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Static Synchronous Series Compensator With Energy Storage

Yogesh N. Tatte
M-Tech III Sem (IPS)
Electrical Engineering
GHRCE Nagpur

Abstract- The static synchronous series compensator (SSSC) is a solid state voltage source converter coupled with a transformer, which is connected in series with a line .When operated without external energy source, output voltage is in quadrature with a line current and controlled independently of the line current. When operated with energy source (SMES, BESS),it provides better performance, PQ decoupled control can effectively control the transmission line power flow. A review of some literature in this area is carried out.

Keywords- FACTS, SSSC, SSSC/ESS, VSI Control Schemes.

1 Introduction-

Flexible AC Transmission system consists of static device used in AC transmission system to enhance the power transfer capability. FACTS devices can potentially overcome the disadvantages of the present working of mechanically controlled transmission system. FACTS devices delay or minimize the requirement to build more transmission lines and power plants [8]. The development of high rating power electronics has made it possible for controllable series and shunt compensators to control power flow in transmission lines.

Static synchronous series compensator (SSSC) is a series FACTS device which injects a controlled voltage into the system in quadrature with the line current but controlled independently of the line current, so as to control impedance which is a function of reactive power .Energy storage system (ESS), when connected with SSSC,can give superior performance .With ESS, the SSSC can provide active power compensation. Without ESS, SSSC can only provide capacitive or inductive impedance compensation, hence reactive power compensation[1].To control both power and voltage, SSSC/ESS is more effective than the SSSC[8].

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2SSSC

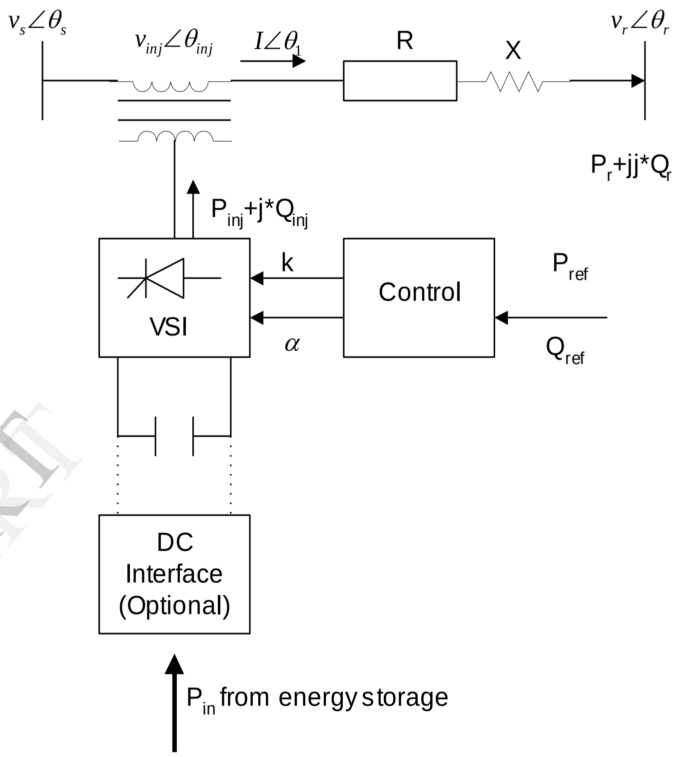

Fig 1 SSSC

FACTS is a power electronic based system and other static equipment that provide control of one or more of AC transmission system parameters [4]. The Static Synchronous Series Compensator (SSSC) is one of the FACTS devices for power transmission line series compensation. It is a power electronic based Synchronous Voltage Generator (SVG) that generates a three phase voltage, from a dc capacitor bank, in quadrature with the line current.

Fig. 1 shows the basic diagram of the SSSC. The SSSC is a solid state voltage source inverter coupled with a transformer, connected in series with a transmission line. It can improve power transfer capability, transient stability, and power oscillation damping, because it can change the power flow on the transmission line by providing inductive or capacitive compensation. When SSSC injects sinusoidal voltage leading the line current, it emulates an inductive reactance in series with a transmission line, which causes the power flow as well as the line current to decrease as the level of compensation increases. Hence the SSSC is operating in inductive mode. When SSSC injects voltage lagging the line current, it emulates the capacitive reactance in series with transmission line causing the power flow and the line current to increase, as the level of compensation increases. Hence the SSSC is operating in a capacitive mode [2].

The VSI is an important part of a SSSC. It allows the power to flow from DC voltage source to system and vice-versa. By switching the power electronics devices on and off, an adjustable voltage V_{inj}. is injected into the power system.VSI generates voltage with levels either 0 or + Vdc or – Vdc. Hence they are called as two level converter. To obtain a quality output voltage or current waveform, they require high switching frequency along with various pulse width modulation strategies. While handling high power ,these inverters have some limitations in operating at high frequency mainly due to switching losses. The multilevel inverters have shown great performance while handling high power. By increasing the number of voltage levels in the inverters , the power rating can be increased ,without requiring higher rating on individual devices. Its output can be reach to high voltages with low harmonics without the use of transformers or series connected synchronized switching devices.

The 24- and 48-pulse converters are obtained by combining two or four 12-pulse VSI. These inverters are obtained by proper phase shifting between all converters. Two 24-pulse GTO- converters can provide the full 48-pulse converter operation. Phase is shifted by 7.5^0 from each other .For high-power applications with low distortion, the 48-pulse converter is preferred[9].

3 SSSC/ESS.

If SSSC coupled with an ESS, providing active power support along with reactive power compensation.SSSC/ESS shown in fig.1. Energy source (SMES, BESS) can improve power system flexibility by exchanging active power and improve system stability , power swings damping. There are different technologies for Energy storage such as ultra-capacitors, batteries, flywheels and SMES which differ from each other pointing energy density, Charging/discharging rate, maintenance. A small part of injected voltage which is in phase with line current provides the losses in the inverter .SSSC can compensate line resistance if it is operated with an energy storage system.

3.1 SMES

In SMES, the energy is stored in the magnetic field, produced by DC current when flowing through closed path. The power can be drawn from SMES unit or can be stored into the SMES unit with almost instantaneous response with energy stored or delivered from an SMES unit over periods ranging from parts of seconds to several hours.

The SMES stored energy and the rated power can be expressed as following

$$Esmes=1/2Lsmes\ I^2smes$$

$$Psmes=(d/dt)Esmes$$

$$=Lsmes\ Ismes\ (d/dt)\ Ismes$$

$$=VsmesIsmes$$

SMES coil is connected to the SSSC dc-bus through a dc-dc chopper, which controls the dc current and voltage levels. The main purpose of connecting a chopper is to control the voltage across SMES coil. A simple typical chopper is shown in Fig.3. The overall chopper operation can be defined by

$$V_{SMES}=(1-2d)V_{dc}$$

where d is duty cycle of chopper .Chopper is in charging mode, if *d* is less than 0.5. and hence the SMES average voltage is positive. In this case, Chopper absorbs energy. Chopper is in discharging mode, when *d* is more than 0.5. In this case, chopper injects energy into the power system. No energy is exchanged with power system, when *d* is 0.5.In this case, Chopper operation is in standby mode and the average voltage across SMES coil will be equal to zero.

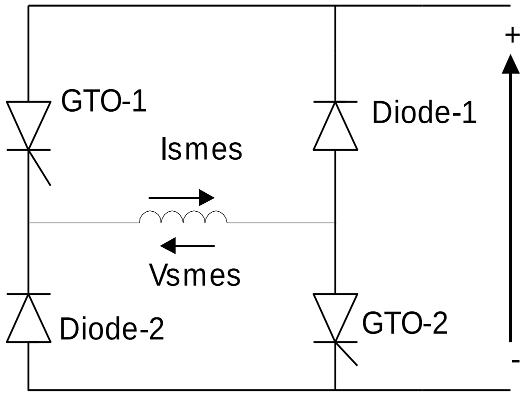

Fig2 Operation of Chopper

SMES systems for power utility applications have received considerable attention due to their characteristics, such as rapid responce (milliseconds), high power (multimegawatts), high efficiency, and four-quadrant control[6].

3.2 BESS

The battery energy storage system (BESS) mainly consists of batteries, control and power conditioning system(C-PCS) and rest of plant. The rest of plant would be designed to provide good protection for batteries and C-PCS. C-PCS is used to convert alternating current (AC) to direct current (DC) and vice versa. A PCS is required that acts as an inverter when the device is discharged (DC to AC) and acts as a rectifier while the energy device is charged (AC to DC) .The batteries are made of stacked cells. Chemical energy in the cells is converted into electrical energy .These cells are connected in series and parallel electrically for obtaining the desire battery voltage as well as current level. The rating of the batteries is in power and energy capacities. Along with high power handling capacity, batteries are efficient, having large life span, high depth of discharge(the percentage of the battery capacity that is discharged during a cycle) and has high energy density.Following are the types of batteries which are used for power system application.

1)Lead acid: Each cell consist of a positive electrode of lead dioxide and a negative electrode of sponge lead. These electrodes are separated from each other by micro-porous material and immersed in an aqueous sulphuric acid electrolyte.

2)Sodium Sulphur(NaS) :It consist of positive electrode made-up of molten sulphur and negative electrode made-up of molten sodium separated by solid beta alumina ceramic electrolyte.

3) Lithium oil (Li-oil): It consists of positive electrode made-up of graphitic carbon with a layer structure and negative electrode made-up of lithiated metal oxide. The electrolyte is made-up of lithium salts dissolved in organic carbonates.

4) Flow batteries: This type of batteries comprises of two electrolyte reservoirs. Electrolytes are circulated through an electrochemical cell consisting of an anode, cathode and a membrane separator .When the two electrolytes flow through electrochemical cell ,the chemical energy is converted into electrical energy[10]

4 Control Schemes

To understand the role of SSSC in controlling Pact. and Qact. Consider the phasor diagram given in [1]. Pr. is directly proportional to |Vinj.E| and Qr is directly proportional to |EVr|. Where Pr is the receiving end active power and Qr is receiving end reactive power.These two characteristics shows that active and reactive power can be controlled Independently .The detail is given in [1].

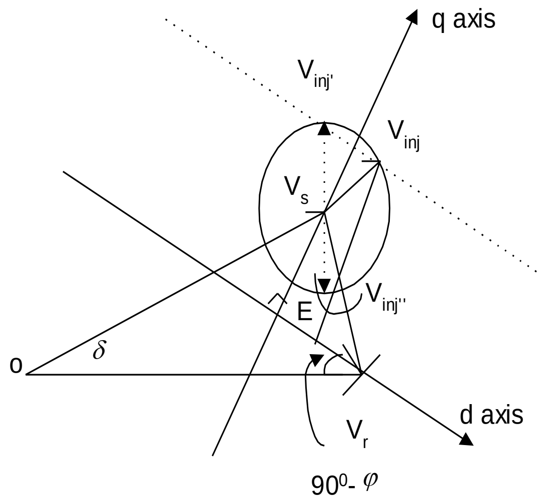

Fig 3 Geometric relationship of the receiving end power

In transient state, power swings occur, SSSC/SMES exchanges active and reactive power with the system, since direct Lyapunov method implies time derivative of both active and reactive powers, prepares an effective control strategy for the SSSC-SMES system to decrease power swings damping time. Since the power system consists of large number of generators, it is expected that controller should be designed approaching nonlinear model. Controller based on nonlinearity will have better dynamic performance than based on linearity. Hence direct Lyapunov strategy to design controller is proposed in [6].

Current controlled –voltage source inverter (CC-VSI), considered as a SSSC works faster and easy to control. It injects sinusoidally varying voltage ($0<V_{pq}<V_{pqmax}$) in magnitude,($0 < \delta_{pq} < 360^0$) in phase, in series with the transmission line. The SSSC not only works as a reactive power compensator but also exhibits the capability of supplying or absorbing the active power to or from the transmission line. This is made possible by incorporating an energy source in the DC link of the CC-VSI. It may be possible to obtain a good dynamic response of the SSSC with a fine-tuned proportional- plus-integral (PI) controller. The fuzzy control is basically nonlinear and adaptive in nature, giving robust performance in those cases where effects of parameter variation of the controller are present[7].

The closed loop control scheme is as shown in fig.4The control is mainly based on the local measurement of voltages and currents. The line current **I** and voltage *V*, are sensed at the point M on the Transmission line. The actual active power (Pact) and actual reactive power(Qact) are calculated..The desired Pref.and Qref.are compared with Pact and Qact respectively. Error signals e_p and e_q are generated. are processed in the controller. The controller generates the gating signals for VSI.

. The sliding mode controller (SMC) is a robust controller and operates on the switching instants, however this controller suffers from the problem of chattering and oscillations.

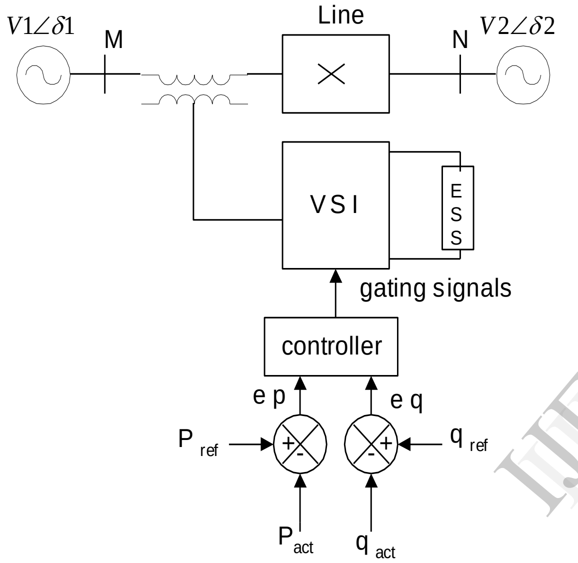

Fig.4 Controller For SSSC/ESS

5. Conclusion

SSSC injects a fast changing voltage in series with the line which is independent of the phase and the magnitude of transmission line current. Energy storage system (ESS), when connected with SSSC, it can give superior performance. With ESS, the SSSC can operate superiorly, while dealing with steady state characteristics and can provide active power compensation. Without ESS, SSSC can only provide capacitive or inductive impedance compensation, hence reactive power compensation. To control both power and voltage, SSSC/ESS is more effective than the SSSC. SSSC/BESS or SSSC/SMES increases flexibility over the traditional FACTS devices. SSSC/BESS improves the steady state characteristics and damp oscillations faster than the SSSC alone.The operation of controller is studied. Direct Lyapunov method is a time dependent method which is used to construct a control scheme for the SSSC/ESS.

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