IOSR Journal of Engineering (IOSRJEN)
ISSN: 2250-3021 Volume 2, Issue 6 (June 2012), PP 09-15
www.iosrjen.org

Sensitivity Approach for the Effective location of TCSC in a Deregulated Electricity Market

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ABSTRACT: - ***I****n a deregulated electricity market it may always not be possible to dispatch all of the contracted power transactions due to congestion of transmission corridors. In a competitive electricity market, congestion occurs when transmission network is unable to accommodate all of the desired transactions due to the violation of system operating limits. Congestion relief can be handled using FACTS device such as TCSC, where transmission capability will be improved. Based on reduction of total system reactive power loss optimal location for the placement of these devices. Congestion management by Transmission Line Relief (TLR) sensitivity method was also examined for IEEE 9 bus system. The approach for this problem was carried out with the help of Power World Simulator software*.

Keywords**:** *Congestion, Deregulated power system, TCSC, Reduction of reactive power losses, Transmission Line Relief (TLR) sensitivity*.

1. INTRODUCTION

Power industry is moving rapidly from regulated conventional setup to a deregulated environment. The main objective of the deregulation of power industry is to introduce competition among the power producers and prevent monopolies. Congestion is a consequence of network constraints characterizing a finite network capacity that precludes the simultaneous delivery of power from an associated set of power transactions [5]. When the producers and consumers of the electric energy desire to produce and consume in amounts that would cause the transmission system to operate at or beyond one or more transfer limit, the system is said to be congested.

Congestion is also defined as when the transmission network is unable to accommodate all of the desired transactions due to the violation of system operating limits. Line outages or higher load demands are the causes of congestion in the transmission network. Congestion occurs in both vertically bundled and unbundled systems but the management in the bundled system is relatively simple as generation, transmission and in some cases, distribution systems are managed by one utility. The management of congestion is somewhat more complex in competitive power markets and leads to several disputes.

Different techniques are used in many papers for solving the congestion problem. In [5] coordination between TCSC and SVC is investigated via Real Genetic Algorithm technique to increase the power transfer. In [6] Ashwini kumar proposed a Zonal based congestion management approach based on Real and Reactive power Rescheduling. In [11] an algorithm for congestion management based on optimal power flow framework and using TCSC has been proposed.

In [14] modelling of TCSC and a sensitivity based approach for optimal location of TCSC is proposed. In [15] two methods such as LMP difference method and congestion rent contribution methods are proposed for the

Placement of series FACTS devices like TCSC to reduce congestion.

FACTS devices are utilized as one of the method which can reduce the transmission congestion and leads to better using of existing grid infrastructure. FACTS devices, especially series FACTS devices like TCSC are considered one such technology which reduces transmission congestion.

Transmission Line Relief (TLR) sensitivities can also be used for the purpose of congestion alleviation by load curtailment.

In this paper a method for Congestion management have been suggested based on Load Curtailment using TLR sensitivity method and based on reduction of total system reactive power losses with the use of FACTS devices.

2. PROBLEM FORMULATION

2.1 Static modelling of TCSC

Thyristor controlled series compensators (TCSC) are connected in series with the lines. The effect of a TCSC on the network can be seen as a controllable reactance inserted in the related transmission line that compensates for the inductive reactance of the line. This reduces the transfer reactance between the buses to which the line is connected. This leads to an increase in the maximum power that can be transferred on that line in addition to a reduction in the effective reactive power losses. The series capacitors also contribute to an improvement in the voltage profiles.

Figure 1. Shows a model of a transmission line with a TCSC connected between buses i and j. The transmission line is represented by its lumped π-equivalent parameters connected between the two buses. During the steady state, the TCSC can be considered as a static reactance *-jxc*. This controllable reactance, *xc*, is directly used as the control variable to be implemented in the power flow equation.

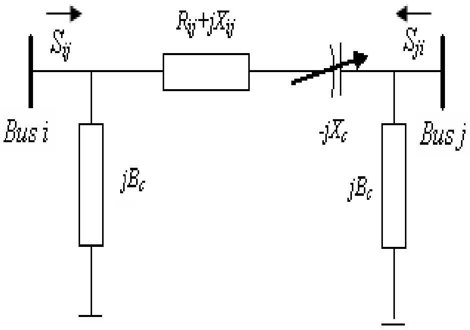

Fig2.1. Model of TCSC in a transmission line.

The following equations are used to model the TCSC.

Let the voltages at bus i and bus j are represented by $V_i\angle\delta_i$ and $V_j\angle\delta_j$ respectively. The complex power from bus i to j is

$P_{ic} = V_i^2 \Delta G_{ij} - V_i V_j [\Delta G_{ij} \cos\delta_{ij} + \Delta B_{ij} \sin\delta_i]$ ..... (2.1)

$P_{jc} = V_j^2 \Delta G_{ij} - V_i V_j [\Delta G_{ij} \cos\delta_{ij} + \Delta B_{ij} \sin\delta_{ij}]$ .... (2.2)

$$\Delta G_{ij} = \frac{x_c r_{ij}(x_c - 2x_{ij})}{(r_{ij}^2 + x_{ij}^2)\left[r_{ij}^2 + (x_{ij} - x_c)^2\right]} \quad \text{.......... (2.3)} \qquad \Delta B_i = \frac{-x_c\,(r_{ij}^2 - x_{ij}^2 + x_c\,x_{ij})}{(r_{ij}^2 + x_{ij}^2)\left[r_{ij}^2 + (x_{ij} - x_c)^2\right]} \quad \text{......... (2.4)}$$

2.2 Reduction of total system VAR power loss

Here it is looked at a method based on the sensitivity of the total system reactive power loss (Q_L) with respect to the control variables of the FACTS devices. For the device TCSC considered the following control parameter:

Net line series reactance (X_{ij}) for a TCSC placed between buses i and j , sensitivity factors with respect to the control variable may be given as follows:

Loss sensitivity with respect to control parameter X_{ij} of TCSC placed between buses i and j,

$$a_{ij} = \frac{\partial Q_L}{\partial X_{ij}}. \qquad \text{.......(2.5)}$$

The loss sensitivities with respect to X_{ij} can be computed as:

$$a_{ij} = \frac{\partial Q_L}{\partial X_{ij}} = \left[V_i^2 + V_j^2 - 2V_iV_j\cos(\delta_i - \delta_j)\right]\frac{R_{ij}^2 - X_{ij}^2}{(R_{ij}^2 + X_{ij}^2)^2} \qquad \text{...(2.6)}$$

3. SELECTION OF OPTIMAL PLACEMENT OF FACTS DEVICES

Using the loss sensitivities as computed in the previous section, the criteria for deciding device location might be stated as follows:

1. TCSC must be placed in the line having the most positive loss sensitivity index a_{ij} .

The procedure is shown in below flow chart fig 2.2

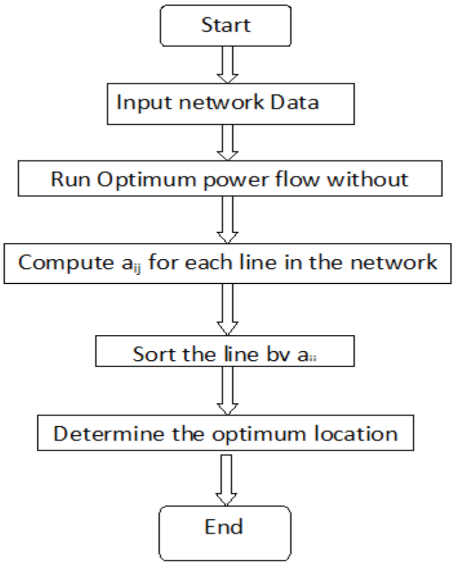

Fig:3.1 Flow chart for proposed method in effective location of TCSC

4. LOAD CURTAILMENT BASED ON TLR SENSITIVITIES

TLR sensitivities can be used for the purpose of congestion alleviation by load curtailment. TLR sensitivities are considered as inverse of power transfer distribution factors (PTDFs). PTDFs are used to determine the sensitivities of transmission line flow to a single power transfer where as TLR sensitivity of the flow on single transmission element to various transactions in the system. In the method of congestion alleviation using load curtailment, TLR sensitivities at all the load bases for the most over loaded line are considered.

TLR sensitivity at a bus k for a congested line i-j is given by equation

$$S_{ij}^{k} = \frac{\Delta P_{ij}}{\Delta P_{k}} \qquad \text{…….(4.1)}$$

Where

ΔP_{ij} is the excess power flow on line i-j

$$\Delta P_{ij} = P_{ij} - \overline{P_{ij}} \qquad \text{........ (4.2)}$$

Where

P_{ij}: Actual power flow through line i-j

$\overline{P_{ij}}$: Flow limit of transmission line i-j

The new load P_k^{new} at bus k can be obtained by

$$P_k^{new} = P_k - \frac{S_{ij}^{k}}{\sum_{i=1}^{N} S_{ij}^{k}} \overline{\Delta P_{ij}} \qquad \text{……(4.3)}$$

P_k^{new} =load after curtailment at bus K

P_k= load before curtailment at bus K

S_{ij}^{k} =sensitivity of power flow on line i-j due to load change at bus k

N= total number of load buses.

5. SIMULATION RESULTS

In this study an IEEE 9 bus system has been analysed for congestion management by the optimal location of FACTS device such as TCSC using the power world simulator software based on sensitivity indices approach Fig 5.1. Indicates the single line diagram of an IEEE 9 bus system drawn in power world simulator.

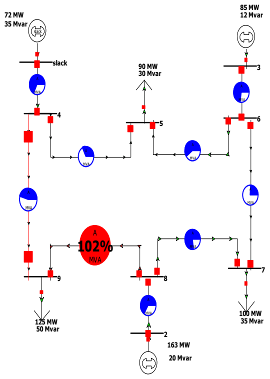

Fig. 5.1. Modified IEEE 9 bus system

From the above figure it was found that the line 8-9 in the system is in congested condition .In order to relieve the system from congested condition FACTS device such as Thyristor controlled series compensator (TCSC) is placed in one of the lines. A reactive power loss sensitivity based approach is used here for optimal placement of this device.

The sensitivity indices for the congested 9 bus system were tabulated below.

Table 5.1 OPF result without TCSC

LINES	FROM BUS	TO BUS	LOADABILITY (%)
1	1	4	66.69
2	4	5	39.13
3	5	6	61.08
4	3	6	71.58
5	4	9	53.60
6	8	7	77.09
7	2	8	65.68
8	8	9	102.02
9	6	7	31.95

The result of the OPF run on the test network is shown in the above table 3.1. From the OPF it was found that the real power flow in line 8 was 102.02 which is more than line loading limit.

5.1 Reactive power loss sensitivity index of IEEE 9 bus system

Table 5.2 sensitivity factors

LINE	FROM BUS	TO BUS	SENSITIVITY INDEX (a_{ij})		
			TCSC (20%comp)	TCSC (40%comp)	TCSC (60%comp)
1	1	4	-0.64546	-0.65990	-0.66714
2	4	5	**-0.12684**	**-0.12385**	**-0.10357**
3	5	6	-0.35638	-0.34761	-0.26126
4	3	6	-0.7407	-0.73801	-0.74401
5	4	9	-0.26500	-0.26851	-0.25751
6	7	8	-0.59930	-0.60259	-0.57969
7	8	2	-2.6885	-2.68448	-2.67225
8	8	9	-0.75807	-0.75434	-0.62786
9	6	7	**-0.07522**	**-0.07902**	**-0.07835**

From the above table the lines having the most positive loss sensitivity index is chosen for the placement of TCSC devices. Hence lines 2 and 9 are selected from the table. TCSC device in the inductive mode of operation are connected in series with these two lines, with inductive reactance of 60% of the line reactance each have been considered.

Table5.3 Power flow list.

lines	Power flow without TCSC (MW)	TCSC with 20% comp	TCSC with 40% comp	TCSC with 60% comp
1	72.09	72.09	72.09	72.11
2	31.03	29.54	28.20	27.00
3	60.29	62.25	63.64	64.90
4	85	85.00	85.00	85.00
5	41.06	42.55	43.89	45.10
6	76.29	77.86	79.27	80.54
7	163	163	163	163
8	86.71	85.14	83.73	82.46
9	24.31	22.75	21.36	20.10

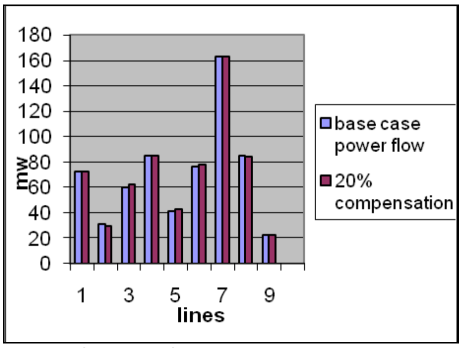

Fig 5.2. Comparison of power flows with (20%comp) and without TCSC.

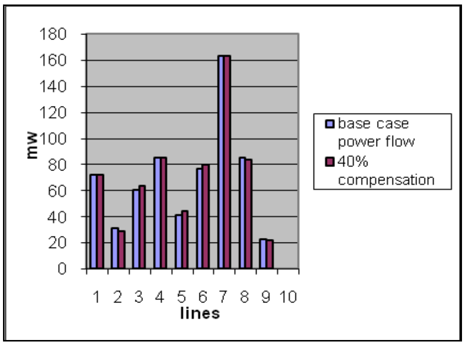

Fig 5.3 Comparison of power flows with (40%comp) and without TCSC.

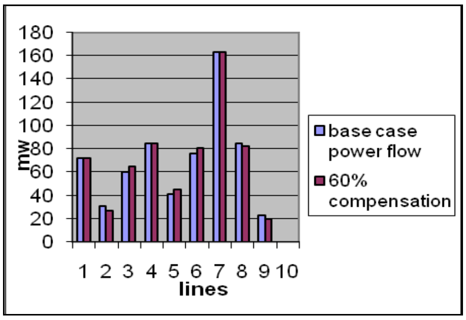

Fig 5.4 comparison of power flows with (60%comp) and without TCSC.

When TCSC (20%) is placed in the lines 4-5 and 6-7, it removes the congestion present in the line 8-9 from 102% to 100%. Again when the lines 4-5 and 6-7 were being compensated by 40%, the congestion in the line 8-9 got relieved from 100% to 99% and the congestion in the line 8-9 is relieved to 97% when the lines 4-5 and 6-7 were compensated by 60%. From the results we can observe that placing the TCSC in the optimal location relieves the congestion in the modified IEEE 9 bus system.

5.2 Transmission line relief (TLR) sensitivity method

This transmission line relief method is based on load curtailment. In this method of congestion management, TLR sensitivities at all the load buses for the most overloaded line are considered. An IEEE 9 bus congested system is considered here.

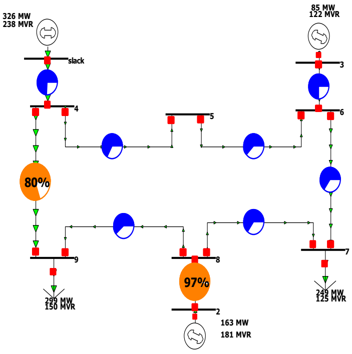

Fig5.5 Congested IEEE 9 bus system.

The TLR values of congested lines of a 9 bus system are tabulated below.

Table: 5.4 TLR sensitivities

BUSES	LINE (4-9)	LINE (7-8)	LINE (7-6)
1	0	0	0
2	0.639	-0.361	0.361
3	0.385	0.385	-0.385
4	0	0	0
5	0.135	0.135	-0.135
6	0.385	0.385	-0.385
7	0.533	**0.533**	**0.467**
8	0.639	-0.361	0.361
9	**0.875**	-0.125	0.125

Load curtailment is to be done at the bus having most positive value. From the table the TLR sensitivity at bus 9 for the line 4-9 is most positive. So load curtailment of 9MW at bus 9 relieves the congestion of line 4-9 and similarly load curtailment at bus 7 relieves congestion from 97% to 90% of the line 8-2

.

6. CONCLUSION

Congestion management is the important issue in the deregulated power system.TLR sensitivity approach have been examined by load curtailment and reduction of total system reactive power loss sensitivity indices are proposed for locating TCSC device to manage the congestion in deregulated electricity market. A power injection Π-model is developed for TCSC and then reduction of reactive power loss sensitivity index is modified for the network containing a TCSC. The proposed methodologies are based on sensitivity that are by-product of OPF problem formulation. The proposed method was tested on modified IEEE 9 bus system.

ACKNOWLEDGMENT

The authors would like to thank QISCET, Ongole for providing the computer lab facility with necessary software.

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