

problem in the power system network by suitably placing a FACTS devices.

2. Modeling of TCSC & UPFC

2.1 Modeling of TCSC

For static application like congestion management FACTS devices can be modeled as Power Injection Model [1]. 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. The advantage of power injection model is that it does not destroy the symmetrical characteristic of the admittance matrix and allows efficient and convenient integration of FACTS devices into existing power system analytical tools. During steady state operation, TCSC can be considered as an additional reactance $-jx_c$. The value of x_c is adjusted according to control scheme specified. Fig. 1(a) shows a model of transmission line with one TCSC which is connected between bus-i and bus-j.

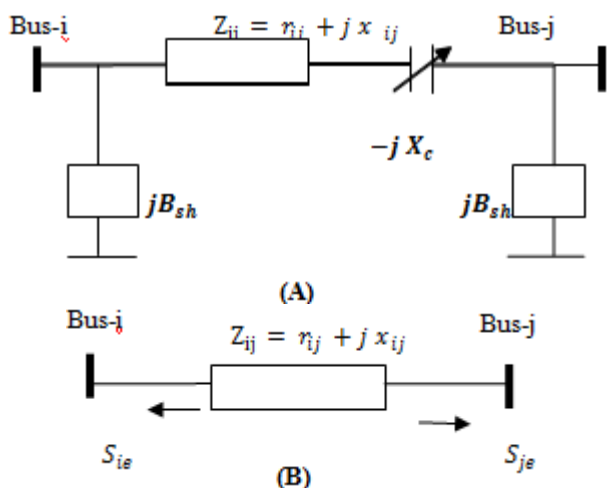


Figure1: (A) TCSC Model; (B) Injection Model Of TCSC

The real power injections at bus- i (p_{ic}) and bus- j (p_{jc}) are given in the below equations are given by [2].

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

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

Similarly, the reactive power injections at bus- i (Q_{ic}) and bus- j (Q_{jc}) are given by below equations.

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

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

$$\text{Where: } \Delta G_{ij} = \frac{x_c r_{ij} (x_c - 2x_{ij})}{(r_{ij}^2 + x_{ij}^2)(r_{ij}^2 + (x_{ij} - x_c)^2)} \quad (5)$$

$$\Delta B_{ij} = \frac{-x_c (r_{ij}^2 - x_{ij}^2 + x_c x_{ij})}{(r_{ij}^2 + x_{ij}^2)(r_{ij}^2 + (x_{ij} - x_c)^2)} \quad (6)$$

Where ΔG_{ij} and ΔB_{ij} are the change in conductance and change in susceptance of the line i-j.

2.2 Modeling of UPFC

The UPFC, which was first proposed by Gyugi in 1991[3], consists of shunt (exciting) and series (boosting) transformers as shown in Fig2. Both transformers are connected by two-gate turn off (GTO) converters and a DC circuit represented by the capacitor. Converter 1 is primarily used to provide the real power demand of converter 2 at the common DC link terminal from the AC power system.

Converter 1 can also generate or absorb reactive power at its AC terminal, which is independent of the active power transfer to (or from) the DC terminal. Therefore with proper control, it can also fulfill the function of an independent advanced static VAR compensator providing reactive power compensation for the transmission line and thus executing indirect voltage regulation at the input terminal of the UPFC. Converter 2 is used to generate a voltage source at the fundamental frequency with variable amplitude ($0 \leq V_T \leq V_{Tmax}$) and phase angle ($0 \leq \phi_T \leq 2\pi$), which is added to the AC transmission line by the series connected boosting transformer. The inverter output Voltage injected in series with line can be used for direct voltage control, series compensation, phase shifter and their combinations. This voltage source can internally generate or absorb all the reactive power required by the different type of controls applied and transfers active power at its DC terminal.

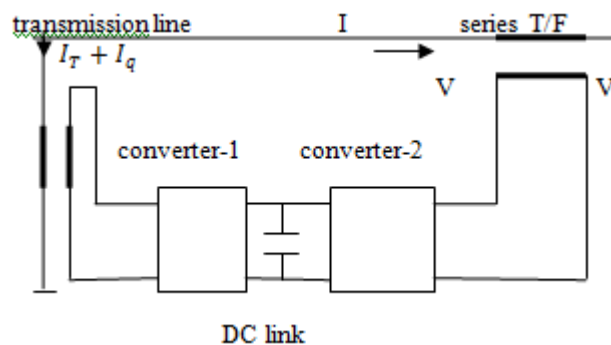


Figure 2: The UPFC basic Circuit Arrangement [3]

With these features, UPFC is probably the most powerful and versatile FACTS device which combines the properties of TCSC, TCPAR and SVC. It is only FACTS device having the unique ability to simultaneously control all three parameters of power flow, voltage, line impedance and phase angle. Therefore, when the UPFC concept was developed in 1991, it was recognized as the most suitable and innovative FACTS device.

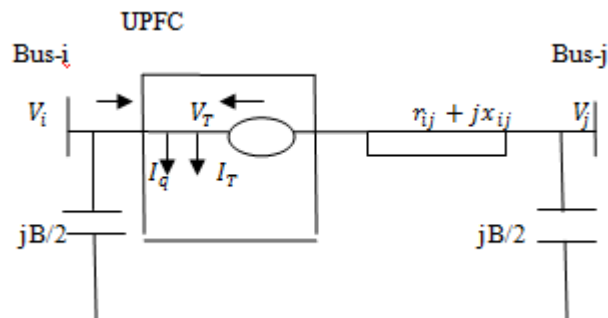


Figure 3: The UPFC Placed Between Bus-i And Bus-j

3. Methodology

3.1 Sensitivity methods for congestion management

These approaches are based upon a new factor, With the help of this factor the level of congestion in transmission line can be determined.

Line utilization factor (LUF)

It is the measure of utilization of a particular line or overall system. It gives an idea about how much percentage of the line is used for the power flow. If the value of utilization is less, it means that less power has been transferred and the system will be less congested and vice-versa [4].

$$LUF_{ij} = \frac{MVA_{ij}}{MVA_{ij}^{MAX}} \quad (7)$$

Where,

LUF_{ij} is the line utilization factor of the line connected to bus- i and bus-j.

MVA_{ij}^{MAX} is the mega volt ampere (MVA) rating of the line between bus- i and bus- j.

MVA_{ij} is the actual MVA rating of the line between bus- i and bus-j.

3.2 Proposed approach

Step by step algorithm to relieve congestion for an IEEE 14-bus system [4].

Step 1: Run power flow for a standard IEEE 14-bus system and calculate LUF for the test system.

Table1 shows the LUF of each line in a 14-bus system. If the utilization reaches a high value, it indicates that the system is more congested

Step 2: conduct power flow analysis for the congested lines before and after series compensation. In this paper, 50% of line compensation is used. The maximum utilized and congested lines 1 to 2, 3 to 4, and one of the minimum utilized line 9 to 10 are considered. The FACTS devices is placed on these lines individually and analyzed. The changes in line flow in the considered lines are shown in Table 2.

From Table 2, it is observed that line flows are reduced in the maximum congested lines. However, no significant effect is observed in the minimum congested line. The above method if applied for all the lines, involves a lot of computation. Hence, fuzzy method is applied for simplifying the procedure.

Step 3: Applying fuzzy method for locating FACTS devices to relieve congestion.

A.) Fuzzification: Fuzzification is a process where the inputs variables are mapped into fuzzy variables. The Fuzzy input variables considered in this paper are line flows before compensation (P_{Line}) and change in line flow after series compensation (ΔP_{line}).

To relieve congestion, the location for placement of FACTS devices is considered as a major issue. Hence, FACTS devices can be placed where the low power loss occurs in the line. Therefore, the change in power loss (ΔP_{loss}) is taken as an output variable. The fuzzy variables for the test case are shown in Table 3.

Table I: Power flows and LUF for IEEE 14-Bus System

Bus No.	Line i-j	Line flow (MW)	Line capacity (MW)	% Line utilization factor (LUF)
1	1-2	156.8924	184.155	85.1958
2	1-5	75.5090	128.816	58.6177
3	2-3	73.2480	129.989	56.3494
4	2-4	56.1131	98.35	57.0545
5	2-5	41.5331	60	69.2219
6	3-4	-23.2759	-24.765	93.9872
7	4-5	-61.0204	97.847	62.3630
8	4-7	27.9856	59.011	47.4244
9	4-9	16.0218	25.093	63.8495
10	5-6	44.2422	59.753	74.0418
11	6-11	7.4332	14.059	52.8715
12	6-12	7.8103	15.24	51.2489
13	6-13	17.7986	29.544	60.2445
14	7-8	0.0065	0.01809	35.9315
15	7-9	27.9856	53.602	52.2100
16	9-10	5.1521	13.189	39.0636
17	9-14	9.3553	15.058	62.1282
18	10-11	-3.8596	-14.012	27.5446
19	12-13	1.6378	6.9959	23.4108
20	13-14	5.7146	15.129	37.7725

B.) Range selection for fuzzy subsets:

The ranges of input and output variables for the test case are shown in Table 4.

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 to inference mechanism level and with considering membership function and rules, outputs are sent to defuzzification to calculate the final outputs. Each rule of 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) and 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 is known as defuzzification. The defuzzification has been achieved using the centre of gravity (COG) method and the output of the fuzzy coordinated controller is COG (set of real numbers).

$$COG(A) = \frac{\sum_{Xmin}^{Xmax} XA(X)}{\sum_{Xmin}^{Xmax} A(X)} \quad (8)$$

Where; $Xmin = 1$; $Xmax = 25$; $A(x) = P_{Loss}$, $X =$ Membership function.

Corresponds to the value of controlled output for which the membership values in the output sets are equal to unity. In

this method ‘AND’ relationship between mappings of two variables are considered.

Step 4 (Analysis of the fuzzy method): The output result of the proposed fuzzy method is analyzed. The defuzzified results are compared with the change in power loss of each line and optimized for the location to place the FACTS devices to relieve congestion

Table 3: Line Flow Before And After Compensation In IEEE 14-Bus System

S No.	Line i-j	Before TCSC	After TCSC Line 1-2	After TCSC Line 3-4	After TCSC Line 9-10
1	1-2	156.8924	146.1199	157.6241	156.8800
2	1-5	75.5090	86.1361	74.7035	75.5224
3	2-3	73.2480	71.5412	76.7410	73.2362
4	2-4	56.1131	52.5112	54.4962	56.0943
5	2-5	41.5331	36.6800	40.3481	41.5521
6	3-4	-23.2759	-24.8773	-20.0067	-23.2870
7	4-5	-61.0204	-65.7558	-59.2735	-60.8664
8	4-7	27.9856	27.7844	28.0534	27.8688
9	4-9	16.0218	15.9060	16.0594	15.9557
10	5-6	44.2422	44.5638	44.1359	44.4290
11	6-11	7.4332	7.6297	7.3669	7.7377
12	6-12	7.8103	7.8347	7.8035	7.7870
13	6-13	17.7986	17.8994	17.7655	17.7043
14	7-8	0.0065	0.0011	0.0090	0.0001
15	7-9	27.9856	27.7844	28.0534	27.8688
16	9-10	5.1521	4.9583	5.2179	4.8535
17	9-14 10-11	9.3553	9.2322	9.3949	9.4710
18	12-13	-3.8596	-4.0529	-3.7938	-4.1570
19	13-14	1.6378	1.6618	1.6310	1.6148
20		5.7146	5.8373	5.6751	5.5993

Table 4: The Fuzzy Inputs and Output Variables For IEEE 14-Bus System

Line	Input variable Line flow(MW)	Input variable ΔP_{line} (MW)	Output variable ΔP_{Loss} (MW)
1-2	156.8924	10.772	0.919
1-5	75.5090	-10.627	0.094
2-3	73.2480	1.707	0.460
2-4	56.1131	3.602	0.372
2-5	41.5331	4.853	0.250
3-4	-23.2759	1.601	0.237
4-5	-61.0204	4.735	0.081
4-7	27.9856	0.201	0.250
4-9	16.0218	0.116	0.250
5-6	44.2422	-0.322	0.250
6-11	7.4332	-0.196	0.250
6-12	7.8103	-0.024	0.250
6-13	17.7986	-0.101	0.250
7-8	0.0065	0.005	0.250
7-9	27.9856	0.201	0.250
9-10	5.1521	0.194	0.250
9-14	9.3553	0.123	0.250
10-11	-3.8596	0.193	0.250
12-13	1.6378	-0.024	0.250
13-14	5.7146	-0.123	0.250

Table 5: Ranges of the Fuzzy Input and Output Variable for IEEE 14-Bus System

Fuzzy subsets	Input variable Line flows(MW)	Input variable Change in line flow ΔP_{Line} (MW)	Output variable Change in Power loss ΔP_{Loss} (MW)
Small	< 15	< 1.25	< 0.002
Small medium	5-45	1-2	0.001-0.01
Medium	35-75	1.5-4	0.009-0.2
Medium high	65-105	3-6	0.09-1
High	>100	>5	>0.5

4. Results and Discussion

To minimize the congestion, the fuzzy based analysis is carried out on standard IEEE 14-bus system. The proposed method is carried in the MATLAB software environment. By locating TCSC in the line 1 to 2, the percentage of LUF has reduced from 84.7357% to 78.9176%. and by locating UPFC in the line 1 to 2, the percentage of LUF has reduced from 84.7357% to 78.0624%

Priority list would capture the congested lines as well as the neighborhood lines that are linked to the congested lines through which the power can be diverted after placement of FACTS devices. The number of lines to be considered for the priority list depends upon the size of the system, and has no hard and fast rule. However, it should at least be greater than the number of congested line in the system. Fuzzy rules have been applied to the overloaded lines and results tabulated in priority Table 5.

Results obtained from fuzzy method, the optimum location of FACTS devices in between the lines 1 to 2 , to relieve congestion for the considered power system. It is observed from priority table that the placement of FACTS devices in the line 1 to 2 is suitable for relieving congestion in the transmission line. If the first optimal location is not suited, then 2 or 3 optimal locations can be considered based on priority Table 5. The advantage of the proposed method helped to form the priority list, for series FACTS device location to relieve congestion directly from fuzzy results and avoid excessive computation. Only few lines in the priority list need to be examined in detail to assess the best location to relieve congestion.

Table 5: Fuzzy Based Priority Table For Location Of UPFC For IEEE 14-Bus System

S No.	TCSC location in line	%LUF	Priority for placing TCSC using fuzzy
1	1-2	85.20	1
2	2-3	56.35	2
3	2-4	57.05	3

Table 6: The LUF for the System before and after compensation in 1 and 2 line

S No.	Line i-j	Before Device	With TCSC	With UPFC
1	1-2	84.7357	78.9176	78.0624
2	1-5	58.6177	66.8675	69.2817
3	2-3	56.3494	55.0364	53.6584
4	2-4	57.0545	53.3922	53.0408
5	2-5	69.2219	61.1334	59.8785
6	3-4	90.3393	80.8622	86.3465
7	4-5	-62.3630	-67.2027	-70.4051
8	4-7	47.4244	47.0835	48.2083
9	4-9	63.8495	63.3883	65.4447
10	5-6	74.0418	74.5800	72.5328
11	6-11	52.8715	54.2691	49.5192
12	6-12	51.2489	51.4085	50.3633
13	6-13	60.2445	60.5857	59.2446
14	7-8	35.9315	6.0807	6.0807
15	7-9	52.2100	51.8347	53.0730
16	9-10	39.0636	37.5941	42.5141
17	9-14	62.1282	61.3108	64.8361
18	10-11	27.5446	28.9246	24.3504
19	12-13	23.4108	23.7534	21.5549
20	13-14	37.7725	38.5838	35.1038

5. Conclusion

Congestion management is an important issue in deregulated power systems. In this paper, fuzzy method is proposed for optimal placement of FACTS device to control the active power flow for congestion management. The sensitivity parameters are used in comparing the alternative locations available for generation capacity and percentage of congestion. The simulations are carried out successfully on the IEEE 14-bus system. The fuzzy technique results of TCSC are compared with the results of UPFC. The comparison confirmed that the UPFC results relieve congestion in better than TCSC. Hence fuzzy method is an alternative means of dealing with congestion and can be applied easily to any number of buses to relieve congestion in a power system.

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