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# Comparison of Facts Devices to Relieve Congestion in Deregulated Power Sector by Using Fuzzy Technique

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**Abstract:** ***The research work described in this paper concentrates on the application of Flexible Alternative Current Transmission System (FACTS) controllers as a solution to the problem of congestion management. The congestion occurs when the generation and consumption of electric power causes the transmission system to operate beyond transfer limits. A line utilization factor (LUF) is used to determine the level of congestion in a transmission line. This paper proposes a fuzzy technique to determine optimal location for FACTS devices like Thyristor Controlled Series Capacitor (TCSC) & Unified-Power-Flow Controller (UPFC) to relieve congestion in transmission system. Among these two FACTS devices UPFC is better to relieve congestion than TCSC. The method has been successfully demonstrated on IEEE 14-bus system.***

**Keywords:** Flexible Alternative Current Transmission System (FACTS), Thyristor Controlled Series Capacitor (TCSC), Congestion Management, Line Utilization Factor (LUF), Fuzzy Logic Controller, Unified-Power-Flow Controller (UPFC).

## 1. Introduction

Electrical power generation in our country has been a bigger challenge to meet the growing demands for more power. The demand is increasing due to rapid industrialization, urbanization and increase in population of the developing countries. As a measure to meet the increasing demand ensuring adequate availability and reliability, private participation is being encouraged. Because of this, the power trading and grid maintenance becomes complex issues. Among them, congestion management is a prime issue.

When the generation and consumption of electric power causes the transmission system to operate beyond transfer limits, the system is said to be under congestion. Congestion management is the process to avoid or relieve the congestion. In a broader sense, congestion management is considered as a systematic approach for scheduling and matching generation and loads in order to reduce congestion

One of the goals of deregulation of electricity industry was providing cheaper energy for the consumers. Transmission line congestion has prevented achieving this objective by adding the congestion cost to consumers.

The restructuring in electric power sector has lead to larger use of transmission grids. In power market, the power system is operated almost to its rated capacity all the times. Congestion may occur in transmission line due to lack of coordination between generation and transmission utilities. So, congestion management becomes very essential in power systems, to relieve the congestion. Independent system operator (ISO) can use mainly two types of techniques which are as fallows[1].

In general, two paradigm methods were employed to relieve congestion in transmission lines.

### 1.1 Cost-Free

- Out-aging of congested lines.
- Operation of transformer taps/ phase shifters.
- Operation of FACTS devices.

### 1.2 Non-Cost-Free

- Re-dispatch of generation in a manner different from the natural settling point of the market. Some generators back down while others increase their output. The effect of this is that generators no longer operate at equal incremental costs.
- Curtailment of loads and the exercise of (not- cost-free) load interruption options.

Among the above two types we are going for cost-free because they posses many advantages as compared with the other techniques. It relieves congestion technically while non-cost free relieves economically, and generation companies & distribution companies will not be involved. In this paper FACTS device are used to relieve the congestion. proper location is a key to maximize the benefits of the expensive FACTS devices.

The objective of this paper is to develop a fuzzy based algorithm to relieve congestion by optimal locating FACTS devices in a transmission line. A line utilization factor (LUF) is used to determine the level of congestion in an transmission line.

These sensitivity parameters are used in comparing the alternative locations available for generation capacity and percentage of congestion. The proposed algorithm is tested in successfully on the IEEE 14-bus system. The fuzzy based results of TCSC are compared with the results of UPFC. This comparison confirms the efficiency of the proposed method, which makes it promising to solve the congestion

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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 –jxc. The value of xc 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.

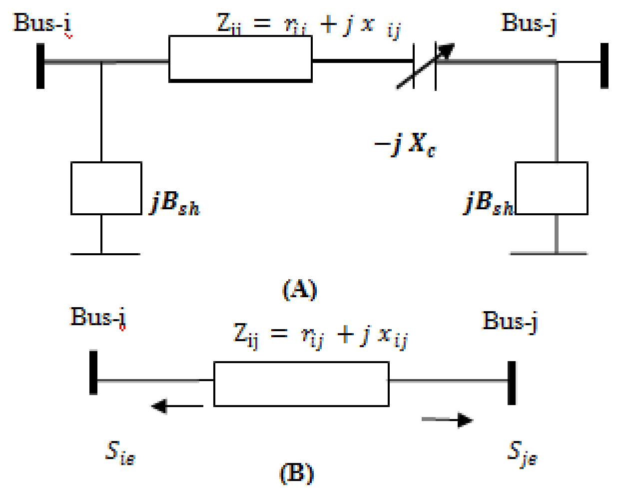


**Figure1:** (A) TCSC Model; (B) Injection Model Of TCSC

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 (Qic) and bus- j (Qjc) are given by below equations.

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

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

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 $\Delta G_{ij}$ and $\Delta B_{ij}$ 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 ($0 \le V_T \le V_T\max$) and phase angle ($0 \le \phi_T \le 2\pi$), 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.

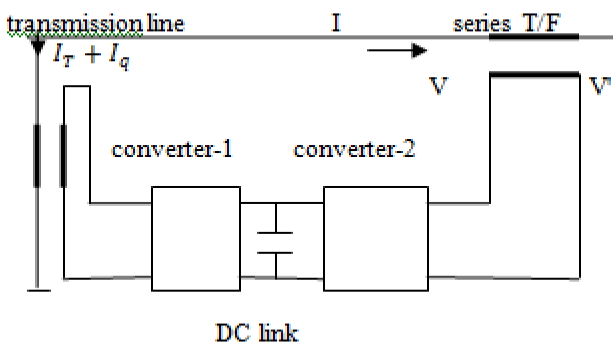


**Figure 2:** The UPFC basic Circuit Arrangement [3]

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.

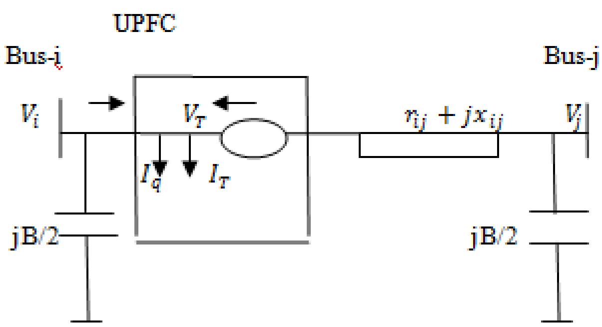


**Figure 3:** The UPFC Placed Between Bus-i And Bus-j

## 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].

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

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 ($\Delta P_{line}$).

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 ($\Delta P_{loss}$) 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 $\Delta P_{line}$. 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 $\Delta P_{line}$ and the output $\Delta P_{loss}$, 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).

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

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 defuzzyfied 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 $\Delta P_{line}$ (MW) | Output variable $\Delta P_{Loss}$ (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 $\Delta P_{Line}$(MW) | Output variable Change in Power loss $\Delta P_{Loss}$ (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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