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Fuzzy Optimization Using TCSC Device for Congestion Management

Ms.Lovisal.C[1], Mr.E.Thangam[2]
Department of Electrical and Electronics Engineering Ranganathan Engineering College Coimbatore
Department of Electrical and Electronics Engineering Ranganathan Engineering College Coimbatore.

Abstract
The management of congestion is somewhat more complex in competitive power markets and leads to several problems. It is one of the challenging tasks in power system deregulation. In a transmission line, congestion occurs when there is an insufficient transmission capacity to simultaneously satisfy all constraints for transmission in deregulated power market. Flexible alternative current transmission system (FACTS) devices have been used for the enhancement of loadability by reducing the flows in heavily loaded lines. It also improves the stability of the network, reduces the cost of production and fulfills all requirements by controlling the power flow in the network. In the proposed work, a non-traditional optimization technique, Fuzzy logic (FL) is used to optimize the various process parameters involved in introduction of FACTS devices in a power system. The various parameters taken into consideration were the location of the device, their type, and their rated value of the devices. The simulation was performed on a 14-bus power system with various types of FACTS controllers, modeled for steady state studies. The effectiveness of the proposed method has been demonstrated on IEEE 14-bus system.

Keywords-Congestion management, Deregulated electricity market, Thyristor Controlled Series Capacitors (TCSC), Fuzzy logic controller.

I. INTRODUCTION

Transmission congestion may be defined as the condition where more power is scheduled or flows across transmission lines and transformers than the physical limits of those lines and transformers. The disputes of congestion in transmission network are more pronounced in deregulated power environment [1, 2].

The limitations of a power transmission network arising from environmental and cost problems are base to both bundled and unbundled power systems. The generation pattern that results in heavy flow tends to incur greater losses, and to threaten stability and security, and finally the generation patterns becomes economically undesirable [3, 4].

To maintain system in a secure state, Independent System Operator (ISO) can use some techniques to relieve congestion.

1. Cost free methods: a) Out-ageing of congested lines b) Operation of transformer taps/phase shifters c) Operation of FACTS devices particularly series devices.
2. Non-cost free methods: a) Re-dispatching the generation amounts b) Curtailment of loads and the exercise of load interruption options.

Among the above two methods, cost free means do have advantages such that it does not touch the economical matters, so GENCO and DISCO will not be involved

Flexible alternating current transmission systems (FACTS) technology has been applied for controlling power and enhancing the usable capacity of the transmission network in power market. By installing these FACTS devices the utilization of power system capabilities has been improved [5]. FACTS devices like TCSC are considered one such technology that reduced the transmission congestion and allows better utilization of the existing grid infrastructure, along with many other benefits.

This paper deals with the optimal placement of TCSC device to manage congestion in deregulated electricity market. The optimal location of TCSC device is based on static or dynamic performance of the system. A sensitivity factor method is used for optimal location of series FACTS devices [6] for static congestion management. The approach is based on the sensitivity of the reduction of total system VAR power loss and real power performance index. A loss sensitivity factor method is used in [7] to determine the suitable location for FACTS device.

II. THYRISTOR CONTROLLED SERIES CAPACITORS (TCSC)

Thyristor Controlled Series Capacitor as one the best proposed devices in FACTS family and its applications in power transmission system. Thyristor-controlled series capacitors (TCSC) is a type of series compensator that can provide many benefits for a power system including controlling power flow in the line, damping power oscillations, and mitigating sub synchronous resonance. In TCSC, the capacitor is inserted directly in series with the transmission line and the thyristor-controlled inductor is mounted directly in parallel with the capacitor [8]. Therefore, no interfacing equipment like for example high voltage transformers is required. This makes TCSC much more economic than some other competing FACTS technologies. Thus it makes TCSC simple and easy to understand the operation.

III. MODELLING OF TCSC DEVICE

Power Injection Model can be used for static application like congestion management using FACTS devices. The injection model describes the FACTS devices as a device that injects a certain amount of active and reactive power to a node, so that the FACTS devices are presented as PQ elements.

A simple transmission line represented by its lumped π equivalent parameters connected between bus-i and bus-j. Let complex voltages at bus-i and bus-j with angle are $V_i\angle\delta_i$ and $V_j\angle\delta_j$, respectively.

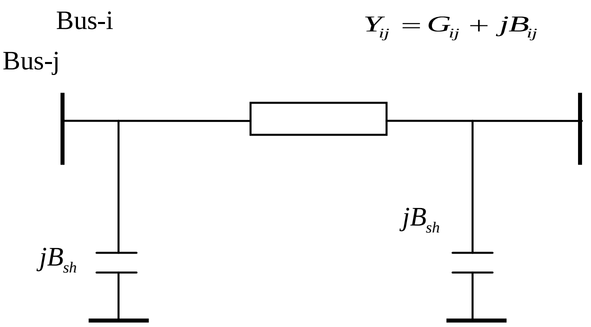

Figure 1. Modelling of transmission line

A model of transmission line with one TCSC which is connected between bus-i and bus-j as shown in Fig.2.

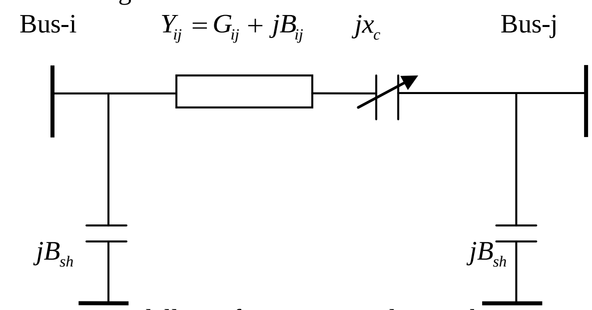

Figure.2 Modelling of transmission line with TCSC

The real and reactive power flow from bus-i to bus-j can be written as

$$P_{ij} = V_i^2 G_{ij} - V_i V_j [G_{ij} \cos(\delta_{ij}) + B_{ij} \sin(\delta_{ij})] \quad (1)$$

$$Q_{ij} = -V_i^2 (B_{ij} + B_{sh}) - V_i V_j [G_{ij} \sin(\delta_{ij}) + B_{ij} \cos(\delta_{ij})] \quad (2)$$

where $\delta_{ij} = \delta_i - \delta_j$.

Similarly, the real and reactive power flow from bus-j to bus-i is

$$P_{ij} = V_j^2 G_{ij} - V_i V_j [G_{ij} \cos(\delta_{ij}) + B_{ij} \sin(\delta_{ij})] \quad (3)$$

$$Q_{ij} = -V_j^2 (Bij + Bsh) + V_i V_j [G_{ij} \sin(\delta_{ij}) + B_{ij} \cos(\delta_{ij})] \quad (4)$$

The change in the line flow due to series capacitance can be represented as a line without series capacitance with power injected at the receiving and sending ends of the line as shown in Fig.3.

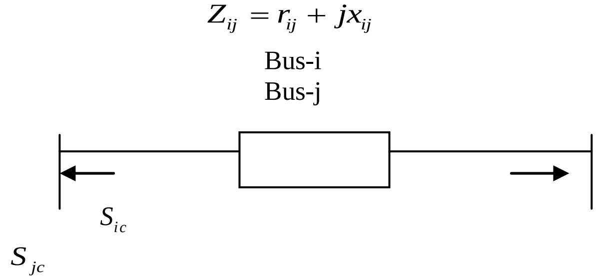

Figure 3. Injection model of TCSC

The model of transmission line with a TCSC connected between bus-i and bus-j is shown in Fig.3. During the steady state the TCSC can be considered as a static reactance -jxc. The real and reactive power flow from bus-i to bus-j and from bus-j to bus-i of a line having series impedance and a series reactance are

$$P_{ij}^c = V_i^2 G_{ij}' - V_i V_j (G_{ij}' \cos\delta_{ij} + B_{ij}' \sin\delta_{ij}) \quad (5)$$

$$Q_{ij}^c = -V_i^2 (B_{ij}' + B_{sh}) - V_i V_j (G_{ij}' \sin\delta_{ij} + B_{ij}' \cos\delta_{ij}) \quad (6)$$

$$P_{ji}^c = V_j^2 G_{ij}' - V_i V_j (G_{ij}' \cos\delta_{ij} + B_{ij}' \sin\delta_{ij}) \quad (7)$$

$$Q_{ji}^c = -V_j^2 (B_{ij}' + B_{sh}) - V_i V_j (G_{ij}' \sin\delta_{ij} + B_{ij}' \cos\delta_{ij}) \quad (8)$$

Where

$$Gij' = \frac{r_{ij}}{r_{ij}^2 + (x_{ij} + x_c)^2}$$

$$Bij' = \frac{-(x_{ij} - x_c)}{r_{ij}^2 + (x_{ij} + x_c)^2}$$

This model of TCSC is used to properly modify the parameters of transmission lines with TCSC for optimal location.

IV. OPTIMAL PLACEMENT USING FUZZY

The FACTS device can be used to change the power system parameters. These parameters give different results on the objective function (14). Also various FACTS device locations, rated value and types have influences on the objective function. The above-mentioned parameters are very difficult to optimize simultaneously by conventional optimization methods. To solve this type of combinatorial problem, fuzzy logic method is proposed. The proposed methods are well developed and utilized effectively for this work. For which C computer coding are developed and for simulated (15).

V. FUZZY LOGIC CONTROLLER

In 1965, Zadeh proposed Fuzzy logic; it has been effectively utilized in many field of knowledge to solve such control and optimization problems. In power system area, it has been used to stability studies, load frequency control, unit commitment, and to reactive compensation in distribution network and other areas. Fuzzy logic algorithm produce very good results, as presented in [15].Further, it reduces the computation time also. According to the situations, rules are established and necessary actions to a solution are determined. A process called defuzzification, which consists in all variables interaction through stochastic techniques, obtains final values. In the FACTS device location problem, rules are established to determine the convenience of having a FACTS device installed in a particular bus or not. The variables Bus voltage (BV) and Power Loss (PL) are used to establish the group of fuzzy rules. The relationship functions of these variables are shown in Table I. Those variables indicate lack of FACTS devices in the power system network and determine the allocation sensibility degree of each bus.The fuzzy rules are established by considering first two extreme situations:

1. If low bus voltage and high MPL, where FACTS devices essential.
2. If high voltage and low MPL, where FACTS devices low attribute.

Fuzzy Logic approach for FACTS device location

1. Calculate bus voltages, power considering power system without FACTS device.
2. Bus voltage (BV) is defined for each bus and power loss(PL) is determined
3. Apply fuzzy logic to determine the subgroup of bus in which the FACTS device locations have more advantages,

TABLE I: FUZZY DECISION RULES

Voltage / Power loss	low	Medium low	medium	Medium high	high
Low	medium low	medium low	low	low	low
Medium low	medium	medium low	medium low	low	low
Medium	medium	medium	medium low	low	low
Medium high	medium high	medium high	medium	medium low	low
High	high	medium high	medium	medium low	medium low

Sensitivity of each line was determined using fuzzy decision rules. If bus voltage is low and power loss is medium high, then FACTS devices are essential.

VI. RESULTS AND DISCUSSIONS

The analysis has been implemented on IEEE 14 bus system to find the optimal locations of TCSC, which is shown in the Fig.4. The FACTS device should be placed on the most sensitive line. Optimizations are carried out with a fuzzy tool developed in MATLAB language. Power flows are solved with a modified version of the free MATLAB power simulation package MATPOWER 2.0.

Table II showed that standard power flow in the IEEE 14 bus system. Table III showed the power flow after the line outage 2-3. System power flow result after placing TCSC in line-5 is shown in Table IV.

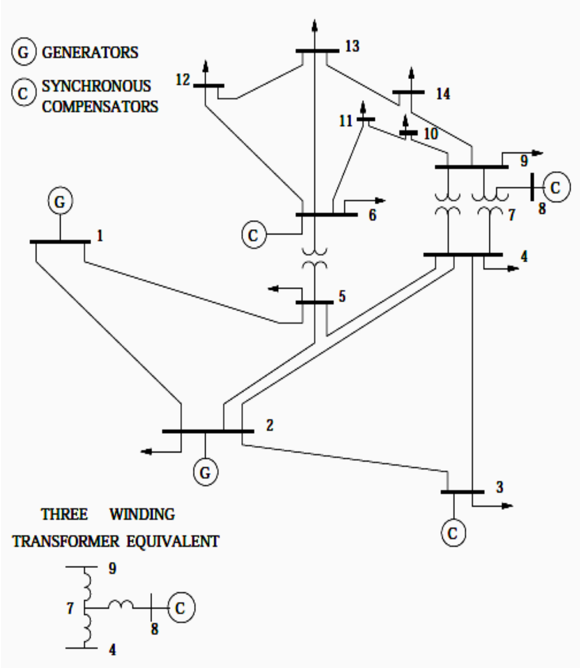

Figure.4 IEEE 14 bus system

TABLE II
POWER FLOW OF IEEE 14 BUS SYSTEMS

Line	*i-j*	*Power Flow(Mw)*	*Line*	*i-j*	*Power Flow(Mw)*
1	1-2	130	11	6-11	30
2	1-5	130	12	6-12	30
3	2-3	130	13	6-13	30
4	2-4	120	14	7-8	30
5	2-5	120	15	7-9	40
6	3-4	120	16	9-10	30
7	4-5	120	17	9-14	30
8	4-7	100	18	10-11	30
9	4-9	60	19	12-13	30
10	5-6	60	20	13-14	30

TABLE III
POWER FLOW OF IEEE 14 BUS SYSTEMS
AFTER LINE OUTAGE 2-3

Line	*i-j*	*Power Flow(Mw)*	*Line*	*i-j*	*Power Flow(Mw)*
1	**1-2**	**148.95**	11	6-11	9.76
2	1-5	94.92	12	6-12	8.24
3	2-3	0	13	6-13	19,1
4	2-4	93.9	14	7-8	0.1
5	2-5	69.47	15	7-9	25.6
6	3-4	-94.2	16	9-10	2.9
7	4-5	-100	17	9-14	7.7
8	4-7	25.6	18	10-11	-6.06
9	4-9	14.6	19	12-13	2.05
10	5-6	48.29	20	13-14	7.363

After applying fuzzy logic to determine the subgroup of bus in which the FACTS device has to be located. If bus voltage is low and power loss is medium high, FACTS devices are essential. Second line (1-5) satisfied the fuzzy rule, shows higher sensitivity. So TCSC device has been placed in (1-5) line and after placing TCSC congestion has been relieved.

TABLE IV
POWER FLOW OF IEEE 14 BUS SYSTEMS
AFTER PLACING TCSC IN LINE (1-2)

Line	*i-j*	*Power Flow(Mw)*	*Line*	*i-j*	*Power Flow(Mw)*
1	**1-2**	**128.31**	11	6-11	10.034
2	1-5	115.92	12	6-12	8.271
3	2-3	0	13	6-13	19.234
4	2-4	93.911	14	7-8	0.100
5	2-5	58.624	15	7-9	25.318
6	3-4	-94.2	16	9-10	2.667
7	4-5	-107.582	17	9-14	7.567
8	4-7	25.318	18	10-11	-6.333
9	4-9	14.418	19	12-13	2.084
10	5-6	48.739	20	13-14	7.529

From Table IV., it is observed that congestion has been relieved after placing the TCSC in line-2 and it also reduced the total system reactive power loss but it will be less effective than placing a TCSC in other lines.

TABLE V
REAL POWER LOSS COMPARISION

Total Real Power Loss Without TCSC	*Total Real Power Loss With TCSC*
P(Mw)	P(Mw)
24.865	20.601

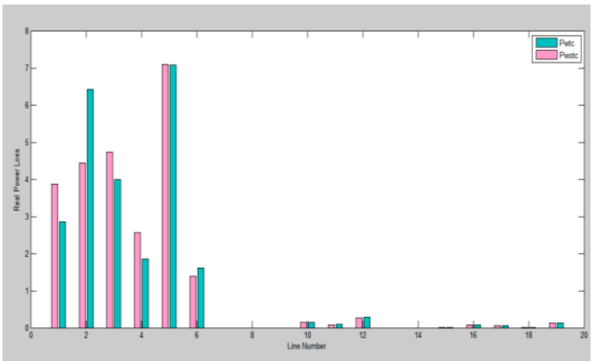

Figure.5 Real Power Loss Comparison

TABLE VI
REACTIVE POWER LOSS COMPARISION

Total Reactive Power Loss Without TCSC	***Total Reactive Power Loss With TCSC***
Q (MVAr)	Q (MVAr)
87.971	76.263

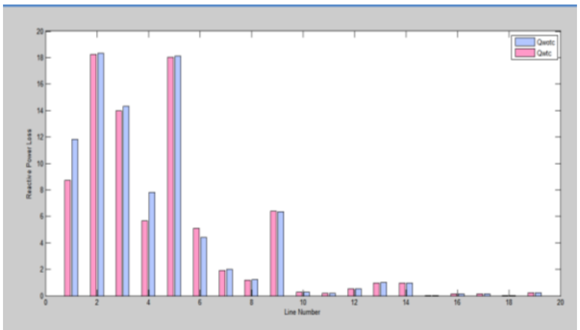

Figure.6 Reactive Power Loss Comparison

VII. CONCLUSION

Congestion management is an important issue in deregulated power systems. FACTS devices such as TCSC by controlling the power flows in the network can help to reduce the flows in heavily loaded lines. Because of the considerable costs of FACTS devices, it is important to obtain optimal location for placement of these devices. In this report sensitivity of each line is computed through fuzzy logic and determined the optimal location of placement of TCSC in an electricity market. Test results obtained on IEEE 14-bus power system show that TCSC cost could be effectively used for determining optimal location of TCSC. The optimal solution is determined using Optimization tool in MATLAB.

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