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Static Synchronous Series Compensator and Dynamic Voltage Restorer-A comparison

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Abstact-With the growth of complex electrical power networks,the use of FACTS(Flexible Alternating Current Transmission System) devices has also increased in Power system.Increased demands on transmission, absence of long term planning, and the need to provide open access to generating companies and customers, all together have created tendencies towards less security and reduced quality of supply. Static Synchronous Series Compensator(SSSC) and Dynamic Voltage Restorer(DVR) are two important devices to mitigate these problems. Even though the role of these two devices in power system has been studied by many resercherers, a comparison between the two is not found much in literature.In this paper,a description of the two devices with their control strategies and a comparison between the two is presented.

Index Terms:-SSSC, DVR, Voltage source converter, Series injection transformer, DC link capacitor.

I. INTRODUCTION

Flexible Alternating Current Transmission System (FACTS) has been implemented to increase the capability of the existing transmission systems. FACTS involves reliable and high-speed power electronic switches instead of mechanically controlled devices. In general, FACTS controllers can be divided into four categories. They are series controllers, shunt controllers, combined series-series controllers and combined series-shunt controllers[1]. SSSC and DVR comes in the category of series connected controllers.

If the line voltage is in phase quadrature with the line current, the series controller absorbs or produces reactive power, while if it is not, the controllers absorbs or produces real and reactive power. Examples of such controllers are Static Synchronous Series Compensator (SSSC), Thyristor-Switched Series Capacitor (TSSC), Thyristor-Controlled Series Reactor (TCSR) and DVR . Among these, Static Synchronous Series Compensator (SSSC) is one of the important series FACTS devices used in transmission system. SSSC is a solid-state voltage source inverter, injects an almost sinusoidal voltage, of variable magnitude in series with the transmission line. The injected voltage is almost in quadrature with the line current. The applications of the SSSC are 1)To control the power flow, 2) To increase the power transfer limits, 3). To improve the transient stability 4) To dampout power system oscillations 5) To mitigate Sub-Synchronous Resonance (SSR) [9].

Dynamic Voltage Restorer (DVR) can provide the most cost effective solution to mitigate voltage sags and swells by establishing the proper voltage quality level that is required by customer.

When a fault happens in a distribution network, sudden voltage sag will appear on adjacent loads. DVR installed on a sensitive load, restores the line voltage to its nominal value within the response time of a few milliseconds thus avoiding any power disruption to the load.

There are many different methods to mitigate voltage sags and swells, but the use of a DVR is considered to be the most cost efficient method.[10] Other than voltage sags and swells compensation, DVR also has added other features like: line voltage harmonics compensation, reduction of transients in voltage and fault current limitations[3].

II. SSSC

The inverter based series compensator, which is now often termed the SSSC, was first proposed in 1989 by Gyugyi.SSSC has several advantages over TCSC(Thyristor controlled series capacitor).These include elimination of bulky passive components ,capacitors and reactors(ii)improvedtechnical characteristics(iii)symmetric capability in both capacitive and inductive operating modes(iv) possibilty of connecting an energy source on the DC side to exchange real power with the AC network[2].

Fig.1 shows basic diagram of SSSC connected to a transmission line.It consists of a series injection transformer which injects the required voltage in series with the line.The voltage source converter is a PWM converter whose output voltage is determined by swithching of PWM converters.The DC link capacitor of SSSC maintains a constant DC bus voltage for the converter.The control circuit controls the switching of the converter ,by operating it at the required time.

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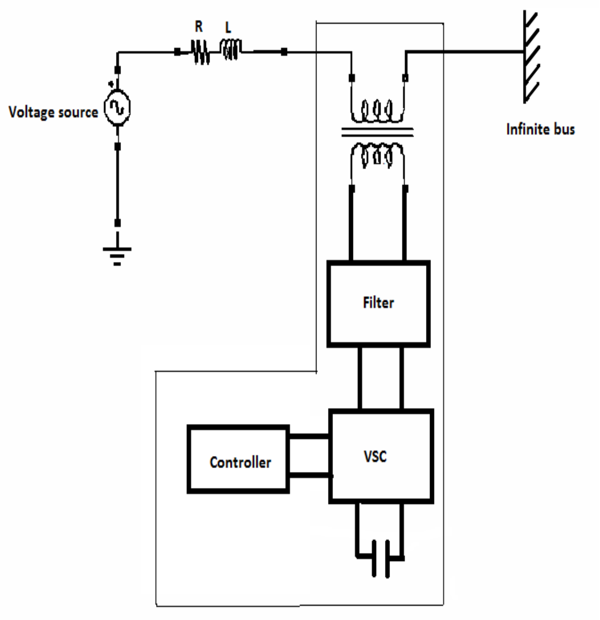

Fig 1. Basic circuit model of SSSC

The simplified equivalent circuit of SSSC is as shown in Fig2.

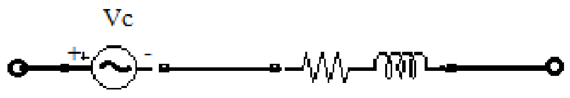

Fig. 2.Equivalent circuit of SSSC

The magnitude of Vc can be controlled to regulate the power flow.The power balance in steady state gives

Re[VcI*] = 0 (1)

A. Modes of operation of SSSC

The SSSC is used to insert, in series into the transmission line, an ac voltage at the synchronous frequency via a series injection transformer to influence the power flow on the line. The magnitude and angle of this injected voltage is controlled by the SSSC depending on its mode of operation. However, when operating as a stand alone SSSC, the device is restricted to the reactive power domain, where the injected voltage must be in quadrature to the line current. Two possible modes of operation are described below [5,6,7]**:**

(i) Line Impedance Emulation Mode

The SSSC injects an ac voltage that emulates capacitive reactance. The voltage injected into the line is in lagging quadrature with the line current i, thus emulating a capacitive reactive voltage drop in series with the transmission line. In practice, the voltage inserted is not in exact quadrature with the transmission line current so that a small amount of real power is supplied by the line to replenish the losses in the inverter. The relationship between the line current phasor I and the injected voltage phasor Vq can be described mathematically by the phasor equation:

$Vq = k\, I\, e^{-j\pi/2}$ (2)

where the term k determines the degree of series compensation. Hence, by controlling k, the degree of series compensation can be continuously varied within the rating of the inverter from zero compensation (k=0) to some maximum value (k= k max). Also, by controlling the term k, the reactive compensation is specified in a similar manner to a conventional series capacitor reactance , where

$k = |Vq| / |I| = Xq$ (3)

From (3), the term k becomes analogous to the ohmic magnitude of a series capacitive reactance emulated by the inverter based series compensator [8]. In other words when,the traditional capacitor banks are replaced by this inverter based series compensator with Xq=k, in effect is equivalent to the fundamental frequency reactance Xc of the conventional series capacitor bank. However, in the case of the inverter-based compensator the magnitude of the compensating reactance is rapidly controllable because the amplitude IVqI of the inverter output voltage can be changed very rapidly.

Various researchers have given this mode of SSSC operation different names. It is sometimes referred to as the "constant reactance mode", or the "Xq-controlled SSSC".

(ii)Direct Voltage Injection Mode

This mode of operation provides a controllable series compensating voltage independent of the magnitude of the line current. i.e.,the injected voltage Vq is typically capacitive in nature, but has no direct enforced magnitude relationship with the line current i. For example, the magnitude of this compensating voltage can be used as part of a closed loop control scheme to force the active and reactive power in the transmission line to follow a desired reference value.However the inverter-based compensator does not emulate any specified value of capacitive reactance.

This mode of operation is also referred to as the "constant quadrature voltage mode" or the "Vq-controlled SSSC" .

B. Control strategies for SSSC[2]

(i) Type 2 converter

In this type of control,the magnitude of the injected voltage to the DC capacitor voltage (k=Vc/Vdc) is held constant,where Vc is the SSSC injected voltage,Vdc is the DC link capacitor voltage.The only control variable now is α ,the phase variable.

(ii) Type 1 converter

The scheme is simple compared to that of Type 2 converter.Here,k is variable in addition to α.The gating pulses are based on the computation of k and α

An energy source may also be used in conjunction with SSSC. In addition to series reactive compensation, with an external dc power supply it can also compensate the voltage drop across the resistive component of the line impedance[4].

III. DVR

Dynamic voltage restorer is a static var device analogous to SSSC.It is a series compensation device, which protects sensitive electric load from power quality problems such as voltage sags, swells, unbalance and distortion through power electronic controllers that use voltage source converters (VSC)[2].

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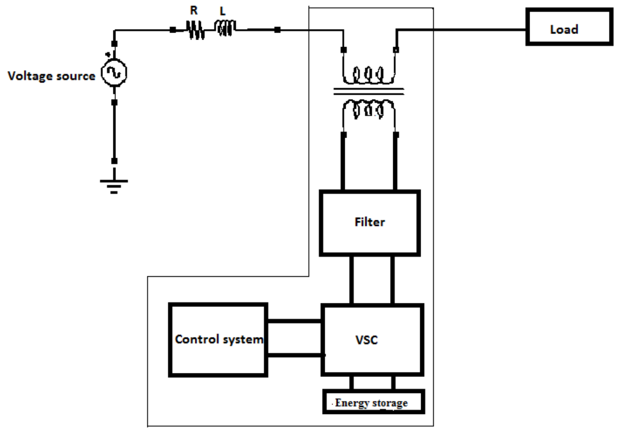

Fig. 3. The basic circuit model of DVR

As shown in Fig. 3 ,the main components of DVR are a series injection transformer,a VSC(voltage source converter,an energy source and a filter.The function of each component is similar to those in SSSC.Whenever there is a power quality problem like voltage sag or swell ,DVR injects a voltage to compensate it.

A. Modes of operation of DVR

(i) Protection mode:

In this particular case, as shown by Fig. 4,a by-pass switch is activated to provide an alternate path for the fault currents. Hence the inverter is protected from the flow of high fault current through it, which can damage the sensitive power electronic components .

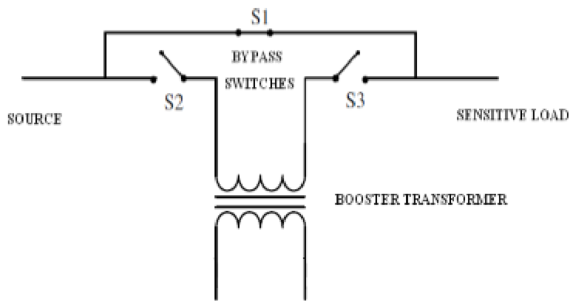

Fig. 4.Protection mode

(ii) Standby Mode:

Since the network is working under normal condition the DVR is not injecting any voltages to the system. In that case, if the energy storage device is fully charged then the DVR operates in the standby mode or otherwise it operates in the self- charging mode. The energy storage device can be charged either from the power supply itself or from a different source.

(iii) Injection/Boost Mode

The DVR injects the difference between the pre-sag and the sag voltage, by supplying the real power requirement from the energy storage device together with the reactive power. The maximum injection capability of the DVR is limited by the ratings of the DC energy storage and the voltage injection transformer ratio. In the case of three single-phase DVRs the magnitude of the injected voltage can be controlled individually. The injected voltages are made synchronized (i.e. same frequency and the phase angle) with the network voltages .

B. Control Strategies[11]

(i) Pre-sag compensation

In this technique the DVR supplies the difference between the pre-sag and the sag voltage, thus restore the voltage magnitude and the phase angle to that of the pre-sag value. Fig. 5 below describes the pre-sag compensation technique. However this technique needs a higher rated energy storage device and voltage injection transformers.

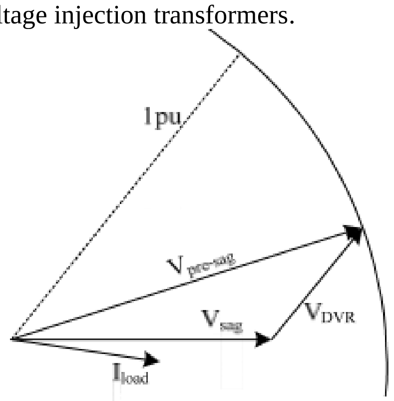

Fig. 5.Pre-sag compensation

(ii) In-phase compensation

The DVR compensates only for the voltage magnitude in this particular compensation method as shown in Fig. 6. i.e. the compensated voltage is in-phase with the sagged voltage and only compensating for the voltage magnitude. Therefore this technique minimizes the voltage injected by the DVR. Hence it is recommended for the linear loads, which need not to be compensated for the phase angle.

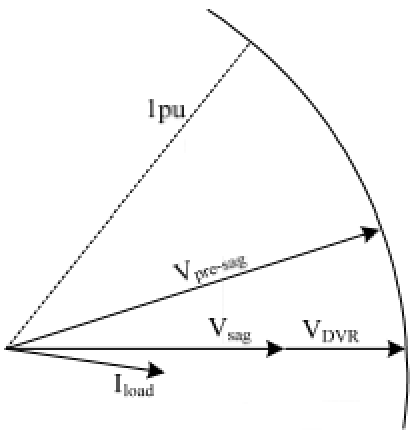

Fig. 6.In phase compensation

(iii) Minimum energy compensation

In this particular control technique, the use of real power is minimized (or made equal to zero) by injecting the required voltage by the DVR at a 90° phase angle to the load current. Fig. 7 depicts the energy optimization technique. However in this technique the injected voltage will become higher than that of the in-phase compensation technique. Hence this technique needs a higher rated transformer and an inverter, compared with the earlier

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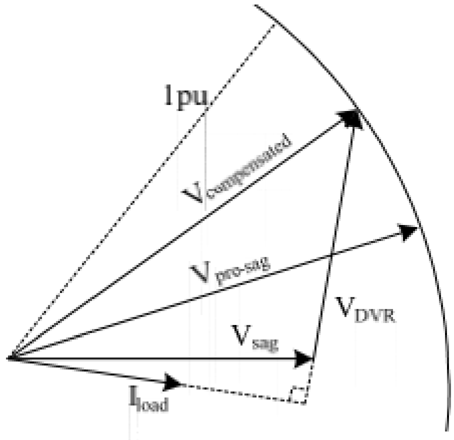

Fig. 7.Minimium energy compensation

IV. CONCLUSION

FACTS controllers are viable alternatives to problems in power systems. Among SSSC and DVR, eventhough both are series connected devices ,they differ in their location, overall complexity ,rating and control strategies. An SSSC is placed mainly in transmission system and has the capability to mitigate problems such as SSR. It increases the transmission capability of line. An SSSC normally has a higher power rating compared to DVR.An energy storage device may also be incorporated with SSSC .The control circuit of SSSC is more complicated than DVR. A DVR is mainly incorporated in the distribution side.It is less costly compared to SSSC.It can be used to mitigate many power quality problems in the load side. Control strategies are also relatively simple.

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