A new algorithm to enhance power transfer using series capacitor

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ABSTRACT

The compensation of transmission line reactance by means of series compensation is an effective method increasing the power transfer capacity and thereby improving the transient stability of the power system. This paper presents a novel series compensation method to increase the power capacity of the system. The proposed method is applied to a 9-bus power system.

Keywords: *Power system transfer capacity, series compensation, transient stability*

1 INTRODUCTION

Earlier power system control was concentrated to the generation and economic operation but with the increased emphasis on the stability a new dimension in operation of power system has been added which is much broader in scope of system monitoring and control (Sinha *et al.* 1994). The transient stability is the inherent ability of power system to recover normal operation following sudden and/or severe disturbance such as faults (Chakrabarti *et al.* 1998; Sauer and Pai 1998). With a given disturbance, there is a definite upper limit of the load, which the power system can transfer without losing stability. This load can be defined as transient stability limit of the system for the given conditions (Sauer and Pai 1998; Kimbark 1948, 1950, 1956). Similar to the transient stability limit there are other limits of the systems such as steady state stability limit, thermal limit, etc. but among these transient stability limit is the lowest and therefore it governs the power transfer capability of the system. The power transfer capability, due to transient stability, should be as high as possible to fully utilize the transmission system. Series compensation is a powerful tool to increase power transfer capability (Nagrath and Kothari 1995; Rajaraman *et al.* 1998, Moghavvemi *et al.* 1999; Kundur 1994; Padiyar 1990; Byerly *et al.* 1974; Pai 1981; Fouad and Vittal 1992; Kimbark 1969).

In this paper a method to identify location and amount of series compensation to increase power transfer capability of power systems is developed. The proposed method is applied to a typical 9-bus power system and results are presented.

2 POWER TRANSFER CAPABILITY ENHANCEMENT BY SERIES COMPENSATION

The power system is never static and the system loads change continually. In a load cycle the loads at all buses may increase or decrease by same or different proportions. The power flows through transmission lines and hence the transient stability depends on the total system load and its distribution. With all possible distributions of the load, there is always a particular maximum system load below which the system is stable. This system load limit may be termed as power transfer capability. This can be obtained by identifying minimum system load for which the system becomes unstable.

Use of series compensation in suitable transmission line(s) can increase the power transfer capability of a power system. Since the stability of a system depends on the power flows through the transmission lines, therefore, the location(s) of series capacitor in the system to increase power transfer capability should depend on the power flows through the different transmission lines. The power flow through a transmission line is given by

$$P = \frac{|V_s||V_R|}{X}\sin\delta \qquad (1)$$

where:

P = Power flow through transmission line.
Vs = Sending end voltage.
V_R = Receiving end voltage.
δ = Difference of phase angle of V_s and V_r
X = Net series reactance of transmission line.

It is known that a lower angle δ means better system stability and conversely, a higher angle δ means poor system stability. Therefore the system stability and hence power transfer capability of the system can be enhanced by lowering angle δ. This can be achieved with the help of series compensation because series compensation reduces net series reactance X and from (1) it may be seen that a reduction in X may result in reduction in δ (Sauer and Pai 1998; Byerly *et al.* 1974). This clearly indicates that the proper location of series capacitor in the line, which has highest angle δ. It may happen that the fault is in the same line in which angle δ is highest. In such a case the compensated line does not transfer power during fault period and if fault is removed by opening the line then the line does not transfer power during post fault period. Therefore, in such a case transmission line does not carry any power during transient period and series compensation in this line is not going to increase power transfer capability of the system. In such a case the series compensation may be provided on the line out of the remaining lines, which has next highest value of δ.

3 PROPOSED METHOD

The proposed method to obtain optimal location and amount of series compensation to increase power transfer capability of the system is comprised of following steps:

(i) Input all possible set of system loads on the basis of load cycle/load curves one by one. For each set of load perform economic dispatch, load flow and transient stability calculations to determine stability.
(ii) Calculate power transfer capability of the system.
(iii) Identify the set of loads, which limit the power transfer capability of the system. For the set of loads perform a load flow study. From the load flow result calculate the difference in phase angles of voltages across each line. Identify the line having maximum difference in phase angles of voltages across it. If the fault is on this line then select this line for series compensation, which has next highest value of difference in phase angles of voltages across it among the remaining lines.
(iv) Apply series compensation up to 60% (or more if required) in suitable steps in the line selected for series compensation in step-3. From practical point of view, it is not desirable to exceed series compensation beyond 80%. If the line is 100% compensated, it will behave as a purely resistive element and would cause series resonance even at fundamental frequency (Kothari and Nagrath 2003). For each compensation recalculate the power transfer capability of the system by repeating steps 1 and 2. Select amount of series compensation, which increases the power transfer capability by the required amount. Flow chart of the proposed method is shown in Figure 1.

4 APPLICATION OF SERIES COMPENSATION TO INCREASE POWER TRANSFER CAPABILITY

A 9 bus, 230 kV power system (Arora 1991; Anderson and Faud 1997) is chosen to illustrate the application of series compensation to increase power transfer capability by the proposed method. Figure 2. depicts a single-line diagram of this system.

The various constraints on the system under study are as follows:

$0.0 \leq PG_1 \leq 247.5$
$0.0 \leq PG_2 \leq 192.0$
$0.0 \leq PG_3 \leq 128.0$
$-999.0 \leq QG_1 \leq 999.0$
$-999.0 \leq QG_2 \leq 999.0$
$-999.0 \leq QG_3 \leq 999.0$

Where PG_i are in MW and QG_i are in MVAR. The details of the disturbance are given in Table 1.

Table 1. Disturbance nature

Type of the disturbance	Duration of the disturbance
Three phase short circuit on transmission line connecting buses 5 and 7, near bus 7. The fault is cleared by opening of the line at both ends	200 milliseconds.

Six hundred different load samples are generated for loads A, B and C according to given means and covariance of loads using the method available in (Arora 1991). The power transfer capability of the system is calculated using the proposed method described earlier. From the load flow results the difference in phase angles of voltages across each line obtained are given in Table 2.

Table 2. Difference in the phase angles of voltages for various transmission lines

Line connecting buses	Difference in phase angles of voltages, δ in degrees
7 - 8	3.265
8 - 9	1.660
6 - 9	4.855
4 - 6	2.582
4 - 5	3.071
5 - 7	6.949

From Table 2, it is observed that the maximum δ occurs for line 5 - 7. The fault is on line 5 - 7 and to clear the fault this line is opened. Therefore series compensation on this line may not increase the power transfer capability. The next highest value of δ for remaining lines occurs at line 6 - 9, therefore, it is be selected for series compensation. In order to see the effectiveness of proposed method the series compensation is applied on all the lines and the results are compared. The power transfer capability of the system with varying amount of series compensation is shown in Table 3.

From Table 3 it is seen that the optimal location of series compensation is line 6 - 9 because the power transfer capability of the system increases continuously and significantly with increase in amount of series compensation in it. The location is same as obtained by proposed method.

5 CONCLUSIONS

In this paper a method to determine location and amount of series compensation to increase power transfer capacity due to transient stability has been developed. The method involves economic dispatch, load flow and transient stability studies for various operating states of the power system. The method has been applied to a power system and results are presented. It may be concluded that the method developed successfully identifies location and amount of series compensation to increase power transfer capability.

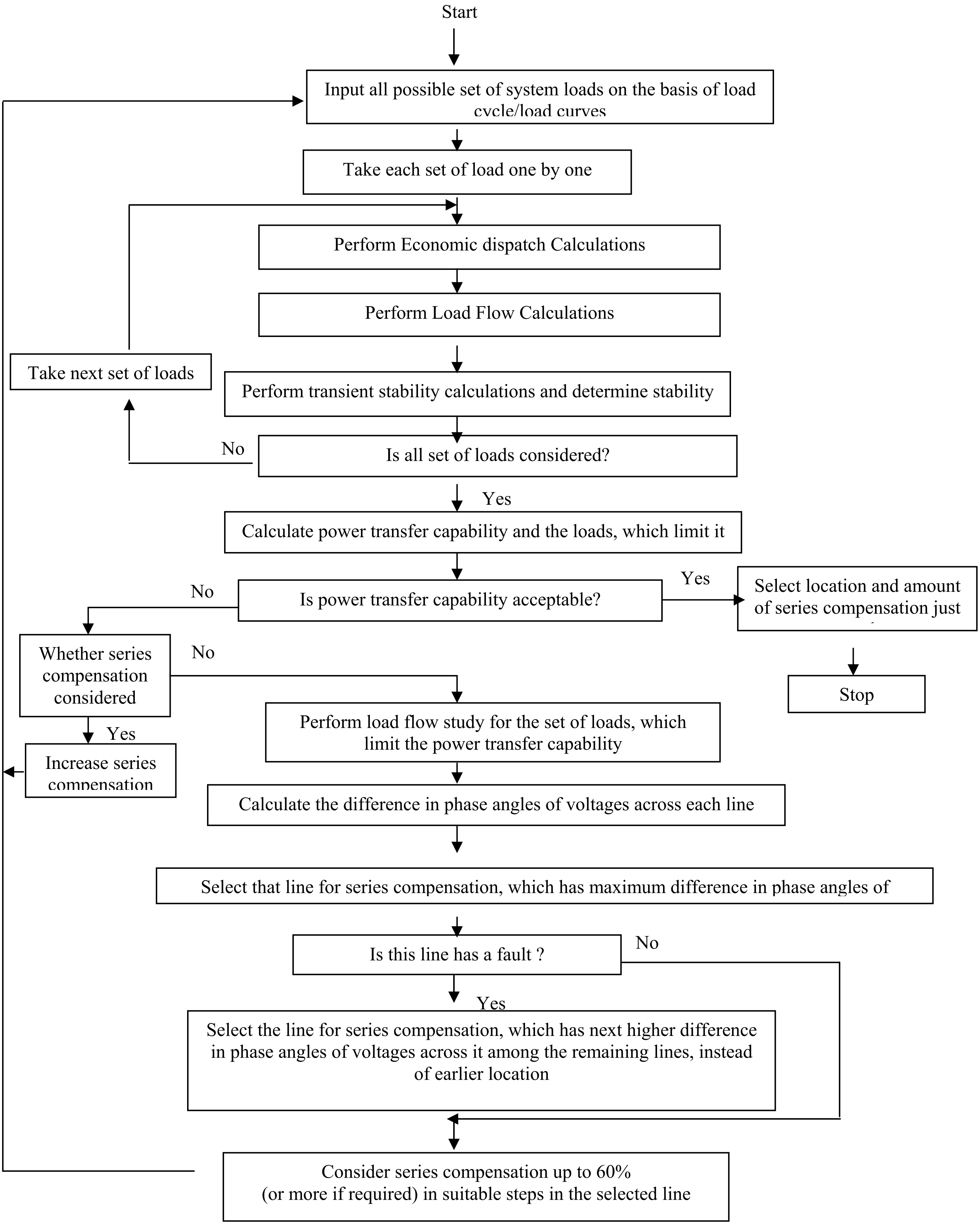

Figure 1. Flow chart of Proposed Method

Table 3. Power transfer capability of the power system (in per unit) for step series compensation in different lines

% Compensation	Line 7 - 8	Line 8 - 9	Line 6 - 9	Line 4 - 6	Line 4 - 5	Line 5 - 7
0	3.571	3.571	3.571	3.571	3.571	3.571
20	3.579	3.571	3.706	3.579	3.503	3.571
40	3.579	3.579	3.899	3.655	3.503	3.579
60	3.655	3.579	4.062	3.699	3.491	3.579

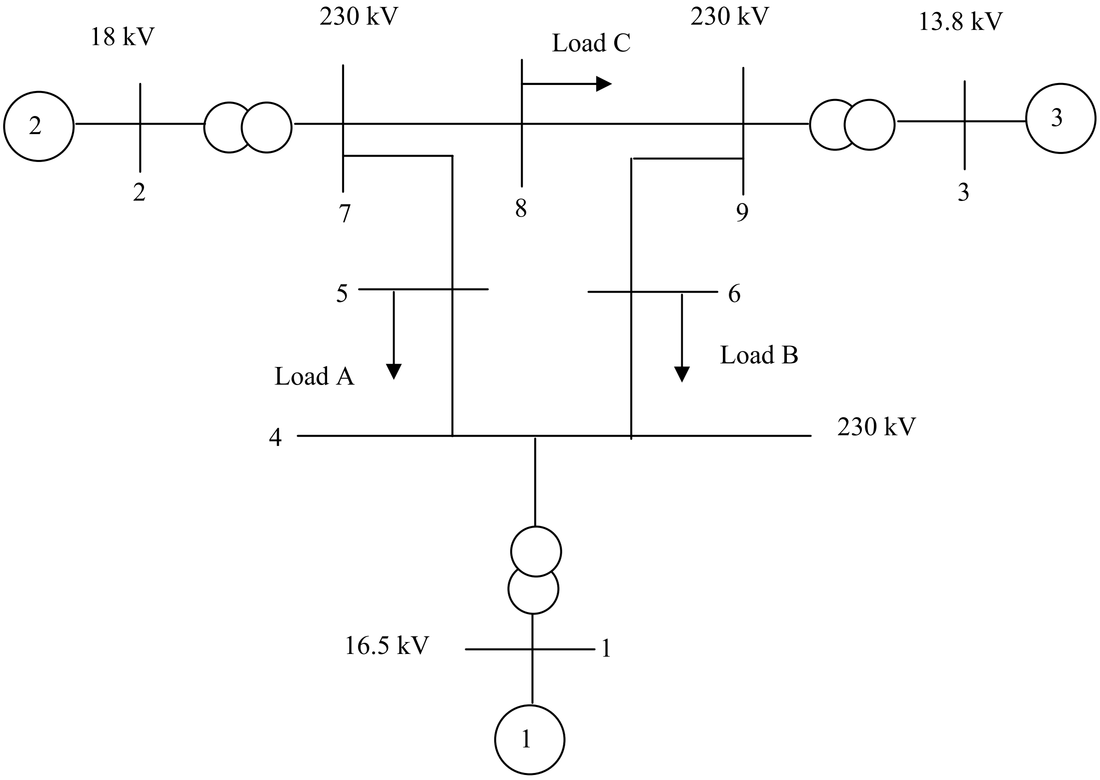

Figure 2. One Line Diagram of Sample System

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