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Enhancement of Voltage Stability of Transmission System Using Series Capacitor and Static VAR Compensator through Matlab Programming

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Abstract: - Today, The power system becomes more complicated and large, just to ensure enough energy for all activities. Due to this complexity, the power engineers would face problems like power system stability and power quality, among others. The Reactive power compensation plays an important role in the planning of a power system. This ensures a satisfactory voltage profile and a reduction in power and energy losses within the system. Reactive power also maximizes the real power transmission capability of transmission lines, while minimizing the cost of compensation. The transmission capacity can be increased by using certain compensation devices. Series capacitor and static VAR compensators can contribute to power systems voltage stabilities. Combining these two methods is the subject of this paper. Effect of the presence of series capacitor on static VAR compensator controller parameters and ratings required to stabilize load voltages at certain values are highlighted. Static VAR compensator rating and controller references and gains are found in order to stabilize load voltage at certain specified values. Interrelation between these two means parameters are highlighted. The focus of this paper is on the application of Static VAR Compensator with series capacitor to solve voltage regulation and power transfer capabilities.

Index Terms— **Static VAR compensator (SVC), thyristor controlled reactor (TCR), automatic voltage regulator (AVR), voltage regulation, MATLAB.**

I. INTRODUCTION

SVC is a mature thyristor based controller that provides rapid voltage control to support electric power transmission voltages during and immediately after major system disturbances. Since the advent of deregulation and the separation of generation and transmission systems in the electric power industry, voltage stability and reactive power-related system restrictions have become an increasingly growing concern for electric utilities.

With deregulation came an “open access” rule to accommodate competition that requires utilities to accept generation and load sources at any location in the existing transmission system. This “open access” structure has challenged transmission owners to continually maintain system security, while at the same time trying to minimize costly power flow congestion in transmission corridors. When voltage security or congestion problems are observed during the planning study process, cost effective solutions must be considered for such problems [5].

Traditional solutions to congestion and voltage security problems were to install new costly transmission lines that are often faced with public resistance, or mechanically-switched capacitor banks that have limited benefits for dynamic performance due to switching time and frequency. One approach to solving this problem is the application of “Flexible AC transmission System” (FACTS) technologies, such as the Static VAR Compensator (SVC). FACTS technologies are founded on the rapid control response of thyristor-based reactive power controls.

The increase of real power transmission in a particular system is restricted by a certain critical voltage level. This critical voltage is dependent on the reactive power support available in the system. Use of series and shunt compensation is one of the corrective measures to produce an acceptable voltage profile, minimize the loss of the investments and enhance the power transmission capability.

II. SINGLE LOAD INFINITE BUS SYSTEM

The characteristics of voltage stability are illustrated by an infinite-bus system. In Figure1, infinite bus has constant voltage, E. The load is assumed have constant power factor. The line impedance is Z=R+ j X.

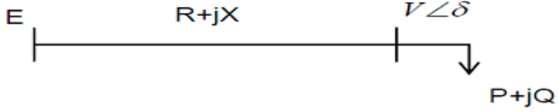

Fig 1 Single load, infinite-bus system

The purpose is to calculate the load voltage V with different values of load. The voltage is calculated by solving the load flow equation:

$$\underline{V}^{*}.\ (\underline{E}-\underline{V})/\underline{Z}=\underline{S}^{*} \qquad 1$$

Where, E is the voltage at the infinite bus, E = E
V is the voltage at the load, V = V∟δ
S is the load power demand, S = P+ j Q
Z is the line impedance, Z = R+ j X
Solving equation 1 for the load voltage by eliminating the voltage angle, if assuming lossless line, or R=0 it is obtained as follows:

$$V=\sqrt{\frac{E^2}{2}-QX\pm\sqrt{\frac{E^2}{4}-X^2P^2-XE^2Q}}$$

The solutions of load voltages are often presented as a PV-curve as show in figure 2.

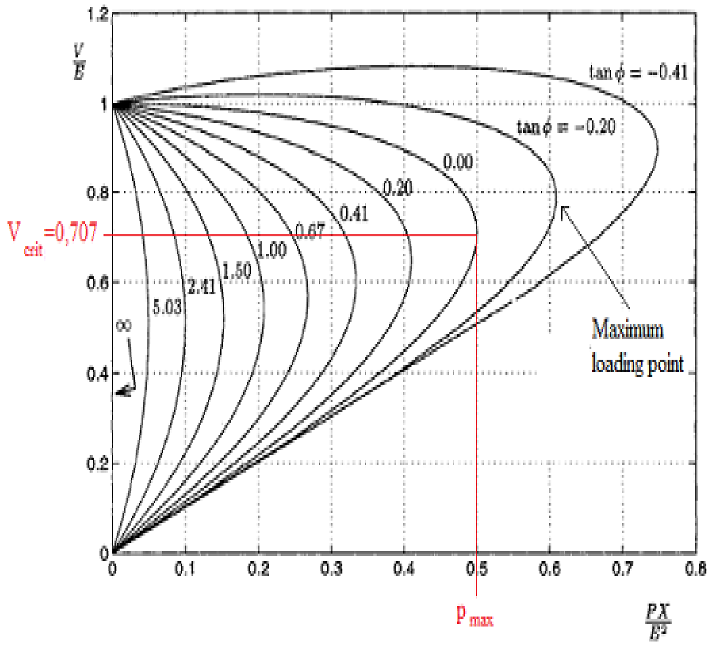

Fig 2 Normalized PV-curves for different power factor

The PV curve presents load voltage as a function of load or a sum of loads. Power systems are operated in the upper part of the PV curve. This part of the PV curve is statically and dynamically stable. The head of the curve is called maximum loading point. The critical point is called the voltage collapse point. The maximum loading point is more interesting from the practical point of view than the true voltage collapse point, because the maximum of power system loading is achieved at this point. The maximum loading point is the voltage collapse when constant power loads are considered, but in general they are different. The voltage dependence of loads affects the voltage collapse point. Voltages decrease rapidly due to requirement for an infinite amount of reactive power. The power system becomes unstable at the voltage collapse point. Power flow programs can only compute the upper part of the curve up to voltage collapse point, because at the lower part of the curve they cannot find a solution. The iteration process is divergent below the voltage collapse point. Thus the whole computation in this project will be finished at voltage collapse point.

As the load is more and more compensated, which corresponds to smaller tanφ, maximum power increases and voltage increases as well. This situation is dangerous, because the maximum transfer capability may be reached at voltages close to normal operation values. For overcompensated loads tanφ < 0, there is a portion of the upper PV curve along which the voltage increases with the load power. Fig. 2 presents PV curves for the system. These curves represent different load compensation cases (tanφ =Q/P). Since inductive line losses make it inefficient to supply a large amount of reactive power over long transmission lines, the reactive power loads must be supported locally. According to Figure 2 addition of the load compensation (decrement of the value of tanφ) is beneficial for the power system. The load compensation makes it possible to increase the loading of the power system according to voltage stability [13-15].

Thus, the monitoring of power system security becomes more complicated because critical voltage might be close to voltages of normal operation range .The opportunity to increase power system loading by load and line compensation is valuable nowadays. Compensation investments are usually less expensive and more environmental friendly than line investments. Furthermore, construction of new line has become time-consuming if not even impossible in some cases. At the same time new generation plants are being constructed farther away from loads centers, fossil-fired power plants are being shut down in the cities and more electricity is being exported and imported. This trend inevitably requires addition of transmission capacity in the long run.

III. STUDIED SYSTEMS

A large Power System which feeds a certain load or power (P+ jQ) through a variable SC is used in this study. The system, at steady-state conditions can be represented by its Thevenin's equivalent seen from node 5 as shown in Fig. 3

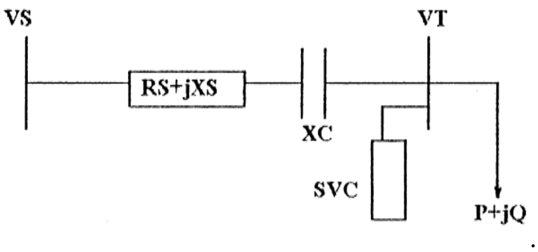

Fig.3 Thevenin's equivalent system shows the load node terminals.

$$\Delta V = |V_S|-|V_T| = \frac{((X_S - X_C)Q + R_S P)}{V_T}$$

Power System Model with Series Capacitor and Static VAR Compensator

A thyristor-control reactor /fixed capacitor (TCR/FC) type is used. Its control system consists of a measuring circuit for measuring its terminal voltage V_T, a regulator with reference voltage and a firing circuit which generates gating pulses in order to command variable thyristor current I_L, through the fixed reactor reactance X_L. This variable current draws variable reactive power (which corresponds to variable virtual reactance of susceptance B_L given by:

$$V_T^2 B_C = I_L^2 X_L$$

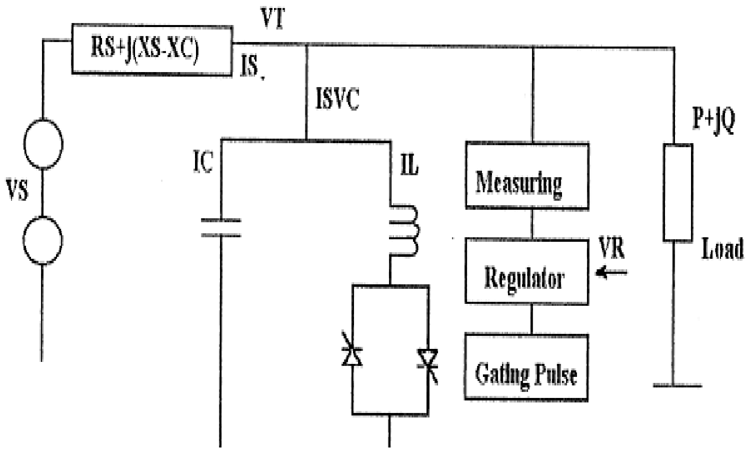

Fig. 4 Static VAR compensator and power system block diagram.

Together with the fixed capacitive reactive power, these from the variable inductive and capacitive reactive power of that static compensator. Fig. 4 shows a block diagram of that compensator when connected to a large Power system [13].

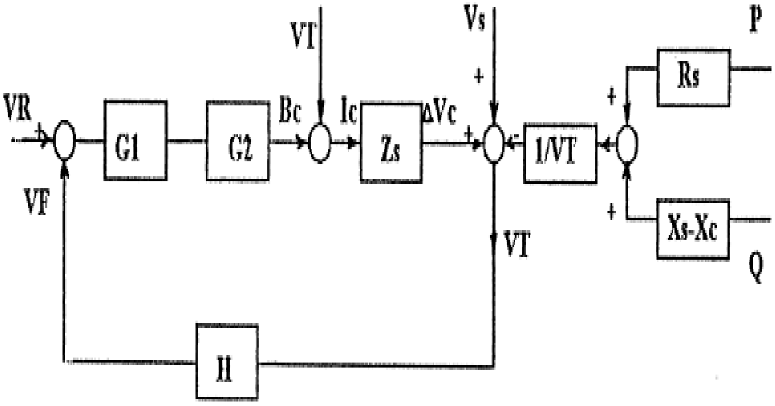

Fig 5 Block diagram of a loaded power system, series capacitor and SVC

Fig. 5 shows the transfer function of the power system provided by the series capacitor and a static VAR compensator.

IV. SYTSTEM EQUATIONS

The controller is usually of the proportional element (1/slop) with certain delay T_1, followed by a controller compensator circuit of the form:

$$G_1 = \frac{\left(\frac{1}{slop}\right)(1+T_2S)}{(1+T_1S)(1+T_3S)}$$

The slop is regulator droop slope equals to $\Delta V_c / \Delta I_{max}$ Volt/ampere. T_1 is a delay time. T_2 and T_3 are the time constants of regulator compensation circuits. The controller output is fed to the firing circuit which may be completely defined by a transfer function, consists of a gain K_d(nearly unity) and a time delay T_d as :

$$G_2 = K_d\, e^{-sT_d} \simeq \frac{K_d}{(1+T_d s)}$$

The limiter refers to the limits of the virtual compensator variable susceptance „Bc.

The measuring circuit forms the feedback link and can be represented by a gain K_H equal nearly unity and a time delay T_H as:

$$H = K_H e^{-sT_H} \simeq \frac{K_H}{(1+T_H S)}$$

T_H of the order of 20-50 ms, While T_H is usually from 8 – 16 ms. K_H usually takes a value around 1.0 p.u,T_2 and T_3 are determined by the regulator designed for each studied system, as they are function in system parameter[11].

Solving block diagram of a loaded power system, series capacitor and SVC. Multiplication of B by V_T yields the SVC current following in the series link (I_S), which is given by:

$$I_S = BV_T$$

The power system which is provided by a series capacitor at the load inlet can be represented by its Thevenin's voltage V_S, system and capacitor reactance $R_S + j\,(X_S - X_C)$.

The load voltage drop to system equivalent series impedance and through the series capacitance link is given by:

$$\Delta V = |V_S| - |V_T| = \frac{((X_S - X_C)Q + R_S P)}{V_T}$$

Where V_T is the load node and SVC terminal voltage and S is the laplace operator, which vanishes in steady-state condition. Defining

$$B_c = G_1G_2(V_R - V_TH)$$

And

$$G = G_1G_2V_T$$

The compensator current I_S is given by:

$$I_S=G\,(V_R-V_TH)$$

And the SVC control system feedback voltage is given by:

$$\Delta V_c=I_sZ_S= G\,(V_R-V_TH)\,Z_S$$

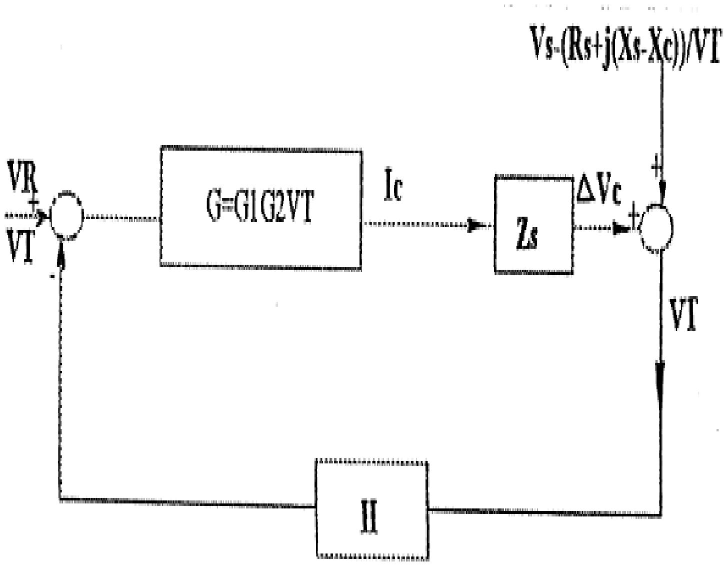

Fig.6 Simplified transfer function block diagram of a loaded power system, series capacitor and SVC

Therefore the load terminal voltage is given by:

$$V_{T\,1} = G\,(V_R-V_TH) + \left(V_S- \frac{R_S}{V_T}P - \frac{(X_S-X_C)Q}{V_T}\right)$$

From which

$$V_T^{\,2}\,(1+GHZ_s)-V_T\,(V_S+GZ_sV_R) +(R_sP+(X_s-X_c)Q)=0$$

On solving the equation

$$V_{T\,1} = \frac{(V_S+GZ_SV_R)+\sqrt{(V_S+GZ_SV_R)^2-4(1+GHZ_S)(R_SP+(X_S-X_C)Q)}}{2(1+GHZ_S)}$$

$$V_{T\,2} = \frac{(V_S+GZ_SV_R)-\sqrt{(V_S+GZ_SV_R)^2-4(1+GHZ_S)(R_SP+(X_S-X_C)Q)}}{2(1+GHZ_S)}$$

V. SYSTEM DATA

Having used the system under study with the mentioned data:

V_S= 1.004 p.u.,
X_S= 0.3125 p.u.,
V_R= 1 p.u.,
H = 1 p.u.,
R_S= 0.08126 p.u.,
Z_S= 0.3228 p.u.

The load reactive power is assumed to be kept constant at Q = 0.18 p.u. In order to kept the terminal voltage constant at V_T= 0.8 p.u up to 1.05 p.u for different System power P[13].

POWER VERSUS VOLTAGE (P-V) CURVE WITH THE PRESENCE OF SERIES CAPACITOR AND STATIC VAR COMPENSATOR

The famous curve of the Voltage/Power relation is plotted. Having a load of constant power factor, the voltage is plotted against the load VA power, in the presence of different SC compensation percentages (0 , 25 , 50 , 75 , 90%) in Fig. 7

CASE1: When G= 0.0 (I.E. Without Compensator Action)

…..0% …..25% …..50%…..75%…..90%

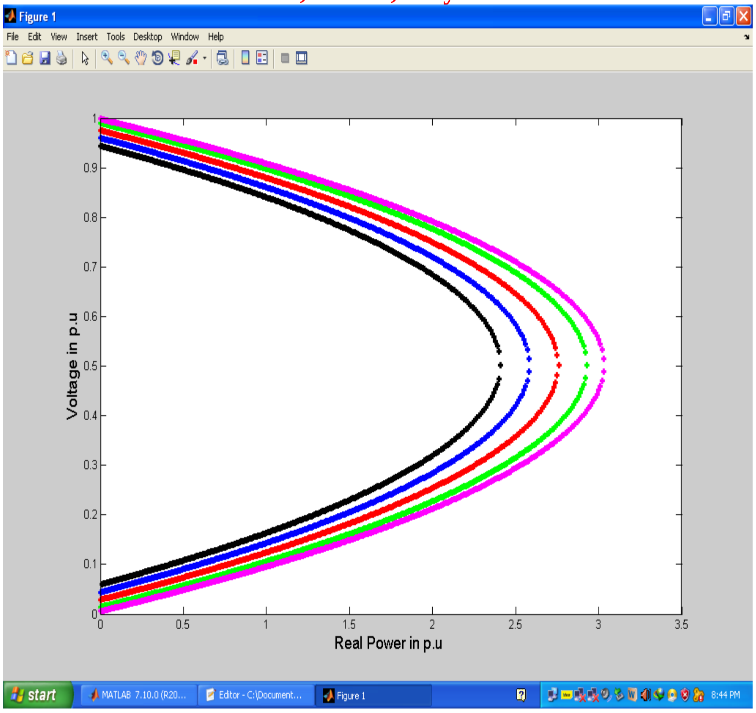

Fig. 7 Voltage/Power response with different series compensation (0-90%), with constant Q and with G = 0

CASE 2: When Varying G and Xc=0.0781 (25% Series Compensation)
…..G=0.0……G=0.5…..G=1.0…..G=1.5…..G=2.0

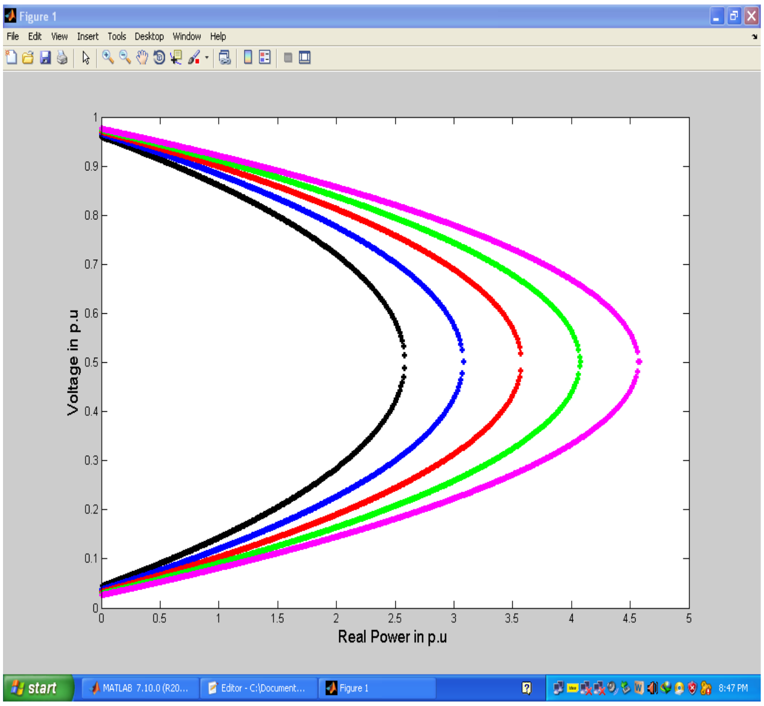

Fig. 8 Voltage/Power response with different SVC gains (0.0-2.5), with constant Q and with XC= 0.0781

As we can see in these plots that by the use of Capacitor in the circuit, the peak-load voltage can be increased by increasing the series compensation. The figure 8 shows that maximum possible critical power increases with the increase of SC series compensation percentage. For example it becomes 125% at 90% compensation and 120% at 75% , 110% at 50% and 105% at 25% compensation .It is noticed that the critical voltage value is constant at 0.5 p.u. at all series compensation percentages . This is due to the fact that the critical voltage is independent of the value of system series reactance X_S. Table -1, however shows the maximum load power corresponding to various values of SVC controller gains. Therefore, at a gain of 1.0 the maximum transmitted power can be increased to 140% and a gain of 2.0 can increase it by 180% of its value without static VAR compensator. This is important result illustrates the limited effects of the series capacitor compared to the static VAR compensator, significant effects, at different controller gains.

TABLE-1: MAXIMUM LOAD POWER AS AFFECTED BY COMPENSATOR CONTROLLER GAINS WITH 25% SERIES COMPENSATION

Compensator gain(G)	Approximate Maximum Power
0.0	2.58
0.7	3.33
1.2	3.78
2.0	4.58

VI. CONCLUSION

Series Capacitor can enhance steady-state voltage stabilities by decreasing the effective series reactance of systems and increasing the load node short-circuits levels. Certain compensation percentages should be avoided while other percentages are recommended. Presence of Static VAR Compensator with different controller gains can Increase the maximum load powers several times its original value without Static VAR Compensator.

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