# Optimal Placing of FACTS Devices to Improve Power System Security

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*Abstract*— **In electric power systems, system no remain in secure operating state due to increased power demand. On other hand, the power system stability has been recognized as an important problem for its secure operation. Several methods are being used conventionally to improve operating margins necessary for system stability. Many of these suffer with excessive response time and considerable amount of power loss. To overcome this difficulty, a rapid development of power electronic devices such as Flexible AC Transmission System (FACTS) devices are used, their primary application is to enhance power transfer capabilities, power system stability and allow more flexible control of power flows. By installing FACTS equipment at optimal sites, the overall system benefits are sought. But the location of these FACTS devices has been big challenge. This challenge is overcome by using Sensitivity Indices analysis method. Here two Sensitivity Indices analysis methods are used and these are; reduction of total system reactive power loss and real power flow performance index sensitivity indices. The 'MATLAB' software is used here to write a programming code for finding out the sensitivity indices for both methods. IEEE-14 bus system is used here for the study purpose.**

***Keywords—sensitivity analysis; sensitivity indices; power system security; PI; FACTS***

## I. INTRODUCTION

With the ongoing expansion and growth of the electric utility industry, including deregulation in many countries, numerous changes are continuously being introduced to a once predictable business. Although electricity is a highly engineered product, it is increasingly being considered and handled as a commodity. Thus, transmission systems are being pushed closer to their stability and thermal limits while the focus on the quality of power delivered is greater than ever [2]. Power system is a network of electrical components used to supply, transmit and use electric power. An example of an electric power system is the network that supplies a region like homes and industry with power. For sizable regions, this power system is known as grid and can be broadly divided into the generator that supply the power, the transmission system that carries the power from the generating centre to the load centre and the distribution system that feeds the power to nearby homes and industries. The power system needs to be operationally secure, i.e. with minimal probability of blackout and equipment damage [3]. An important component of power system security is the system's ability to withstand the effects of contingencies [4]. The power system operation is said to be normal when the power flows and the bus voltages are within acceptable limits despite changes in load or available generation. From this perspective, security is the probability of a power system's operating point remaining in a viable state of operation [5].

The system operation is governed by three sets of generic equations – one differential and two algebraic (generally non-linear). Out of two sets of algebraic sets, one set comprises equality constraints (E) which express balance between the generation and load demand. The other set consists of inequality constraints (I) which express limitation of the physical equipment (such as current and voltages must not exceed maximum limits). The classification of the system states is based on the fulfillment or violation of one or both sets of these constraints, Fig. 1 shows the system operating state [6].

### A. *Normal State*

Here all equality(E) and Inequality(I) constraints are satisfied.

### B. *Alert State*

This state implies that there is a danger of violating some of the inequality (I) constraints when subjected to disturbances enables the transition from an alert state to secure state.

### C. *Emergency State*

Here inequality (I) constraints are violated. The system, however, would still be intact, and emergency control action could be initiated to restore the system to alert state.

### D. *In-Extremis State*

Here both equality(E) and inequality(I) constraints are violated.

### E. *Restorative State*

From this state, the system can transit to either the alert or the normal state depending on the circumstances.

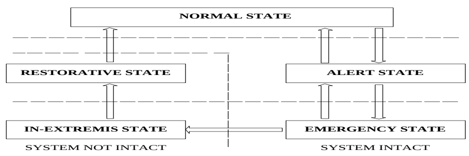


Fig. 1. Power System Operating State

In the present day scenario, transmission systems are becoming increasingly stressed, more difficult to operate, and more insecure with unscheduled power flows and greater losses because of growing demand for electricity and restriction on the construction of new lines. However, many high-voltage transmission systems are operating below their thermal ratings due to constraints, such as voltage and stability limits. Now, more advanced technology is used for reliable operation of transmission and distribution in power system. To achieve both reliable and benefit economically, it has become clearer that more efficient utilization and control of the existing transmission system infrastructure is required. Improved utilization of the existing power system is provided through the application of advanced control technologies. Power electronics has developed the Flexible AC Transmission System (FACTS) devices. FACTS devices are effective and capable of increasing the power transfer capability of a line and support the power system to work with comfortable margins of stability and used to overcome the insecure problem of power system [7] [8].

FACTS is defined by the IEEE as "a power electronic based system and other static equipment that provide control of one or more AC transmission system and increase the capacity of power transfer" [9].

In this paper, the optimal location of FACTS devices is find out using sensitivity indices analysis method. The 'MATLAB' software is used here to write a programming code for finding out the sensitivity indices for both methods. For the study purpose electrical IEEE-14 bus system is used here.

## II. Benefits Of Utilizing FACTS Devices

The advantages of utilizing FACTS devices in power system can be given as below;

- Existing transmission system can be utilize in better way with the help of FACTS devices.
- Reliability and availability of transmission system increases.
- Environmental friendly.

In many countries, increasing the energy transfer capacity and controlling the load flow of transmission lines are of vital importance, especially in de-regulated markets, where the locations of generation and the bulk load centers can change rapidly. Frequently, adding new transmission lines to meet increasing electricity demand is limited by economical and environmental constraints. FACTS devices help to meet these requirements with the existing transmission systems [10].

## III. Static Model Of Transmission Line

A simple transmission line, connected between bus-I and bus-j with the line admittance given as $g_{ij}+jb_{ij}=1/(r_{ij}+jx_{ij})$, can be represented by its limped $\pi$ equivalent parameters as shown in Fig. 2 [11].

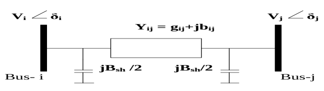


Fig. 2. Static Model Of Transmission Line

The real ($P_{ij}$) and reactive ($Q_{ij}$) power flows from bus-i to bus-j can be written as;

$$P_{ij} = V^2_i g_{ij} - V_i V_j ( g_{ij} Cos\delta_{ij} + b_{ij} Sin\delta_{ij} ) \quad (1)$$

$$Q_{ij} = - V^2_i ( b_{ij} + B_{sh}/2 ) - V_i V_j (g_{ij} Sin\delta_{ij} - b_{ij} Cos\delta_{ij}) \quad (2)$$

Where,
$\delta_{ij} = \delta_i - \delta_j$

Similarly, the real (Pij) and reactive (Qij) power flows from bus-j to bus-I can be expressed as;

$$P_{ji} = V^2_j g_{ij} - V_i V_j ( g_{ij} Cos\delta_{ij} - b_{ij} Sin\delta_{ij} ) \quad (3)$$

$$Q_{ji} = - V^2_j ( b_{ij} + B_{sh}/2 ) + V_i V_j (g_{ij} Sin\delta_{ij} + b_{ij} Cos\delta_{ij}) \quad (4)$$

Where,
$B_{sh}$ is full line charging impedance.

## IV. Proposed Sensitivity Analysis Method

Following are two sensitivity analysis methods for finding the optimal location of FACTS devices [12] [13].

- Reduction Of Total System Reactive Power Loss.
- Real Power Flow Performance Index Sensitivity Indices.

### A. *Reduction Of Total System Reactive Power Loss*

Here we look at a method based on the sensitivity of the total system reactive power loss with respect to the control variable of the FACTS devices. For FACTS devices placed between buses i and j we consider net line series reactance as a control parameter. Loss sensitivity with respect to control parameter of FACTS devices placed between buses i and j can be written as [14] [15],

$$a_{ij} = \frac{\delta Q_L}{\delta X_{ij}} = [V_i^2 + V_j^2 - 2V_i V_j \, Cos\delta_{ij}] \frac{(r_{ij}^2 - X_{ij}^2)}{(r_{ij}^2 + X_{ij}^2)^2} \quad (5)$$

### B. *Real Power Flow Performance Index (PI)Sensitivity Indices*

The severity of the system loading under normal and contingency cases can be described by a real power line flow performance index, as given below [16] [17] [19];

$$PI = \sum_{m=1}^{N_L} \frac{W_m}{2n} \left( \frac{P_{Lm}}{P_{Lm}^{max}} \right)^{2n} \quad (6)$$

Where,
$P_{Lm}$ is the real power flow,
$P_{Lm}^{max}$ is the thermal limit of line m,
n is an exponent used to adjust the index value to avoid the masking effect in the contingency,
$W_m$ is the weighting coefficient used to reflect the importance of lines.

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## V. CRITERIA FOR OPTIMAL PLACING OF FACTS DEVICES

The FACTS devices should be placed on the most sensitive line. Following criteria can be used for deciding optimal placement [15].

- In reactive power loss reduction method, the FACTS devices should be placed in a line having the most positive loss sensitivity index.

- In real power flow performance index method, the FACTS devices should be placed in a line having most negative sensitive index.

## VI. SYSTEM DESCRIPTION

Study of power system stability using sensitivity indices is done here. In this paper, idea about, which line is most sensitive in network is explain here. The analysis is done on IEEE-14 bus system. The single line diagram of the IEEE-14 bus standard test system is shown in Fig. 3, which consists of five synchronous machine, including two generators, located at bus 1 and 2 as well as three synchronous compensators used only for reactive power support, located at bus 3, 6 and 8. Bus 1 is a slack/ reference bus while bus 2, 3, 6 and 8 are PV bus and other all are PQ bus [18]. The generating capacity of each generator, value of load and value of resistance and reactance are also shown in it.

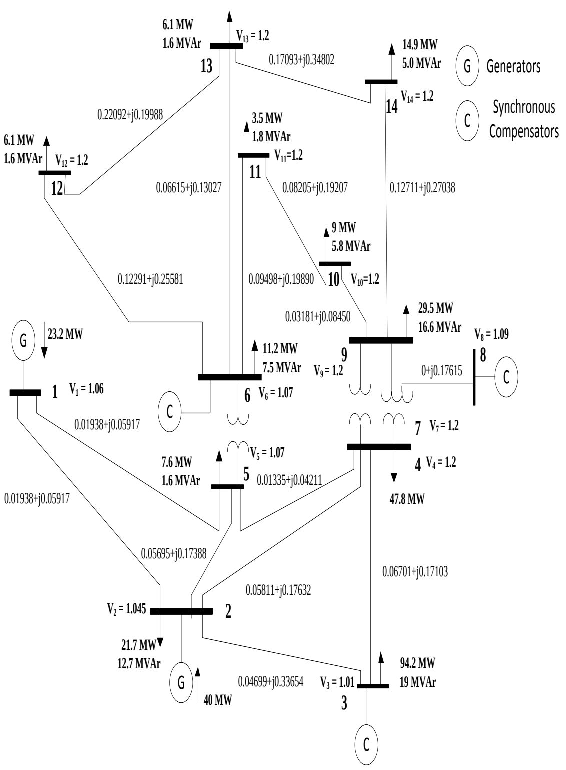


Fig. 3. IEEE-14 bus system

## VII. RESULT AND DISCUSSION

The result obtained from the MATLAB programming are shown in TABLE I by using reduction of total system reactive loss and real power flow performance index sensitivity indices analysis method. Column 3rd gives sensitivity indices by using total system reactive loss and it is denoted by $a_{ij}$ whereas 4th column gives the sensitivity indices by using real power flow performance index sensitivity analysis method and it is denoted by $b_{ij}$. According to total system reactive loss method (column 3rd), the line no. 19 ($a_{ij}$ = 0.0048 )is more sensitive and line no. 19 is suitable for placing the FACTS device and according to real power flow performance index method (column 4th), line no. 6 (bij = -56813.7 ) is more sensitive and line no. 6 is suitable for optimal placement of FACTS device. In this way to overcome the security problem of power system, optimal placement of FACTS devices can done with the help of sensitivity analysis indices method.

TABLE I. CALCULATED SENSITIVITY INDICES

| **Line** | **i-j** | **$a_{ij}$** | **$b_{ij}$** |
|---|---|---|---|
| 1 | 1-2 | -0.0053 | $-2.25e^{-05}$ |
| 2 | 1-5 | -0.0004 | $5.14e^{-08}$ |
| 3 | 2-3 | -0.0181 | 0.02800 |
| 4 | 2-4 | -0.0103 | $-2.32e^{-17}$ |
| 5 | 2-5 | -0.0019 | $-4.61e^{-18}$ |
| 6 | 3-4 | -0.0931 | **-56813.7** |
| 7 | 4-5 | -0.0608 | 0 |
| 8 | 4-7 | -0.3631 | 0 |
| 9 | 4-9 | -0.0435 | 0 |
| 10 | 5-6 | -0.0009 | 0 |
| 11 | 6-11 | -0.2187 | 0 |
| 12 | 6-12 | -0.1637 | $-6.24e^{-12}$ |
| 13 | 6-13 | -0.5723 | $-4.57e^{-16}$ |
| 14 | 7-8 | -0.1160 | 0 |
| 15 | 7-9 | -0.0083 | 0 |
| 16 | 9-10 | -0.0022 | 429.89 |
| 17 | 9-14 | -0.0001 | $-3.33e^{-10}$ |
| 18 | 10-11 | -0.0008 | 0 |
| 19 | 12-13 | **0.0048** | $1.25e^{-05}$ |
| 20 | 13-14 | -0.0037 | $9.29e^{-17}$ |

## CONCLUSION

The system security is the important thing in the power system. As per expected goal, in large power system, the finding of the optimal location of FACTS devices is important step. The optimal place of FACTS devices to improve power system security is find out by introducing some sensitivity indices analysis method, the analysis approach has been utilized to find the most sensitive line in power system network and on sensitive line FACTS devices are placed to improve the system stability and system security.

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