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Enhancement of Voltage Stabilityin A Power System Using Static Var System

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Abstract

This paper proposes a simple and direct method of determining the steady state voltage stability limit of a series compensated power system when equipped with a static var compensator (SVC). The maximum permissible loading of a particular bus in a power system is determined through a simplified equivalent model of the original system. The method is very efficient and does not require repetitive load flow simulations to generate the system P-V or Q-V curve. The effectiveness of the proposed method is then tested on a simple 2-bus series compensated power system . The effects of load power factor and SVC rating and degree of series compensation in the line on voltage stability limit are also studied. Also effect of SVC rating, load power factor and degree of compensation on critical voltage is studied in detail.

Keywords: Voltage stability, SVC, FACTS, degree of series compensation.

1. Introduction

Power utilities are now forced to increase the utilization of existing transmission facilities to meet the growing demand without constructing new lines that are not only expensive but also environmentally unfriendly. The loading of a transmission network can be increased by maintaining proper voltage profile through injecting appropriate reactive power into the system. One of the major problems that may associate with such a stressed system is the voltage instability or collapse. Many incidents of system blackout due to voltage collapse have been reported worldwide [l]. Determination of steady state voltage stability limit is thus very important in order to operate the system with an adequate stability margin.

Voltage stability can be considered as a steady state "viability" problem and thus can be accessed through steady state analysis like load flow simulations [l]. When a system approaches the voltage collapse point, the voltage magnitude of some critical buses decreases rapidly with the increase of load. In fact, the voltage stability problem is associated with reactive power and can be solved by providing adequate reactive power support to the critical buses. Usually fixed switched capacitor banks are used to support the voltage by injecting reactive power. The control of reactive power of a switched capacitor bank is usually discrete in nature. Recent trend is to replace the switched capacitor banks by SVC to have a smooth control on reactive power. SVC has the capability of supplying dynamically adjustable reactive power within the upper and lower limits [2]. In the normal operating region, a SVC adjusts its reactive power output to maintain the desired voltage. For such an operation, the SVC can be modelled by a variable shunt susceptance. On the other hand, when the operation of the SVC reaches the limit, it cannot adjust the reactive power anymore and thus can be modelled by a fixed shunt susceptance. Several methods of assessing the steady state voltage stability limit are reported in the literature. Reference [3] considered the minimum singular value of the load flow Jacobian matrix as an index to measure the voltage stability limit. The difference between the higher and lower voltage solutions of load flow studies can also be considered as a voltage stability index [4]. Energy method [5, 6] and bifurcation theory [7] are also used by some researchers to determine the voltage stability limit. However, most of the researchers used the conventional P- V or Q- V curve as a tool to assess the voltage stability limit of a power system [1, 8]. Both P-V and Q-V curves are usually generated from the results of repetitive load flow simulations under modified initial conditions. Once the curves are generated, the voltage stability limit can easily be determined from the "noise point" of the curve. The process of generating the curves is very time consuming, especially for a large system. However, the computational time can significantly be reduced if the nose point can directly be determined without practically generating the curves. Direct determination of the nose point is possible if the power system can faithfully be represented by an equivalent 2-bus system. Many researchers [9-12] used such an equivalent model to assess the voltage stability of a power system by various methods. This paper proposes a simple and direct method of determining the maximum loading, within the voltage stability limit, of 2- bus power system when equipped with a series capacitor at the centre of line and SVC of finite reactive power rating at the load end. The maximum loading or nose point of the P-V curve is determined through a 2-bus equivalent of the system without practically generating the curve. The effects of load power factor ,degree of series compensation and reactive power rating of the SVC on voltage stability limit are also studied. Effect of load power factor angle, degree of series compensation and SVC rating on critical voltage is also studied in detail

2. Determination of steady state voltage stability limit

This Section describes the technique of directly determining the voltage stability limit or noise point of the P-V curve of a simple 2-bus system of Fig 1. Data for the system is given in appendix .The system transfers power from a generating station to a load centre through a transmission line which is series compensated at the centre. A SVC of finite reactive power rating is also placed at the load end.

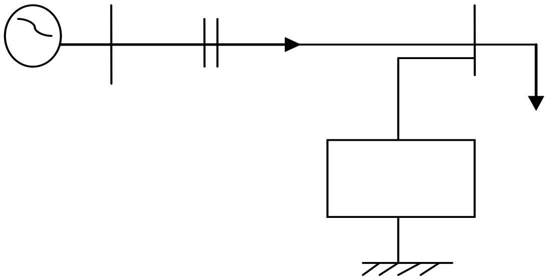

Fig1. Single line diagram of a simple series compensated 2 –bus system

The SVC is usually connected through a step down transformer as shown in Fig2. It consists of a fixed capacitor C and a thyristor controlled inductor L. The reactive power of the SVC can be adjusted by controlling the firing angle of the thyristor. When the load increases, receiving end voltage of the line and the SVC injects capacitive reactive power to boost the voltage. However , when the operation of the SVC hits the upper limit, it cannot adjust the reactive power anymore to maintain the desired voltage. Thus the load voltage decreases with further increase in load and the ultimate result is voltage collapse. It may be mentioned here that the voltage collapse may not occur until the operation of the SVC reaches the upper limit. For such an operation, the SVC can be represented by a fixed capacitive susceptance Bc.The feasible solutions (real and positive) can be used to generate the p-v curve of the system. At typical P-V curve of the system (with Bc=0), for a constant load power factor .Points ‘a ‘and ‘e’, represent the open circuit and short circuit conditions respectively and point ‘c’ represents the critical point or noise point of the P-V curve. The voltage and power at the nose point are called the critical voltage (Vcr) and the critical apparent power (Scr) respectively.

For any load beyond Scr, there is no feasible solution of load voltage magnitude and thus the corresponding operation in not possible. However, for any load S (Scr) there are two feasible solutions of load voltage magnitude and are represented by points ‘b’ and ‘d’.Point ‘b’ is called the stable or high voltage solution and point ‘d’ is called the unstable or low voltage solution. For a given load power factor angle can be expressed by a second order polynomial can be considered as the critical load apparent power Scr at the noise point of the P-V curve. Note that the value of Scr depends on the load power factor.

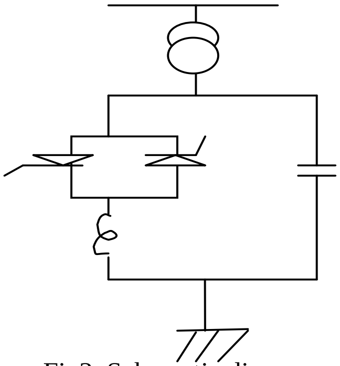

Fig2. Schematic diagram of a SVC

3. Determination of critical apparent power of a series compensated power system

For determining the steady state voltage stability limit of a simple system, transmission line is series compensated and load bus is equipped with a SVC of finite reactive power. Data of the system is given in the appendix. The results obtained by the proposed method in the series compensated 2-bus system are briefly described in the following sections for two different cases.

CASE 1: When series compensation(s) is zero SVC rating is varied

The critical value of load apparent power of the system is determined for various values of load power factor and capacitive susceptence Bc of the SVC.It can be observed that the value of Scr increases as the value of Bc, of the SVC is increased.At unity power factor,the value of Scr,without a SVC(or Bc=0),is found as 485 MVA and it increases to 657 MVA for Bc=2.5pu.

TABLE1

Critical load apparent power (MVA) of the system for different values of SVC rating (Bc)and load power factor.(s=0.0)

LOAD POWER FACTOR				
Bc,p.u.	**1.0**	**0.9lag**	**0.9 lag**	**0.85 lag**
0.0	485	352	320	302
1.0	542	395	360	340
1.5	576	421	384	363
2.0	614	450	412	389
2.5	657	484	443	419

It can also be observed that, for a given Bc the value of Scr, decreases as the lagging power factor angle of the load is increased. For Bc=25 pu,the value of Scr , decreases from 657MVA (at unity power factor)to 419 MVA(at 0.7 power factor).Table 1 summarizes the simulation results of the system for various values of Bc and load power factor.

CASE 2. When SVC is fixed at Bc=2.5 pu and series compensation(s) in the line is varied

The critical value of load apparent power of the systems is determined for various values of load power factor and series compensation(s)of the transmission line when SVC rating is kept at maximum i,e,(Bc=2.5 pu). The variation of Scr against the power factor angle for different values of series compensation(s).The value of Scr, increases as the value of series compensation(s) is increased. At the unity power factor, the value of Scr, without compensation (%s=0.0), is found as 657 MVA and it increases to 1280 MVA for series compensations=0.6.It can also be observed that, for a given series compensation the value of Scr, decreases as the lagging power factor angle of the load is increased.

TABLE 2

LOAD POWER FACTOR				
S	**1.0**	**0.9lag**	**0.8 lag**	**0.7 lag**
0.0	657	484	443	419
0.2	780	587	520	500
0.4	980	700	640	600
0.6	1280	950	870	800

Critical load apparent power Scr(MVA)of the system for different values of series

For s=0.6, the value of Scr , decreases from 1280 MVA(at unity power factor) to 800 MVA(at 0.7 power factor).Table 2 summarizes the results of the system for various values of series compensation(s)and load power factor.

4. Determination of critical voltage of power system

CASE 1: when series compensation(s) is zero and SVC rating is varied

The critical voltage (Vcr) of the system of Fig.1 is determined for various values of load power factor and capacitive susceptance (Bc) of the SVC. It can be observed that the value of Vcr , increases as the value of Bc, of the SVC is increased. At unity power factor, the value of Vcr without a SVC (or Bc=0), is found as 0.755 pu and it increases to 1.044 pu for Bc=2.5 pu. It can also be observed that, for a given Bc the value of Vcr, decreases as the lagging power factor angle of the load is increased. For Bc=2.5 pu, the value of Vcr, decreases from 1.044 pu(at unity power factor) to 0.875 pu(at 0.7 power factor). Table 3 summarizes the results of the system for various values of Bc and load power factor.

TABLE 3

Critical load voltage (Vcr) of the system for different values of SVC rating (Bc) and load power factor (s=0.0)

LOAD POWER FACTOR				
S	**1.0**	**0.95lag**	**0.9 lag**	**0.85 lag**
0.0	0.755	0.67	0.645	0.625
1.0	0.85	0.758	0.73	0.71
1.5	0.91	0.81	0.771	0.750
2.0	0.975	0.87	0.838	0.81
2.5	1.044	0.93	0.895	0.875

CASE 2: When SVC rating is fixed at Bc = 2.5p.u. And series compensation(s) in the line is varied.

The critical voltage (Vcr) of the system of fig.1 is determined for various values of load power factor and series compensation(s) of the transmission line when SVC rating is kept maximum.i.e. (Bsc)=2.5p.u

Critical load voltage (Vcr) of the system for different values of series compensation(s) and load power factor when Bc=2.5

TABLE: 4

LOAD POWER FACTOR				
S	**1.0**	**0.95lag**	**0.9 lag**	**0.85 lag**
0.0	1.044	0.930	0.895	0.875
0.2	0.985	0.872	0.844	0.817
0.4	0.920	0.815	0.776	0.756
0.6	0.845	0.740	0.720	0.708
0.8	0.730	0.665	0.642	0.630

It can be observed that the value of Vcr, decreases as the value of series compensation(s) is increased. At unity power factor, the value of Vcr, without compensation(s=0.0), is found as 1.044 p.u. and it decreases to 0.845 p.u. for series compensation(s= 0.6). It can also be observed that for a given series compensation the value of Vcr,decreasess as the lagging power factor angle of the load is increased.

For s=0.6, the value of Vcr, decreases from 0.845 p.u.(at unity power factor) to 0.708 p.u.(at 0.7 power factor). Table 4 summarizes the simulation results of the system. So it can be interpreted that both SVC and series compensation in the line increases steady state limit of power factor i.e. both increases critical apparent power (Scr). Critical voltage of system decreases when series compensation in the line is increased but increases when SVC rating is increased.

5. Conclusion

In this paper SVC is used to support voltage in a simple series compensated 2-bus system. SVC has the capability of improving the steady state voltage stability limit. A very simple and direct method of determining the steady voltage stability limit is described without practically generating the P-V curve of the system. The effects of the SVC rating, degree of series compensation and load power factor on the voltage stability limit are also studied in details. It is found that critical apparent power of 2-bus system increases with increase in SVC rating and degree of series compensation. It is also observed that with increase in SVC rating critical voltage of load bus increases whereas with increase in degree of compensation, critical voltage decreases. It is also found out that leading power factor angle increases both critical apparent power and critical voltage whereas lagging power factor angle decreases both.

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7. Appendix

Data of 2-Bus system
Transmission line: 345 kV, 450 Km long
Series impedance (0.02986+j0.2849)/KM
Shunt admittance: j3.989*10^-6 S/KM
Base quantities: 100MVA, 345 kV
Sending end voltage magnitude; 1.0 pu