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Placement of shunt FACTS Devices for maximum power transfer capability in a Series Compensated LT Line

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ABSTRACT

Maximum power transfer capability in the transmission line is the utmost important consideration in power systems. VAR Compensator (SVC) and Static Synchronous Compensator (STATCOM) are important devices in FACTS family, and is widely recognized as an effective and economical means to solve the power system stability problem. SVC and STATCOM are used as shunt in transmission system. In the present work a series compensated long transmission line with a shunt FACTS device considered for the optimal location of the shunt FACTS devices to get the highest possible benefits of maximum power transfer and system stability. The Effect of degree of change in series compensation on the optimal location of the shunt Facts devices in terms of power transfer capability and stability of the system. This paper presents a two stage approach, a conventional method is used to determine the optimal location of shunt facts device in a series compensated line and then fuzzy logic is used to determine the optimal placement. The proposed method is considered for 13.8KV Base, 6*350 MVA and 450 km long transmission line. All the simulations for the above work have been carried out using MATLAB /SIMULINK software.

Key words: Fuzzy logic controller, Maximum power transfer capability, optimal placement, Statcom, svc, series compensation.

I. INTRODUCTION

Over the past two decades, electric power systems have experienced a continuous increase in power demand without a matching expansion of the transmission and generation facilities. Worldwide transmission systems are undergoing continuous change due to steady growth in demand for electric power, most of which has to be transmitted over a long distances. It is not that much is easy to construct an new plant or placing an additional machine for power generation to meet the load .However there are some short term methods to meet the demand, In which the Transmission interconnections are enables taking advantages of diversity of loads, availability of sources and fuel prices in order to supply at minimum cost with required reliability. In order to meet demand by choosing a power delivery system was made up of radial lines from individual plants i.e. Local generators without being part of a grid system. This makes many more generation resources would be needed to serve the load with the same reliability and the cost of electricity would be much higher. With these perspectives, transmission capability is often an alternative for a new generation resource less transmission capability means that more generation Resources are required regardless of whether the system is made up of large or small power plants.

As power systems have evolved through continue growth in interconnections with use of new technologies controllers. This increased operation in interconnections makes system operation is in highly stressed conditions and results system instability. For a Interconnected system voltage stability, frequency stability, inter area oscillation have become greater concerns for effective operation. The FACTS technology opens up new opportunities for controlling and enhancing the usable power capacity of present, as well as new upgraded lines. These opportunities arise through the ability of FACTS controllers to control the interrelated parameters that governs the operation of transmission system including series impedance, current, voltage and phase angle damping of oscillations.

FACTS devices are capable of controlling the network condition in a quick manner and this unique feature of FACTS devices can be exploited to improve the transient stability of the system. Reactive power compensation is an important issue in electrical power systems and Shunt FACTS devices play an important role in controlling the reactive power flow to the power network and hence the system voltage fluctuations and transient stability. The FACTS are now recognized as a viable solution for controlling the transmission voltage, power flow, dynamic response and also represents a new era for transmission systems. It uses high-current power electronic devices to control the voltage, power flow, etc. of a transmission system. FACTS devices are very effective and capable of increasing the power transfer capability of a line, if the thermal limit permits. While maintaining the same degree of stability FACTS controllers can enable to carry power transfer closer to its thermal rating. FACTS technology also lends itself to extending usable transmission limits in a step-by-step manner with incremental investment as and when required.

2. MODELING OF SHUNT FACTS DEVICES

STATCOM and SVC are members of FACTS family that are connected in shunt with the system. Even though the primary purpose of shunt FACTS devices is to support bus voltages by injecting (or absorbing) reactive power and also capable of improving the transient stability by increasing (decreasing) the power transfer capability when the machine angle increases (decreases), which is achieved by operating the shunt FACTS devices in capacitive (inductive) mode.

2.1 STATCOM

STATCOM is one of the important shunt connected Flexible AC Transmission Systems (FACTS) controllers to control power flow and make better transient stability. The basic structure of STATCOM is shown in Figure 1. It regulates voltage at its terminal by changing the amount of reactive power in or out from the power system. When system voltage is low, the STATCOM inject reactive power. When system voltage is high, it absorbs reactive power.

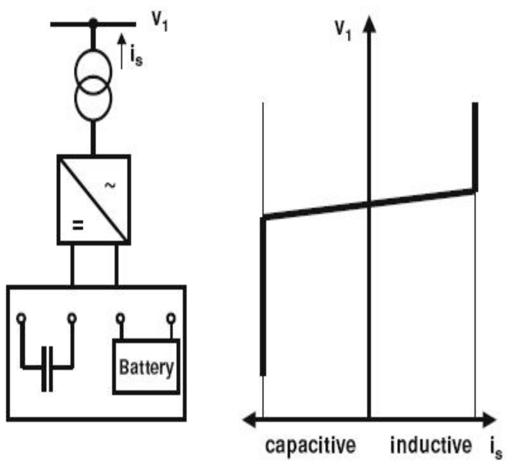

Figure 1: V-I Characteristics Of Statcom

2.2. Operating Principle of the STATCOM

The operating principle of STATCOM is explained in the figure1 showing the active and reactive power transfer between a power system and a VSC. In this figure3, V1 denotes the power system voltage to be controlled and V2 is the voltage produced by the VSC.

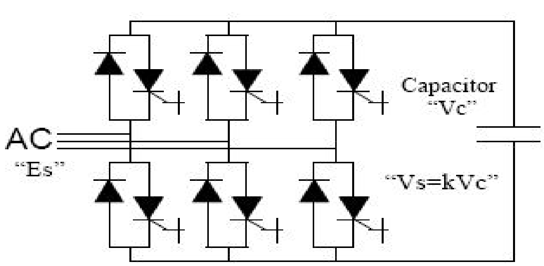

Figure 2: 6-pulse Statcom

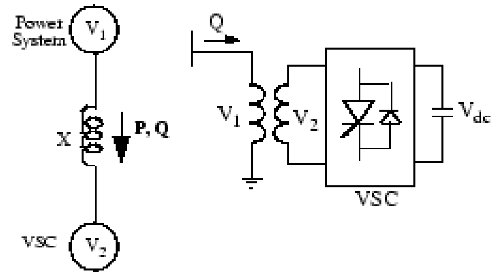

Figure 3: Schematic Diagram of Statcom

During steady state working condition the voltage V2 produced by the VSC is in phase with V1, so that only reactive power is flow (Active power P=0). If the magnitude of voltage V2 produced by VSC is less than the magnitude of power system voltage V1 reactive power Q is flowing from power system to VSC (STATCOM is absorbing reactive power mode). If V2 is greater than V1, Q is flowing from VSC to power system (STATCOM is producing reactive power mode). If V2 is equal to V1 the reactive power exchange is zero. The amount of reactive power is given by

$$Q= V_1(V_1 - V_{2)})/X$$

2.3 SVC

The static VAR compensator (SVC) is a shunt device of the flexible AC transmission systems (FACTS) family using power electronics to control power flow and improve transient stability on power grids. The SVC regulates voltage at its terminals by controlling the amount of reactive power injected into or absorbed from the power system. Each capacitor bank is switched on and off by three thyristor switches (Thyristor Switched Capacitor or TSC). Reactors are either switched on-off (Thyristor Switched Reactor or TSR) or phase-controlled (Thyristor Controlled Reactor or TCR).

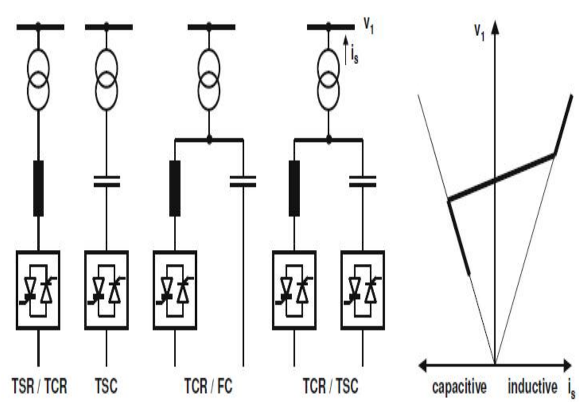

Figure 4: Schematic Diagram of SVC and V-I Characteristics.

The V-I characteristic is described by following three equations, SVC is in regulation range ($-B_{cmax} < B < B_{lmax}$),

$$V=I/B_{cmax}$$

$$V = V_{ref} + X_s . I$$

SVC is fully capacitive (B= (B_{cmax}))

$$V = I / (Bl_{max})$$

SVC is fully capacitive (B= Bl_{max})

Where, V = Positive sequence voltage (p.u.)

I = Reactive current (p.u / P_{base}) (I > 0 indicates an inductive current)

X*s* = Slope or droop reactance (p.u. / P_{base})

3. OBJECTIVES OF THE PROJECT

1. To find the maximum power and the corresponding location of the shunt FACTS devices when the actual line model is considered.
2. To find the optimal location of shunt FACTS device at various series compensation in a long transmission line.
3. To compare the optimal location obtained for both the simplified and fuzzy models of a 345kV, 450km line.

3.1 Transmission line model

In this study, it is considered that the transmission line parameters are uniformly distributed and the line can be modeled by a 2-port, 4-terminal networks as shown in Figure 1.

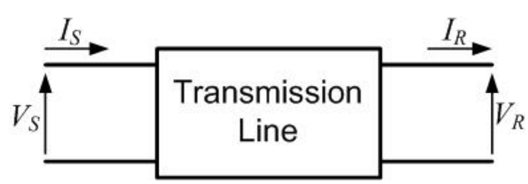

Figure 6: Two port four terminal model of a transmission line.

A transmission line on a per phase basis can be regarded as a two port network, wherein the sending end voltage Vs and current Is are related to the receiving end voltage V_R and current I_R through ABCD constants as

$$V_S = AV_R + BI_R$$

$$I_S = CV_R + DI_R$$

The ABCD constants of a line of length 'L', having a series impedance of 'z' Ω/km and shunt admittance of 'y' S/km are given by

$$A = D = \cosh(\gamma l),$$

$$B = Z_C \sinh(\gamma l),$$

$$C = \sinh(\gamma l)$$

Where, $$Z_C = \sqrt{\frac{Z}{Y}}, \gamma = \sqrt{ZY}$$

Z_C=characteristic impedance of the line.
γ =propagation constant of the line.
z=series impedance/unit length/phase.
y=shunt admittance/unit length/phase to neutral.
L =transmission line length.
α=attenuation constant.
β=phase constant.

3.2 POWER FLOW THROUGH A TRANSMISSION LINE FOR AN ACTUAL LINE MODEL

The principle of power flow through a transmission line is instanced through a single transmission line (2-node/2-bus system). Let us consider receiving-end voltage as a reference phasor (│Vs│∠ δ) and let the sending end voltage lead it by an angle δ is known as the torque angle. The complex power leaving the receiving end and entering the sending-end of the transmission line can be expressed as

$$S_R = P_R + JQ_R = VI^* \quad ..(1)$$

$$S_S = P_S + JQ_S = V_S I_S \quad ..(2)$$

Receiving and sending end currents can be expressed in terms of receiving and sending end voltages.

$$I_S = 1/BV_S\angle(\delta-\beta) - A/BV_r\angle(\alpha-\beta) \quad ..(3)$$

$$I_S = D/BV_S\angle(\alpha+\delta-\beta) - A/BV_r\angle(-\beta) \quad (4)$$

We can write the real and reactive powers at the receiving-end and the sending end as

$$p_s = c_1\cos(\beta-\alpha) - c_2\cos(\beta+\delta) \quad ..(5)$$

$$p_r = c_2\cos(\beta-\delta) - c_3\cos(\beta-\alpha) \quad ..(6)$$

$$Q_s = c_1\sin(\beta-\alpha) - c_2\sin(\beta+\delta) \quad ..(7)$$

$$Q_r = c_2\sin(\beta-\delta) - c_3\sin(\beta-\alpha) \quad ..(8)$$

Where, $C_1 = AV_S^2/B$
$C_2 = V_S V_R/B$
$C_3 - AV_R^2/B$
$A = A\angle\alpha$
$B = B\angle\beta$
$V_S = V_s\angle\delta$
$V_R = V_R\angle 0°$

Consider that the line is transferring power from a large generating station to an infinite bus and equipped with a shunt FACTS device at point m. a parameter 'K' is used to show the fraction of line length at which the FACTS device is placed.

4. POWER FLOW IN A TRANSMISSION LINE WITH FACTS DEVICE

4.1 Shunt FACTS devices in a power system

Consider that the line is transferring power from a large generating station to an infinite bus and equipped with a shunt FACTS device at point m. a parameter k is used to show the fraction of line length at which the FACTS device is placed.

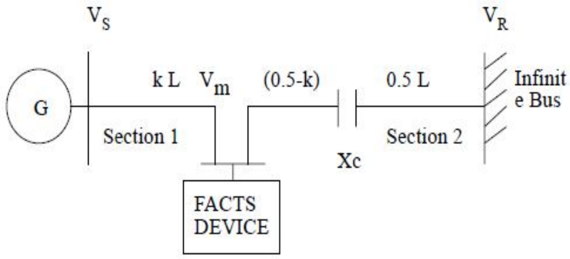

Figure 7: Transmission Line Model

4.1.1 Simplified Model:

The power transfer through the line for given values of SE and RE voltage magnitude is written as

$$P = P_m \sin\delta$$

Here the maximum power P_m is

$P_m = (V_S V_R)/X$

When a shunt FACTS device is connected to the line both P_m and δ_m are increased and their values depend on the k factor. The power transmitted through the line is

$$P_S = \frac{V_S V_M}{KX_L}\sin\delta_S = \frac{V_R V_M}{(1-K)X_L}\sin\delta_R \qquad (9)$$

Here the Sending power (SE) is equal to the Receiving power (RE) because the line is lossless

$P_S = P_O \sin\delta_S/K = P_O \sin\delta_R/(K-1)$

5. CASE STUDY RESULTS AND DISCUSSION

For a simplified model, when there is no FACTS device connected to the line, maximum power transfer through the line is given by

$$P = P_m \sin\delta$$

The optimal location of shunt FACTS device for a simplified model is at K= 0.5 when there is no series compensation in the line. For such cases maximum power transmission capability (Pm) and maximum transmission angle (δ_m) become double. One of the objectives of this paper is to find the maximum power and corresponding location of shunt FACTS device for different series compensation levels (%S) located at the center of the line. A sophisticated computer program was developed to determine the various characteristics of the system of Figure 7 using an actual model of the line sections. The constant of the same RE power of section (1) and SE power of section (2) ($PR1 = PS2$) is incorporated into the problem. In all cases, $V_S = V_R = V_M = 1.0$ p.u. unless specified. The maximum power Pm and corresponding angle δ_m are prior determined for various values of location (K).

Figures 8-12 shows the variation in maximum RE power(P_{Rm}), maximum sending end power and transmission angle (δ_m) at the maximum sending end power, respectively, against (K) for different series compensation levels (%S).It can be noticed from Figures 5 and 6 that $P_{Sm} > P_{Rm}$ for any series compensation level (%S) because of the loss in the line.

The Sending end power for different locations of shunt facts devices at various series compensation levels are shown below. The when %S = 0 the value of P_{Sm} increases as the value of (K) is increased from zero and reaches the maximum value of 19.44 p.u. at K = 0.3. Slope of the P_{Sm} curve suddenly changes at K= 0.3 and the value of P_{Sm} decreases when K > 0.3.When series compensation in the line is taken into account, we observe that the optimal location of the shunt FACTS device will change and shifts towards the generator side. As seen from Figure 5, when %S = 15 then P_{Sm} increases from 15.49 p.u. (at K = 0.1) to its maximum value 24 p.u. (at K = 0.25). When K is further increased then P_{Sm} decreases. It means that, for maximum power transfer capability, the optimal location of the shunt device will change when series compensation level changes. When %S = 30, the optimal location further shifts to the generator side and P_{Sm} increases from 20.4 p.u. (at K = 0.1) to its maximum value 27.5 p.u. (at K = 0.2).

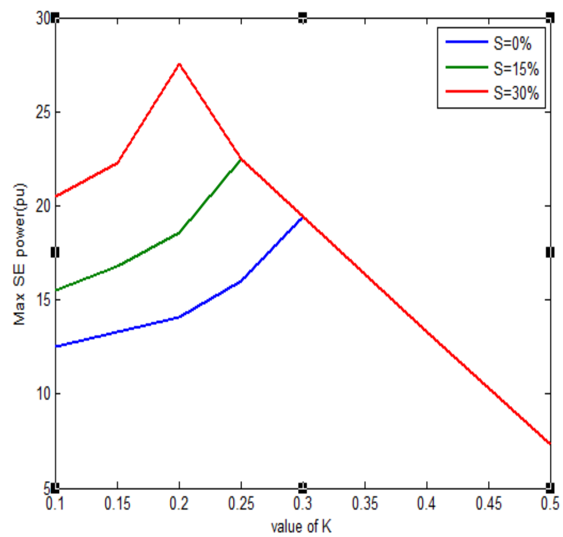

Figure 8: Variation in Maximum SE Power for diff. value S%

A similar pattern for P_R can be observed from Figure 9 for different series compensation levels.

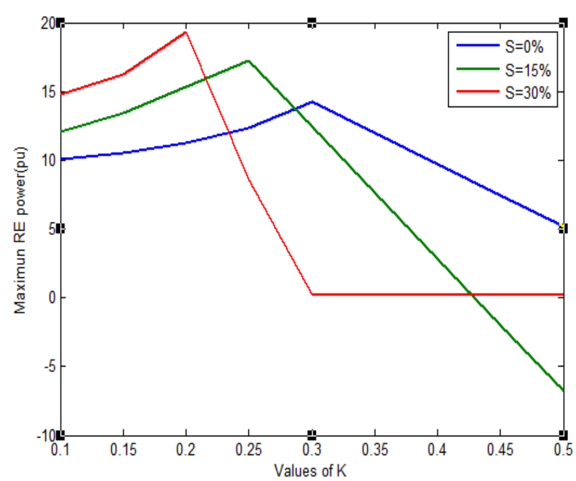

Figure 9: Variation in Maximum RE Power for diff. value s%

Figure 10 shows it can be observed that in the absence of series compensation (%S = 0) the angle at the maximum SE power increases from 111.8^0 at K = 0.1 to its maximum value 174.1o at K = 0.33. When %S = 15 then δ_m increases when K is increased and reaches its maximum value 180.5^0 at K = 0.375. When %S = 30 then δ_m increases when K is increased and reaches its maximum value 186^0 at K = 0.3 and the degree of series compensation level (%S) increases, the stability of the system increases and the optimal location of the shunt FACTS device changes.

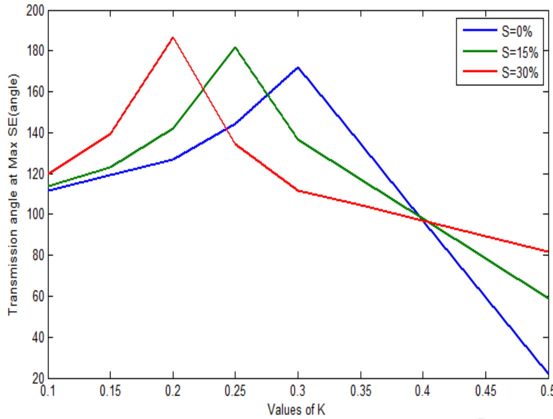

Figure 10: Variation in Transmission Angle at The Max. SE Power for diff. %S.

5.1 OPTIMAL LOCATION OF SHUNT FACTS DEVICES

Figure 11 shows the variation of the maximum RE power of section 1 (PR1m) and maximum SE power of section 2 (PS2m) against the value of K for different series compensation levels (%S). It can be seen in Figure 8 that for an uncompensated line then maximum power curves cross at K = 0.445 and the crossing point is the transition point.

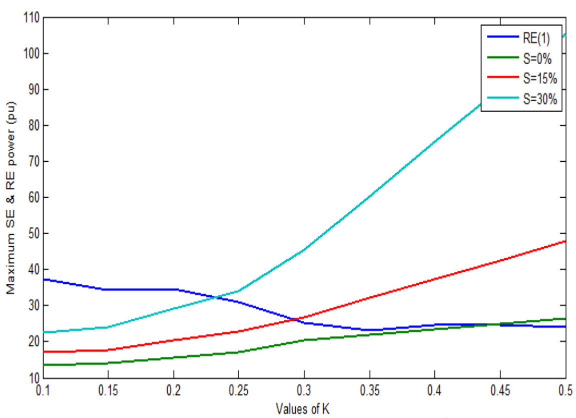

Figure 11: Variation in the Maximum RE Power of Section-1 and SE Power of Section-2 against k for diff. value of %S.

The highest benefit in terms of maximum power transfer capability and system stability, the shunt FACTS device must be placed at K = 0.445 for %S = 0%, which is slightly off- center. When the series compensation level is taken into account then for %S = 15 the maximum power curves cross at K = 0.3 and maximum power transfer capability increases. It gives that when series compensation level (%S) is increased then the optimal location of the shunt device shifts towards the generator side. Similarly when %S = 30 then the optimal location is at K = 0.225. Figure 12 shows the variation in optimal off-center location of the shunt FACTS device against the degree of series compensation level (%S) for the given R/X ratio of the line. It can be observed in fig 9 that the optimal off-center location is 10% for the uncompensated line. When series compensation level (%S) is increased then optimal off-center location increases linearly and reaches its highest value 55% for %S = 30.

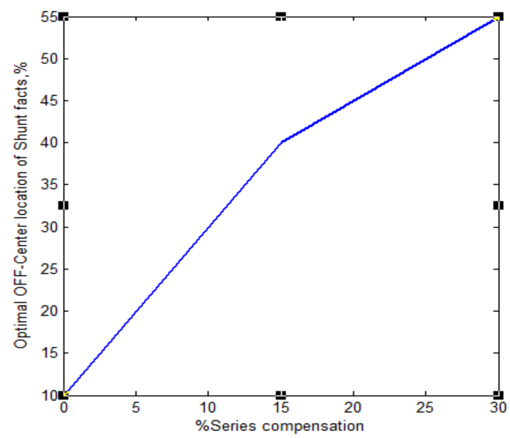

Figure 12: Optimal OFF-Center Location of Shunt Facts Device

5.2 OPTIMAL LOCATION USING FUZZY CONTROL

The methods prior to fuzzy logic are even though good depends mainly on the valuable data. Fuzzy logic provides a remedy if any lack of uncertainty are present in the data. Fuzzy logic has the advantage of having heuristics and representing engineering judgments into the optimal placement of shunt facts device. Furthermore, the solutions obtained from a fuzzy controller can be quickly assessed to determine their feasibility in being implemented in the transmission systems.

A.Benefits of Fuzzy control

- Implementation of expert knowledge for a higher degree of automation
- Robust non-linear control.
- Relates Input to Output in Linguistic terms, which are easily understood by lay persons.
- These are capable of handing complex Non-Linear, Dynamic systems using simple solutions.
- Reduction of development and maintenance time.
- In daily home appliances like washing machines self focusing cameras etc.

B.Development of Fuzzy logic system

Developing a fuzzy logic system desires the following steps to be carried out.

- Creating linguistic variables of the system. The linguistic variables are the "vocabulary" of the in which the rule work.
- Designating the structure of the system. The structure represents the information flow within the system; that is what input variables are combined with which other variables black and so on.
- Formulation the control strategy a fuzzy logic rules.
- Selecting the appropriate defuzzification method for the application.

Power angle and value of k (value of fraction of line length) are modeled using fuzzy membership functions. A Fuzzy Inference (FIS) containing a set of rules is then used to determine where the maximum power transfer capability is obtained by placing shunt facts device in various series compensation levels. A Fuzzy Inference System (FIS) is developed using MATLAB with two input and one output variables. The inputs and outputs of FIS are modeled by fuzzy membership functions. Two inputs are power angle and degree of compensation (%c) and one output for value of k are designed. The membership functions for are triangular and are denoted by L, LM, M, MH and H.

The values of per unit ranges from [0-180^0]. The membership functions for (%c) are triangular and are denoted by LM, M, MH and H. The values of per unit ranges from [0-0.30]. The membership functions for value of k are triangular and are denoted by L, LM, H, HM and H. The membership functions of the variables as shown in figures given below.

Table1: The values of membership functions for δ

L	LM	M	HM	H
0-30	22-66	55-100	100-140	140-180

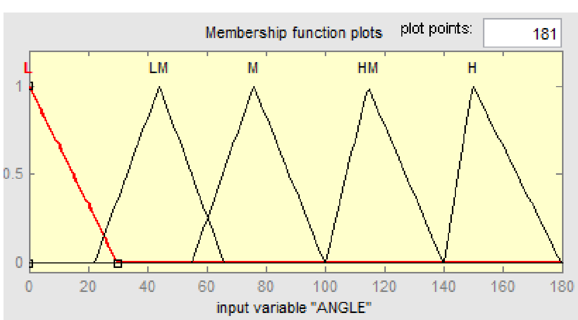

Figure13: Membership function of δ

Table2: Values of Membership function %C:

L	LM	M	HM	H
0-0.66	0-0.10	0.06-0.15	0.125-0.25	0.2-0.3

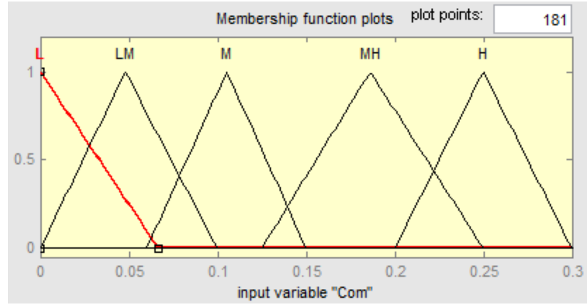

Figure14: Membership function %C

Table3: Values of Membership function for K:

L	LM	M	HM	H
0-0.125	0-0.25	0.125-0.375	0.25-0.42	0.375-0.5

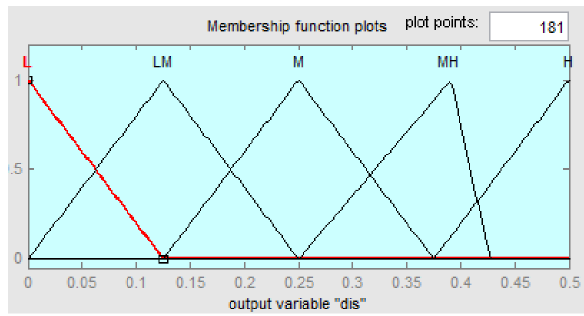

Figure15: Membership function of Location in Distance (k)

All the Rules are framed in the form -IF premise THEN conclusion. These Rules are used to find out the suitability of a particular location of shunt facts device.
Rules are framed by using decision matrix
1. If (input 1 is L) and (input 2 is L) then (output 1) is H.
2. If (input 1 is L) and (input 2 is LM) then output is H.
Like this there are 25 rules are framed by using decision matrix.FIS {Fuzzy Interface system} receives the inputs, depends on the rules framed in the decision matrix, it figures out the suitability membership function of each value. This is then deffuzified for determine the optimal placing of shunt facts device.

Table4: comparison of optimal location of shunt Facts

Location of shunt FACTs device	
Conventional method	Fuzzy logic method
0.225	0.25

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CONCLUSION

This paper analyzes the impact of series compensation on the placing of a shunt FACTS device to get the most possible benefit of maximum power transfer and system stability. Several results are found for an actual line model of a series compensated 345 kV, 450 km transmitted line.

From the results it has been found that the placement of the shunt FACTS device is not permanent at a location it changes with the variation in levels of series compensation. The changes in the location of the shunt FACT device from the center point of line is depends upon the degree of series compensation and it increases almost linearly from the center point of the transmission line towards the generator side as the degree of series compensation (%S) is increased. This paper also verifies the optimal location of the shunt facts device by using fuzzy logic control method and found that the optimal placement is at K =0.25 shifted towards the generator side and also improves the maximum power transfer capability of the transmission line.

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