RESEARCH ARTICLE

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Transmission Congestion Management in Restructured Power System using Fuzzy Method

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Abstract

Restructuring in electric power system has led to major usage of the transmission system and to make new transmission lines it is very difficult and impossible. In this situation, it is necessary for the system operators to control power flows in lines so that the existing transmission network can be operated in the most safe state. However, power system restructuring is found to be associated with a concept called transmission congestion. Therefore it is necessary to solve this issue. This paper looks for relieving line congestion by using fuzzy technique or method to determine the optimal location of series Flexible AC Transmission Systems (FACTS) device like thyristor controlled series capacitor (TCSC) in a 5-bus system.

Keywords: Congestion Management, Flexible AC Transmission Systems (FACTS), Fuzzy Method, Thyristor Controlled Series Capacitor (TCSC), Optimal Location.

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Introduction

The main challenge of modern India is to meet electrical power generation with increasing demand. This demand is increasing day by day due to rapid growth in industrialization and urbanization. To meet this growth of power (demand), private participation is being encouraged and this gives issues like grid maintenance, power transactions, transmission congestion etc. Among these issues, transmission congestion needs to be addressed. When producers and consumers of electric energy desire to produce and consume in amounts that would cause the transmission system to operate at or beyond one or more transfer limits, the system is said to 'congested'. The action taken to limit congestion is called congestion management (CM). In this restructured power system independent system operator (ISO) or transmission system operator (TSO) has to relieve the congestion so that the system is maintained in a secure state. To decrease the congestion, ISO or TSO can use mainly two types of methods, which are as follows[1]:

1) Cost-free methods (No Cost is involved):

- Out-ageing of congested lines
- Operation of transformer taps/phase shifters
- Operation of FACTS devices, particularly series devices.

2) Cost-based methods (Cost is involved)

- Load curtailment
- Rescheduling generation.

Among the above two main methods, cost-free means have advantages such as without disturbing economic status, so generation company (GENCO) and distribution company (DISCO) will not be involved. The objective of using FACTS devices,[2] especially series FACTS devices like thyristor controlled series capacitor (TCSC) is considered one of the method that reduced the transmission congestion in the transmission network. In this paper, where the objective is to provide maximum relief to the congested line, the optimal location of the FACTS device is found out by using the Fuzzy method.

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Concept, Characteristics and Static Modelling of TCSC

Concept and Characteristics

It consists of the series compensating capacitor shunted by a thyristor controlled inductor, as shown in Figure 1. TCSC is used to increase transmission line capacity by decreasing lines series impedances and increase network reliability. The bi-directional thyristor valve is fired with an angle α ranging between 90° and 180° with respect to the capacitor voltage. This makes TCSC much more economical than some other competing FACTS technologies.

Figure 2 shows the impedance characteristics curve of a TCSC device.[2,3] It is drawn between effective reactance of TCSC and firing angle α. The effective reactance of TCSC starts increasing from X_L value to till the occurrence of parallel resonance condition $X_L(\alpha) = X_C$, theoretically X_{TCSC} is infinity. This region is called as an inductive region. Further increasing of $X_L(\alpha)$ gives capacitive region. Thus, impedance characteristics of TCSC shows, both capacitive and inductive region are possible though varying firing angle (α).

- $\alpha_{clim} \leq \alpha \leq$ capacitive region
- $0 \leq \alpha \leq \alpha_{Llim}$ inductive region

While selecting inductance, X_L should be sufficiently smaller than that of the capacitor X_C. Suppose if X_C is smaller than the X_L, then the only capacitive region is possible in impedance characteristics. In any shunt network, the effective value of reactance follows the lesser reactance present in the branch. So only one capacitive reactance region will appear. Also, X_L should not be equal to X_C, if they are equal, resonance will develop and that will result in infinite impedance and unacceptable conditions.

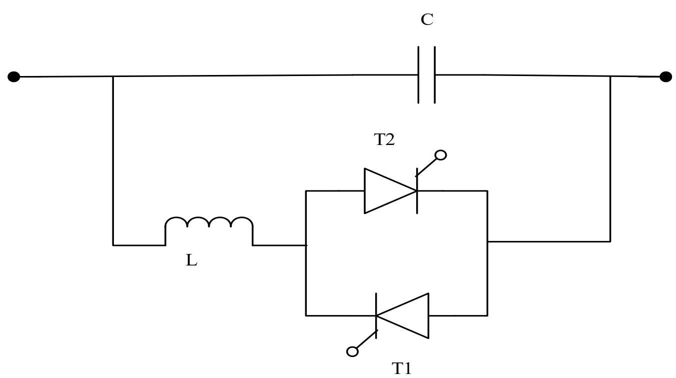

Figure 1: Schematic diagram of TCSC

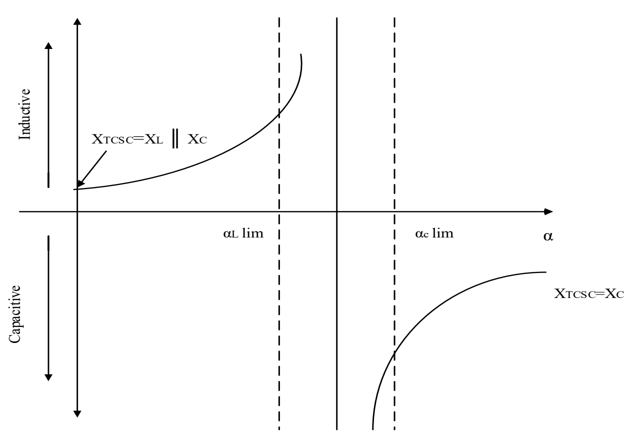

Figure 2: Variation of impedance in case of TCSC

B. Static Modelling

Figure 3 (a) shows a simple transmission line represented by its lumped π equivalent parameters connected between bus a and bus-b. Let complex voltage at bus-a and bus-b are $V_a\angle\delta a$ and $V_b\angle\delta b$, respectively. The real and reactive power flow from bus-a to bus-b can be written as,[4-6]

$$P_{ab} = V_a^2 G_{ab} - V_a V_b [G_{ab}\cos(\delta_{ab}) + B_{ab}\sin(\delta_{ab})] \quad (1)$$

$$Q_{ab} = -V_a^2 (B_{ab} + B_{sh}) - V_a V_b [G_{ab}\sin(\delta_{ab}) - B_{ab}\cos(\delta_{ab})] \quad (2)$$

Where similarly, the real and reactive power flow from bus-j to bus-I is,

$$P_{ba} = V_b^2 G_{ab} - V_a V_b [G_{ab}\cos(\delta_{ab}) - B_{ab}\sin(\delta_{ab})] \quad (3)$$

$$Q_{ba} = -V_b^2 (B_{ab} + B_{sh}) + V_a V_b [G_{ab}\sin(\delta_{ab}) + B_{ab}\cos(\delta_{ab})] \quad (4)$$

The transmission line model with a TCSC connected between bus-a and bus-b is shown in Figure 3 (b) Table 1. During the steady-state, the TCSC can be considered as a static reactance - jx_c. The real and reactive power flow from bus-a to bus-b, and from bus-b to bus-a of a line having series impedance and a series reactance are,

$$P_{ab}^c = V_a^2 G'_{ab} - V_a V_b [G'_{ab}\cos(\delta_{ab}) + B'_{ab}\sin(\delta_{ab})] \quad (5)$$

$$Q_{ab}^c = -V_a^2 (B'_{ab} + B_{sh}) - V_a V_b [G'_{ab}\sin(\delta_{ab}) - B'_{ab}\cos(\delta_{ab})] \quad (6)$$

$$P_{ba}^c = V_b^2 G'_{ab} - V_a V_b [G'_{ab}\cos(\delta_{ab}) - B'_{ab}\sin(\delta_{ab})] \quad (7)$$

$$Q_{ba}^c = -V_b^2 (B'_{ab} + B_{sh}) + V_a V_b [G'_{ab}\sin(\delta_{ab}) + B'_{ab}\cos(\delta_{ab})] \quad (8)$$

The active and reactive power loss in line with having TCSC can be written as,

$$P_L = P_{ab} + P_{ba} = G'_{ab}(V_a^2 + V_b^2) - 2V_a V_b G'_{ab}\cos(\delta_{ab}) \quad (9)$$

$$Q_L = Q_{ab} + Q_{ba} = -(V_a^2 + V_b^2)(B'_{ab} + B_{sh}) + 2V_a V_b B'_{ab}\cos(\delta_{ab}) \quad (10)$$

Where

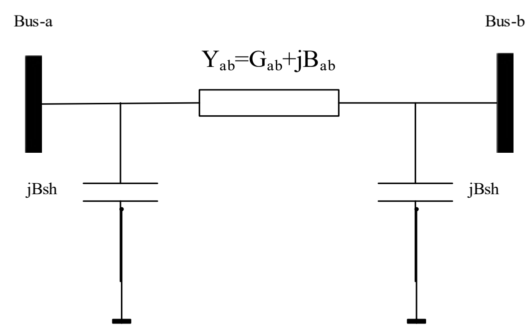

Figure 3 (a): Model of Transmission line

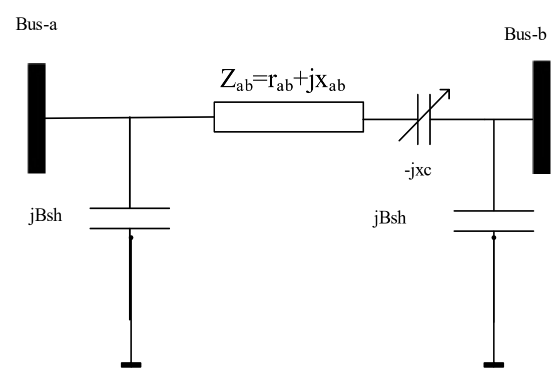

Figure 3 (b): Model of TCSC

$$G'_{ab} = \frac{r_{ab}}{r_{ab}^2 + (x_{ab} - x_c)^2}$$

and

$$B'_{ab} = \frac{-(x_{ab} - x_c)}{r_{ab}^2 + (x_{ab} - x_c)^2}$$

The change in the line flow due to series capacitance can be represented as line without series capacitance with power injected at the receiving and sending ends of the line, as shown in Figure 3(c). The real and reactive power injections at bus-a and bus-b can be expressed as,

$$P_{ac} = V_a^2 \Delta G_{ab} - V_a V_b [\Delta G_{ab} \cos(\delta_{ab}) + \Delta B_{ab} \sin(\delta_{ab})] \quad (11)$$

$$P_{bc} = V_b^2 \Delta G_{ab} - V_a V_b [\Delta G_{ab} \cos(\delta_{ab}) - \Delta B_{ab} \sin(\delta_{ab})] \quad (12)$$

$$Q_{ac} = -V_a^2 \Delta B_{ab} - V_a V_b [\Delta G_{ab} \sin(\delta_{ab}) - \Delta B_{ab} \cos(\delta_{ab})] \quad (13)$$

$$Q_{bc} = -V_a^2 \Delta B_{ab} + V_a V_b [\Delta G_{ab} \sin(\delta_{ab}) + \Delta B_{ab} \cos(\delta_{ab})] \quad (14)$$

Where,

$$\Delta G_{ab} = \frac{x_c r_{ab} (x_c - 2x_{ab})}{(r_{ab}^2 + x_{ab}^2)(r_{ab}^2 + (x_{ab} - x_c)^2)}$$

And

$$\Delta B_{ab} = \frac{-x_c (r_{ab}^2 - x_{ab}^2 + x_c x_{ab})}{(r_{ab}^2 + x_{ab}^2)(r_{ab}^2 + (x_{ab} - x_c)^2)}$$

Due to the high cost involved in FACTS devices, it is necessary to find out the optimal location of FACTS devices in a transmission network.

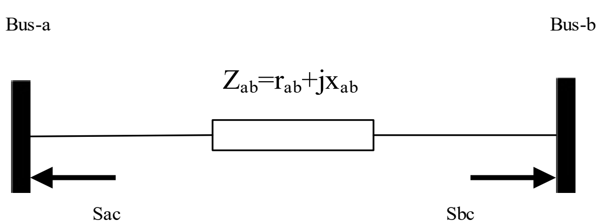

Figure 3 (c): Injection Model of TCSC

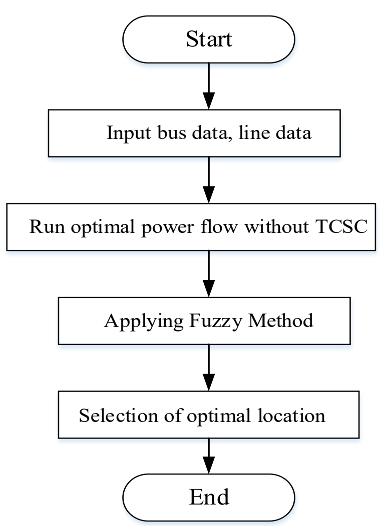

Figure 4: Flow chart for the proposed method for effective location of TCSC in network

Optimal Location of TCSC

The proposed approach of fuzzy method algorithm for effective location of TCSC in the network to relieve congestion: (Figure 4)

Following flow chart followed for the effective location of TCSC in the network. By using this flow chart, congestion relief is possible in a given network.

Applying fuzzy method for locating TCSC to relieve congestion Figure 5 . In the given algorithm Fuzzy method has the following steps:

a) Fuzzification: In fuzzification where input variables are mapped into fuzzy variables. Power flowing through the line before compensation (P_{line}) and power flowing through line after series compensation (ΔP_{line}) are fuzzy input variables considered in this paper. The membership functions of input variables are shown in Figures 6 and 7. To relieve congestion, the location for placement of TCSC is considered as a major challenge. Therefore, the change in power loss (ΔP_{loss}) is taken as an output variable. The membership function of the output variable is shown in Figure 8 and also the fuzzy variables for the test case are shown in Table 2.

b) Range selection for fuzzy subsets: The ranges of input and output variables selected for fuzzy subsets.

c) Fuzzy control rules: To begin with P_{line} and ΔP_{line}, values will be converted into fuzzy variables. After the fuzzification, fuzzy inputs enter the inference mechanism level and consider membership function and rules; outputs are sent to defuzzification to calculate the final outputs. Each rule of

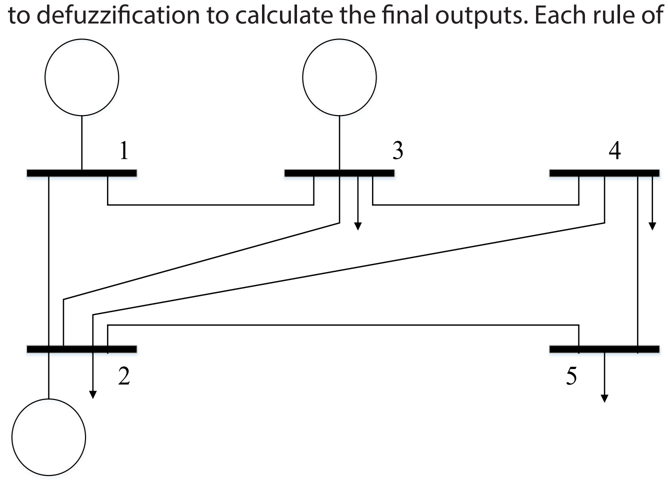

Figure 7: 5-Bus System

Power flow of above 5-Bus system are calculated.

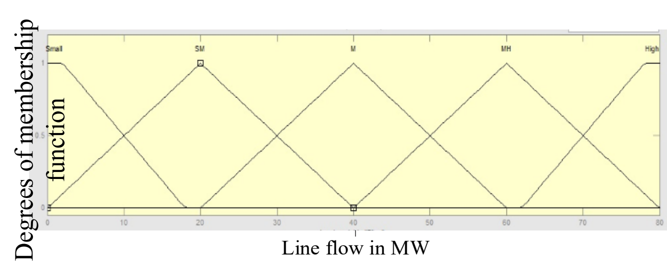

Figure 5: Membership function of input variable-P_{line}. Membership function of input variable- ΔP_{line}

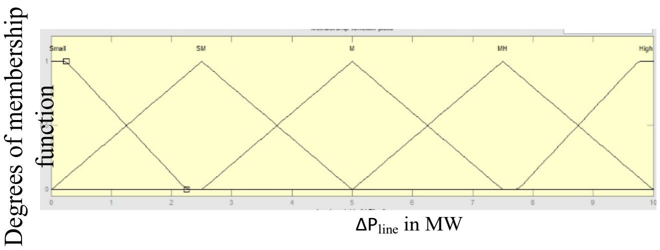

Figure 6:. Membership function of input variable-ΔP_{line}. Output variable membership function- ΔP_{loss}

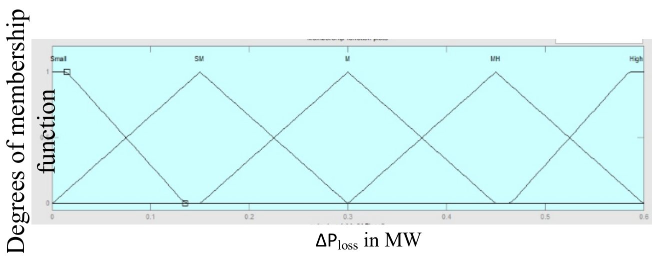

Figure 8: Membership function of output variable-ΔP_{loss}.

Table 1: Line flow before and after compensation in 5-bus system

Line	i-j	Power flow without TCSC in MW	After TCSC in line in MW		
			Line 1-2	*Line 2-5*	*Line 2-3*
1	1-2	74.513	67.278	72.627	73.042
2	1-3	28.816	36.184	31.140	30.271
3	2-3	13.573	10.398	17.203	9.341
4	2-5	57.721	56.418	47.697	58.647
5	3-4	51.672	55.0584	57.474	48.893

Membership function of input variable- P_{line}

Table 2: The fuzzy input and output variables for 5-bus system

Line	i-j	Input Variable in MW		Output variable in MW
		P_{line}	ΔP_{line}	ΔP_{loss}
1	1-2	74.513	7.235	0.428
2	1-3	28.863	-7.364	0.0511
3	2-3	13.738	3.175	0.144
4	2-5	67.093	1.303	0.133
5	3-4	56.315	-3.912	0.046

Table 3: Fuzzy based priority table for location of TCSC for 5 bus systems

Line	i-j	Priority for placing TCSC
1	1-2	1
2	1-3	5
3	2-3	2
4	2-5	3
5	3-4	4

fuzzy control follows the basic if then rule. In this work, for both the inputs P_{line} and ΔP_{line} and the output ΔP_{loss}, five fuzzy subsets are used. They are S (small), SM (Small medium), M (Medium), MH (medium-high), and H (High). The triangular membership functions are used for the above sub-sets.

d) Defuzzification: After evaluating inputs and applying them to the rule base, the fuzzy-logic controller will generate a control signal. The output variables of the inference system are linguistic variables. This will be evaluated for the derivation of the output control signal. This process is defuzzification.

Simulation Results

To find out optimal location of TCSC by fuzzy method, the analysis has been implemented on a 5-bus system as shown in Figure 7 below. MATLAB has been used for simulation.

The defuzzyfied results obtained on 5-bus system were compared with the output variable (ΔP_{loss}) of each line and found that line 1 to 2 is suitable compared to other lines. Hence, line 1 to 2 is considered as the optimal location for placement of TCSC to relieve congestion. By locating TCSC in line 1 to 2, the power flow reduced in lines 2 to 3 from 13.573 to 10.398 MW.

Fuzzy rules have been applied to the overloaded lines and results tabulated in priority Table 3. The parameters of ΔP_{loss} and ΔP_{line}, are being considered for the optimum location of TCSC to relieve congestion. Results obtained from fuzzy and conventional methods[7] confirmed that the FACTS device's optimum location is between lines 1 to 2 to relieve congestion for the considered power system. If the first optimal location is not suited, then 2 or 3 optimal locations can be considered based on priority Table 3.

The proposed method's advantage helped form the priority list for TCSC device location to relieve congestion directly from fuzzy results and avoid excessive computation.

Conclusion

From the above discussion, it is observed that congestion is a major issue in the deregulated power system and needs to be solved on an urgent basis. FACTS devices are useful for reducing power flow in heavily loaded lines due to their advantages. Because of FACTS devices' considerable costs, it is important to obtain an optimal location for placement of these devices.

In this paper, the fuzzy method is proposed for optimal placement of TCSC to control the active power flows for congestion management. The simulations are carried out successfully on the 5-bus system. The fuzzy technique results are compared to the solution given by the conventional sensitivity method. The comparison confirmed the efficiency of the proposed method, and the results could be effectively used for determining the optimal location of TCSC to solve the congestion problem in a power system network. Hence, fuzzy method is an alternative means of dealing with congestion and can be applied easily to any buses to relieve congestion in a power system.

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