value. Thus a perfect converter would generate sinusoidal output voltage and draw pure dc input current without harmonics. In practice due to system unbalance and other imperfections, as well as to economic considerations, these ideal conditions are not achieved, but approximated satisfactorily by converters of sufficiently high pulse numbers (24 or higher). For economical and hardware assembly reasons, 24-pulse or higher converters are usually employed in electric Utility Grid.

III. BASIC CONTROL OF THE STATCOM

As mentioned earlier, the STATCOM voltage, Vs, is always in phase with transmission line voltage, Vt , and by fast control of the magnitude of Vs the reactive power exchange can be regulated according to compensation level. Since two level, multipulse converters are the most practical and economical converters in FACTS applications, this section deals with this type of converters.
Unlike the PWM and three level converters, two level converters do not have internal capability of voltage magnitude control and only the phase angle of the output AC voltage can be regulated by gating signals. Therefore the only way to control the magnitude of the AC output voltage is by adjusting the input DC voltage should increase and vice-versa. In other words charging or discharging the dc capacitor voltage control is achieved by a small phase displacement, Δα , between the STATCOM voltage, Vs, and the transmission system voltage, Vt . If Vs lags Vt , real power flows from transmission system to dc side and the capacitor is charged. Similarly if Vs leads Vt, real power flows from the dc side to the transmission system and the capacitor is discharged. Therefore the real power exchange is a function of phase displacement, Δα , as shown in Fig.4.
This phase displacement is also required to compensate the converter switching losses by the transmission system. In practice, Vs always lags Vt by a small value and a small real power flows from the transmission system to dc capacitor in order to compensate the converter switching and transformer losses.

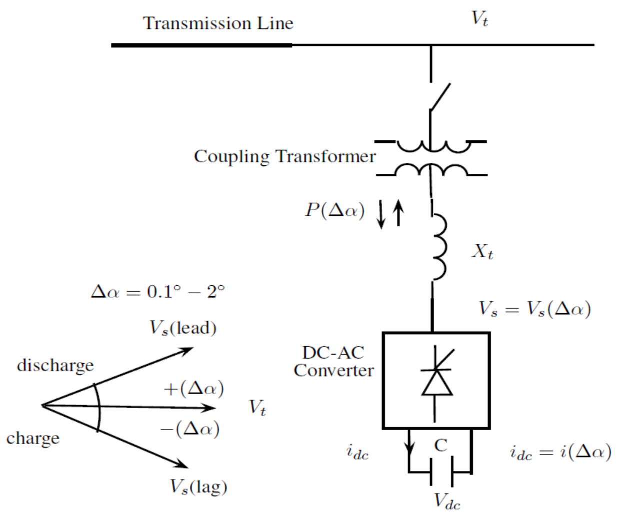

Fig. 4: STATCOM real power exchange

Additional temporary positive or negative phase displacement is required to charge or discharge the capacitor as a part of additional control system requirements.

IV. VECTOR CONTROL ANALYSIS

The concept of vector control of the VSC-FACTS was developed by Schauder and Mehta [3]. A decoupled control is obtained by using the Park transformation. The AC output current I of the STATCOM can be considered as a two-component current vector. The major part of the current is reactive current and performs the basic function of the STATCOM. Besides, a small portion of the current is real current that compensates for converter switching losses and charges or discharges the dc capacitor. Therefore if the STATCOM current is decomposed into real and reactive components, a decoupled control can be obtained which makes the STATCOM control simple. In general using the Park transformation, asset of three phase, symmetric variables can be decomposed into direct and quadrature components, also known as d-q transformation.

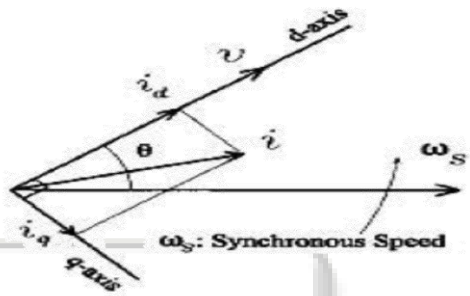

Fig. 5: Fig.1 shows the basic diagram of the STATCOM. Basically, the STATCOM is a Synchronous Voltage Generator (SVG) that generates a three phase voltage from a dc source in synchronism with the line voltage [1].

Direct and Quadrature Components of Current Vector

Fig.5 shows d-q components of a current vector with respect to a reference voltage vector. The direct and quadrature coordinates within this synchronously rotating reference frame are given by the following time-varying transformation, which is called Park or d-q transformation:

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\theta & \cos(\theta-120^\circ) & \cos(\theta+120^\circ) \\ -\sin\theta & -\sin(\theta-120^\circ) & -\sin(\theta+120^\circ) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

Where i_a, i_b and i_c are the three phase currents, i_d and i_q are the direct and quadrature components of current vector with respect to the rotating reference. i_0 is the zero component of the current vector and for a symmetric three phase variable, is always zero. Under balanced, steady-state conditions, the coordinates of the voltage and current vectors in the synchronous reference frame are constant quantities. This feature is useful for decoupled control strategy of the VSC-FACTS.

By using this transformation and considering the transmission system voltage, Vs, as the rotating reference vector, the STATCOM current can be decomposed into direct axis component, which is in phase with Vt , and quadrature axis component, which is in quadrature with Vt. The d-axis current is the real current and compensates the converter switching and coupling transformer losses as well as charges or discharges the dc capacitor. The q-axis current is the reactive current and performs the basic operation of the STATCOM which is generation or absorption of reactive power.

V. REFERENCE SIGNAL AND REGULATION SLOPE

Since the basic purpose of the STATCOM is to regulate the transmission system voltage by reactive power compensation, line voltage, Vt, is the basic reference signal for the control of the STATCOM operation. It provides an external reference value for the STATCOM control [4].

In many applications the STATCOM is not a perfect voltage regulator, i.e. it does not provide a fixed voltage for the transmission system, instead, a regulation slope is considered for the voltage and it is allowed to be less than the nominal voltage at full capacitive operation and higher than the nominal voltage at full inductive operation of the STATCOM[5]. The reasons are: (1) A practical STATCOM has maximum capacitive and inductive current ratings. The linear operation range of the STATCOM can be extended if a regulation slope is allowed. (2)Perfect regulation (zero slopes) could result in poorly defined steady state operating point and a tendency of oscillations. (3) A regulation slope tends to enforce automatic load sharing between static compensators, as well as other regulator devices in the grid.

A typical regulation characteristic of the STATCOM is shown in Figure.6.

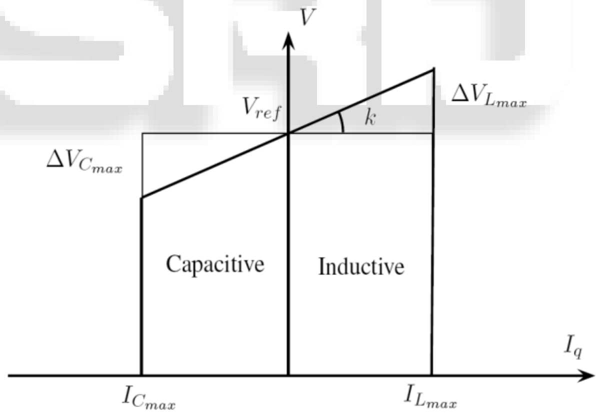

Fig. 6: Voltage Regulation and Regulation Slope

The regulation slope, k, is defined as:

$$k = \frac{\Delta V_{C\max}}{I_{C\max}} = \frac{\Delta V_{L\max}}{I_{L\max}} \qquad \text{Eq. (5.1)}$$

Where V_{Cmax} is the maximum line voltage drop at full capacitive and V_{Lmax} is the maximum overvoltage at full inductive operation of the STATCOM. I_{Cmax} and I_{Lmax} are the corresponding STATCOM current ratings. The reference voltage with regulation slope, $V*_{Ref}$, will be:

$$V_{Ref}* = V_{Ref} + kI_q \qquad \text{Eq. (5.2)}$$

I_{Lmax} and I_{Cmax} are determined by the STATCOM Var capacity. Depending on the maximum capacitive or reactive power compensation, I_{Lmax} and I_{Cmax} can be determined. The voltage regulation of the STATCOM is linear if the required compensation current is between I_{Cmax}

and I_{Lmax} and beyond these currents it is no longer linear and additional capacitive or reactive compensation by parallel capacitor or reactor banks can be added to meet the compensation requirements.

VI. CONCLUSIONS

The basic operation and control strategy of the STATCOM is presented. The Static Synchronous Compensator (STATCOM) works as the shunt Voltage-Source Converter-Based FACTS (VSC-FACTS) device. The control of VSC-FACTS is based on d-q transformation and decoupled control, so that the concept of direct and quadrature axes and Park Transformation is used. VSC-FACTS converter is capable of generating a three phase, almost sinusoidal voltage. When the real power demand of the load increases the amount of the required reactive power also increases and shunt compensation is required to provide this additional reactive power demand. This can be achieved by STATCOM. This paper describes the general concept of AC transmission system compensation using tools such as shunt capacitive or reactive compensation and then the new concept of solid - state, converter-based Flexible AC Transmission Systems.

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