Reactive Power Compensation Using Static Var Compensators (SVCs)

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Abstract: Reactive power compensation is a very important task in the control, expansion, planning and operation of power system. Reactive power has a profound effect on the security of power systems because it affects voltages throughout the system: deficiencies of reactive power cause voltages to fall, while excesses cause voltages to rise. Static var system (SVS) is equivalent to a shunt capacitor and a shunt reactor, both of which can be adjusted to control reactive power in a prescribed manner. This paper discusses the use of SVS for reactive power compensation and its allocation. Reactive power compensation for: National Grid of Sudan (NGS) 77-bus is taken as a case study.

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1- Introduction:-

A voltage collapse occurs when the system is trying to serve much more load than the voltage can support. Inadequate reactive power supply lowers voltage; as voltage drops, current must increase to maintain the power supplied, causing the lines to consume more reactive power and the voltage to drop further. If current increases too much, transmission lines trip, or go off-line, overloading other lines and potentially causing cascading failures. If voltage drops too low, some generators will automatically disconnect to protect themselves. Voltage collapse occurs when an increase in load or loss of generation or transmission facilities causes dropping voltage, which causes a further reduction in reactive power from capacitors and line charging, and still further voltage reductions. If the declines continue, these voltage reductions cause additional elements to trip, leading to further reduction in voltage and loss of load. The result is a progressive and uncontrollable decline in voltage. This is because that the power system is unable to provide the reactive power required to supply the reactive power demand. Reactive power needs are a critical part of the planning process. Under & over voltage of lines, causes instabilities of electrical network, decrement of energy quality and destruction of equipment insulation. So, one of the most important limitations of reactive power compensation is to maintain the voltage profile in a reasonable range. Reactive power compensation can not be transmitted over long distances, so voltage control has to be affected using special devices dispersed through out the system. One of these devices is SVS which is discussed in some what details in this paper [Lin Chen, Jin Zhong and Deqiang Gan] proposed some modeling and economic issues to the optimal reactive power planning of radial distribution systems with distributed generation using SVS [1]. Where [Tamer Mohamed Khalil , Hosam K.M. Youssef and M.M. Abdel Aziz] presented a binary particle swarm optimization for optimal allocation and sizing of capacitor banks in radial distribution lines with non sinusoidal substation voltages [2]. [Effective methods for optimum reactive power compensation are reported in [3], [5], [6]]The literature relevant to optimal allocation of shunt dynamic Var source SVC is categorized by [Wenjuan Zhang, Fangxing Li, and Leon M. Tolbert [4]]. [S Dey and A Chakrabarti] addressed the application of SVS for minimizing transmission lines losses and improving the voltage stability [7].

2- Characteristic of SVS:-

From the view point of power system, a SVS is equivalent to a shunt capacitor and a shunt reactor, both of which can be adjusted to control reactive power at its terminals (of nearby bus) in a prescribed manner. Ideally, a SVS should hold constant voltage (assuming that this is the desired objective) posses unlimited var generation or absorption, capability with no active and reactive losses and provides instantaneous response. Practically SVS consists of a controllable reactor and a fixed capacitor. The performance of the SVS can be visualized on a graph of controlled ac voltage (V) plotted against the SVS reactive current (Is) and its characteristic can be shown as follows:-

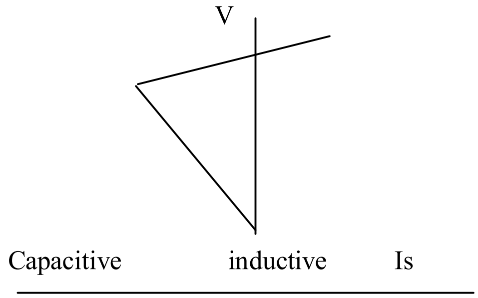

Figure (1) SVS Characteristic

3- Elements of SVS:-

In general the elements of a SVS operate on the principle of adjustable susceptance which is either a reactor or a capacitor. The most commonly used elements are thyristor controlled reactor (TCR), thyristor switched capacitor (TSC) and mechanically switched capacitor (MSC).

3-1 Thyristor controlled reactor:-

The basic elements of TCR are a reactor in series with a bidirectional thyristors. The thyristor conduct on alternate half-cycles of the supply depending on firing angle α , which is measured from zero corresponding of voltage. Full conduction is obtained with firing angle 90^0. The current is actually reactive and sinusoidal. Practical conduction is obtained with firing angle between 90^0 and 180^0. Firing angles between zero and 90 are not allowed since they produce symmetrical currents with a dc component.

Let σ be the conduction angle, related to α by :

$$\sigma = 2\left(\prod - \alpha\right) \tag{3-1}$$

The instantaneous current i is given by:

$$i = \frac{\sqrt{2V}}{X_L}\left(\cos\sigma - \cos wt\right) \tag{3-2}$$

Fourier analysis of the current waveform gives the fundamental component:

$$I = \frac{V}{X_L}\frac{\left(\sigma - \sin\sigma\right)}{\prod} \tag{3-3}$$

Where I and V are rms value, and X_L is the reactance of the reactor at fundamental frequency.

When α increases, σ decreases and therefore I decreases. This is equivalent to increasing the effective inductance of the reactor. In effect, so far as the fundamental frequency current is concerned, the TCR is a controllable suceptance. The effective one as a function of α is:

$$B\left(\alpha\right) = \frac{I}{V} = \frac{\sigma - \sin\sigma}{\prod X_L} \tag{3-4}$$

$$B\left(\alpha\right) = \frac{2\left(\prod - \alpha\right) + \sin 2\alpha}{\prod X_L} \tag{3-5}$$

The maximum value of the effective suceptance is $1\backslash X_L$ at (α = 90^0, σ = 180^0).

The minimum value is zero with α = 180^0 and σ 0^0. This suceptance control principle is known as phase control, and the suceptance is switched in to the system for a controllable fraction of every half cycle.

The TCR require a control system which determines the firing angle measured from the last zero crossing of the voltage. The control system responds to error signals such as voltage deviation and auxiliary stabilizing signals. In some designs the control system responds to a signal that directly represents the desired suceptance. As α is increased from 90^0 to 180^0, the current waveform becomes less sinusoidal, in other words the TCR produces harmonics. Odd harmonics are produced for the single phase system, For three phase systems, the preferred arrangement is to have the three single phase TCR elements connected in delta 6-pulse TCR. For balanced condition, all triplen (3,9,…) harmonics circulate within the closed delta and therefore are absent from the line current. Elimination of 5^{th} and 7^{th} can be achieved by using two 6-pulse TCRs of equal rating, fed from two secondary windings of the step down transformers, one connected in Y and the other in Δ. Since the applied voltage to the TRCs have a phase difference of 30^0, the 5^{th} and 7^{th} harmonics are eliminated from the primary- side current. The lowest order characteristics harmonics are 11^{th} and 13^{th}, and they can be filtered using a simple capacitor bank.

The TCR responds in about 5 to 10 ms, but delays are introduced by control circuits. For control room stability the response time should be around 1 to 5 cycles of the supply frequency.

3-2 Thiristor Switched Capacitor:-

A thiristor switched capacitor scheme consists a capacitor bank split up into appropriately sized units, each of which switched on and off by using thiristor switches. Each single phase unit consists of a capacitor c in series with a bidirectional thiristor switch and small inductor L. The inductor is to limit switching transients, to damp inrush current and to prevent resonance with network. The three phase system can be obtained by connecting three single-phase of TSCs in delta connection. The switching of capacitors excise transients which may be small or large according to the resonant frequency of the capacitors with the external system. This can be minimized by selecting the switching instant when the voltage across the thyristor switch to be at minimum, ideally zero. The suceptance control principle used by TSC is known as integral cycle control, the susceptance is switched in for an integral number of exact half cycles. The susceptance is divided into several parallel units, and it is varied by controlling the number of units in conduction. A change can be made every half cycle.

3-3 Mechanically Switched Capacitor (MSC):-

MSC scheme consists of one or more capacitor units connected to the power system by a circuit-breaker. A small reactor might be connected in series with capacitor to damp energizing transients and reduce harmonics. The response time is equal to the switching time of the circuit-breaker arrangement which is about 100 ms.

4- Practical Static Var System:-

A static var compensation scheme with any desired control range can be formed by using the above described elements. The required response speed, size range, losses, flexibility and cost are among the consideration in selecting the configuration for any particular application. All most SVS scheme, consisting of a TCR, units of TSC and harmonic filters is used. The filters are connected in shunt to eliminate the harmonics which are caused due to thyristor operation. Filters for 5th and 7th harmonics are always provided.

5- Control System for SVS:-

Reactive power compensation using SVS is achieved by controlling phase angle of thyiristor valves of TSC and TCR. The bus voltage and current flowing into compensator are both sensed by means of voltage transformers (VT) and current transformers (CT).Both these values are fed to the automatic voltage regulator (AVR) and SVS which they perform the following tasks:-

- Sending a command to switched capacitor banks for voltage control.
- Controlling the phase of triggering of thyristor in SVS.

SVS control is integrated with sub-station, SCADA system and system status processor.

The total control system incorporates a status processor and cathode ray tube (CRT) display. The primary functions of the status processor are the monitoring of the control circuits in operation for any alarm or trip conditions and the execution of control commands and adjustments of operating parameters by the operator. The status processor also includes diagnostic software routines accessible via CRT terminal on the SVS control panel.

6- Optimal Allocation of SVS :-

Many methods can be used for SVS allocation such as voltage level performance index (VLPI) method, voltage deviation (VD) method and mean load bus voltage increase method. In this paper VD method is discussed, VD is defined as follows :-

$$VD = \frac{\sum_{i=1}^{N} \left| V_i^* - V_i \right|}{N} \qquad (6\text{-}1)$$

Where:

VD : is the average voltage deviation.

Vi : is the actual voltage at bus i in per unit.

Vi* : is the desired voltage at bus i in per unit.

N : is number of buses [9].

Allocation of SVS using VD method can be done in the following steps:-

- Add reactive power source with constant MVAr at one of system load buses.
- Perform load flow analysis and calculate VD using equation (6-1).
- Repeat the above two steps for all load buses.
- Make a list of VD with the location of the reactive power source.
- Rank the buses according to values of VD beginning with the smallest value. The decrease of VD due to specified allocation gives an indication of the effectiveness of compensation at that point [10].

7- Application to the Case Study:-

SVCs are applied to NGS system with 77- bus and 91 transmission lines and transformers which suffers from high voltage drop recently after addition of Merowe Damp plant (MDP) to the system. This because the system largely depends on MDP in supplying the total connected load, and this let it appears as semi-radial. VD method has been used for optimal SVS allocation during heavy load. The system description for case study is given in table (1).

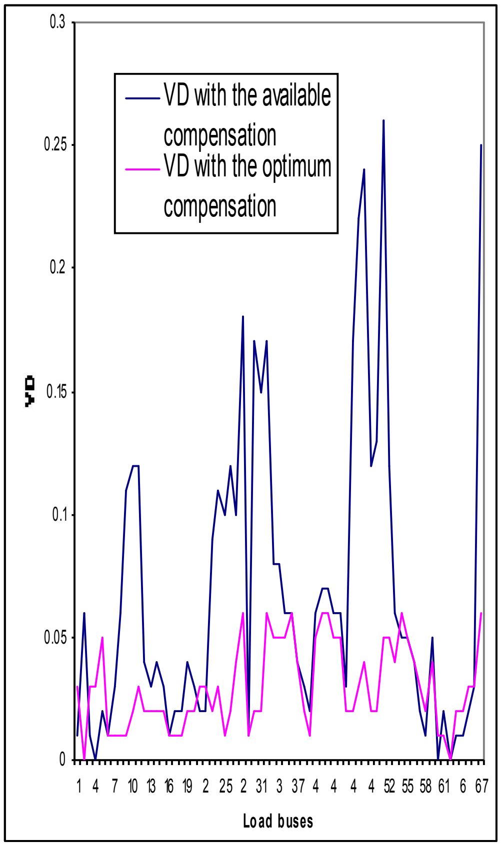

Figure (1); VD with the available, and optimal compensation in NGS

Table (1), system description

Variables	77- bus system
Buses	77
Branches	91
Generators	10
Generators buses	9

Figure (1) shows the voltage deviation at each bus with the available compensation and the optimal compensation.

Conclusion:-

SVS acts within a few seconds and provide a fast voltage control and improves voltage stability, and this is the greatest advantages for SVS compared with the other methods of voltage control. Never the less SVS is capable of controlling individual phase voltages of the buses to which they are connected, therefore it can be used for negative and positive sequences voltages control. These advantages and others make SVS a more suitable method in many applications of voltage control, such as voltage regulation of transmission systems, fast accurate voltage control of sub-stations control of over-voltage in transmission systems which is caused due to load rejection, improving of transient stability of power systems by controlling the sending and receiving voltages as well as rotor angle and dynamic compensation for lamp flickers and voltage dips. Figure (1) shows that the voltage profile is improved after applying the optimum compensation. The VD at all load buses is not more than 6 %, which is the permissible value for voltage drop and rise.

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