Facts Placement for Maximum Power Transfer Capability And Stability in a Transmission Line

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Abstract:

Maximum power transfer capability in the transmission line is the utmost important consideration in power systems. Facts devices are very effective and capable of increasing power transfer capability of a line, as thermal limit permits, while maintaining the same degree of stability. So, as to transfer maximum power to the consumer through a transmission line. Shunt FACTS devices are placed at the midpoint of the transmission line and degree of series compensation is provided to get the maximum possible benefit. It is observed that the optimal location of facts devices deviates from the centre of the line towards the generator side with the increase in the degree of series compensation.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, 360 km long transmission line.

Keywords: Fuzzy logic, Maximum power transfer, optimal placement, shunt FACTS devices, series compensation, stability.

1. Introduction

During the past two decades, the increase in electrical energy demand has presented higher requirements from the power industry, including deregulation in many countries; numerous changes are continuously being introduced to a once predictable business. Although electricity is a highly engineered product, it is necessarily being considered and handles as a commodity, is necessary to study the stability and security of the transmission system. Thus transmission systems are being pushed closer to their stability and thermal limits while the focus on the quality of power delivered is greater than ever.

In the modern days, the financial and market forces are, and will continue to demand a more optimal and profitable operation of a power system with respect to generation, transmission and distribution. Now, more than ever the demands of the power system are lower power losses, faster response to parameter change, higher stability and reliability .to achieve both operational and financial profitability Flexible AC Transmission systems(FACTS)[1]based on the success of research in power electronics switching devices and advanced control technology of choice in voltage control, reactive/active power flow control, transient and steady state stabilization and improves the functionality of existing transmission system[2]

FACTS technologies is allowed for improved transmission system operation with minimum infrastructure investment. Environmental constraints and economical impact are the two important constraints forced the power utilities to meet the future demand by utilizing the existing transmission system without building the new lines. FACTS are effective and capable of increasing power transfer capability of line, as thermal limits permits, while maintaining the same degree of stability.

Benefits of utilizing FACTS devices in electrical transmission systems can be summarized as follows.

1. Better utilization of existing transmission system assets.
2. Increases transmission system reliability and availability.
3. Increases dynamic and transient grid stability.
4. Increases quality of supply for sensitive industries.
5. Environmental Benefits.

FACTS devices can be connected to a transmission line in various ways .the series FACTS devices (SSSC, TCSC) which are connected in series with transmission line is known as series compensation. The shunt FACTS devices such as (SVC, STATCOM)connected in shunt with the transmission line is known as shunt compensation.

Series compensation aims to directly control the overall series line impedance of the transmission line. The AC power transmission is primarily limited by the series reactive impedance of the transmission line. A series connected can add a voltage in opposition to the transmission line voltage drop, therefore reducing the series line impedance. The voltage magnitudes of sending end and receiving end are assumed are equal V_S=V_R=V. And the phase angle between them is δ the transmission line model is assumed lossless and represented by the reactance X_L.

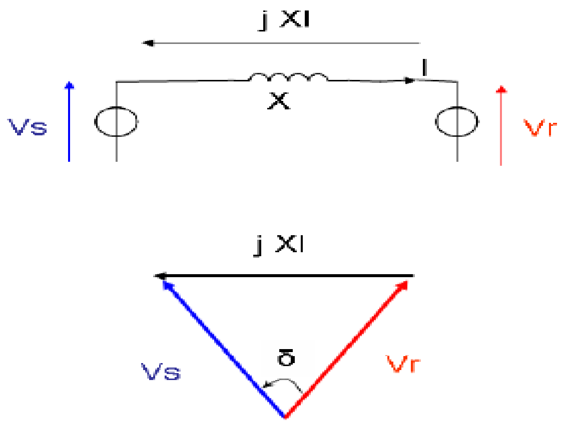

Figure .1 series compensation

shunt compensation ,especially shunt reactive compesation is used in transmission system to improve voltage quality and to enhance the system stability[4]shunt reactors used to reduce the over-all voltages while shunt capacitors are used to maintain voltage levels of the transmission line.

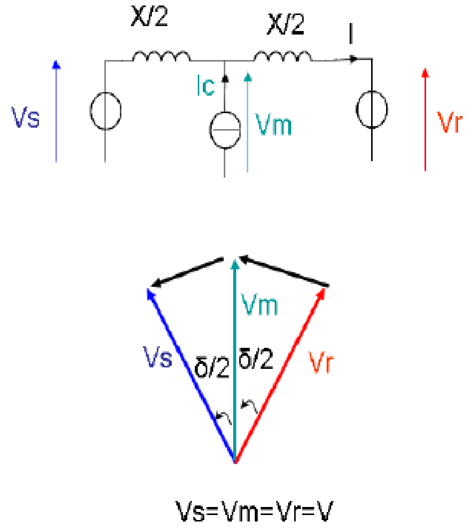

Figure.2 shunt compensation

Optimal location of facts Devices

In power systems, optimal location[5] of these devices is important, properly placed FACTS devices enhances the stability of the system ,where as improperly placed FACTS may become counterproductive. Many researchers found that the optimal location is at K=0.5 at the midpoint of the transmission line .in this paper a series compensation is provided to a transmission line. One of the objectives of this paper is to find the maximum power flow corresponding optimal location of shunt FACTS device, when a series compensation level changes (%C). The rating of shunt FACTS device is selected in such a way so as to control the voltage equal to sending end voltage at the bus of shunt FACTS device. It is observed that the optimal location of shunt FACTS device deviates from the centre of the line towards the generator side with the change in degree of series compensation (%C)

Transmission line model

In this study, it is considered that the transmission line parameters are uniformly distributed and the line can be modeled by 2 port-4 terminal network.

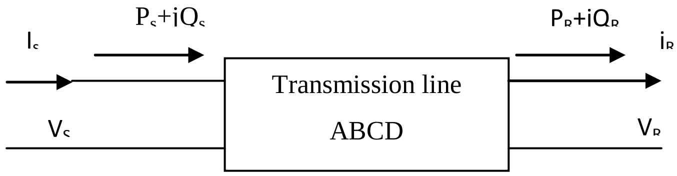

Figure 3: Two – port four terminal model of a transmission line

The relationship between the sending end(SE)and receiving end(RE)quantities of the line can be written as

$$V_S = AV_R + BI_R \quad (1)$$

$$I_S = CV_R + DI_R \quad (2)$$

The ABCD constants of a line length l, having a series impedance of Z Ω/km and shunt admittance of Y S/km are given by

$$A = D = \cosh(\gamma l) \quad B = Z_C \sinh(\gamma l) \quad C = \sin(\gamma l)/Z \qquad (3)$$

Where y = $\sqrt{z}y$ and Z_c = $\sqrt{z}/y$

The active and reactive power flows at the SE and RE of the line cab be written as [11]

$$P_S = C_1 \cos(\beta - \alpha) - C_2 \cos(\beta + \delta) \quad (4)$$

$$Q_S = C_1 \sin(\beta - \alpha) - C_2 \sin(\beta + \delta) \quad (5)$$

$$P_R = C_2 \cos(\beta - \delta) - C_3 \cos(\beta - \alpha) \quad (6)$$

$$Q_R = C_2 \sin(\beta - \delta) - C_3 \sin(\beta - \alpha) \quad (7)$$

Where

$$C_1 = AV_S^2/B, C_2 = V_S V_R/B, C_3 = AV_R^2/B$$

$$A = A\underline{|\alpha}, B = B\underline{|\beta}, V_R = V_R\underline{|0} = V_S = V_S\underline{|\delta}$$

It is clear from eqn 6 that the RE power P_R reaches the maximum value when the angle δ becomes β. However the SE power P_S of eqn 4 becomes maximum at δ=(π-β).for the simplified model of the line, the resistance and capacitance are neglected. For such model, the ABCD constants of the line become

$$A = D = 1\underline{|0^0} \quad B = xl\underline{|90^0} \quad C=0 \quad (8)$$

Here X is the series reactance of the line in Ω/km. In this case, the line is represented by only a lumped series reactance X= X_L and both P_R and P_S become maximum at δ =90^0.such model may provide reasonably a good results for short transmission line .when a shunt fact device is connected in a long transmission line to increase the power transfer capability the following model is designed.

In this paper, it is considered that the line is transferring power from a generation station to a load and is equipped with a series capacitor 'C' at the centre and shunt FACTS device at a point 'm' as shown in figure 4 .parameter 'K' is used to show the fraction of line length. In this study we considered 13.8 KV Base,6*350 MVA and it is supplying a load of 30,000MVA ,735 KV is considered , the series impedance of the line is found to be Z = (0.01273+j0.9337) Ω/Km at 60 Hz respectively. Here the transmission line is divided in to two sections (section1 and 2) and section 2 is further divided in to two sections. Each section is represented by a separate 2 port, 4-terminal network.

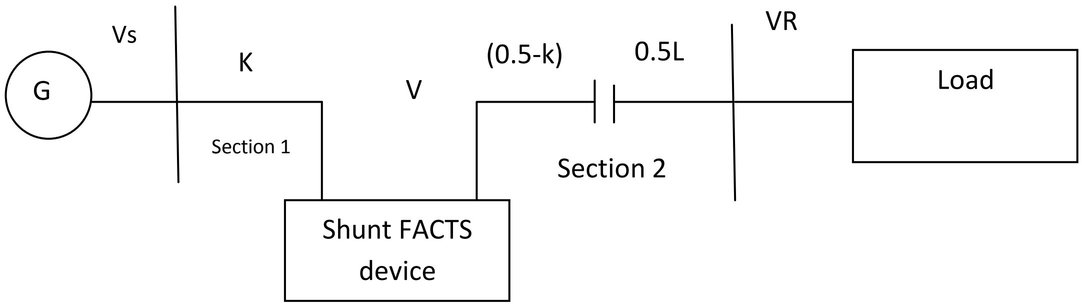

Figure .4: Series compensated transmission line with a shunt FACT device

Maximum power transfer capability

First consider that the line is represented by its simplified model and there is no facts device connected to the line, for such case, the maximum power transfer through the line for given values of SE and RE voltage magnitudes, cab be written as

$$P = P_m \sin\delta \qquad (9)$$

Here the maximum power pm is $V_s V_R / x$ and it occurs at an angle $\delta^m=90^0$.when a shunt facts device is connected to the line , both Pm and δ^m are increased and their values depends upon the k factor. For k=0.5 and $V_S = V_R = V_M$ both P_M and δ^m become double or increases to $2 V_s V_R / x$ and 180^0, respectively [8].when k exceeds 0.5 both P^M and δ^m decreases after reaching the maximum value. In this paper (%c) degree of series compensation is provided for a long transmission line. As the (%c)increases, the value of k changes the maximum power and corresponding angle are first determined for various values of k.

A sophisticated computer program has been carried out to determine the various characteristics of the system of fig.3 using the simplified and actual models of the line sections. The constraints of the same RE power of section1 and SE power section2 ($P_{R1} = P_{S2}$) is incorporated in to the problem, in all cases ,$V_S = V_R = V_M$=1.0 p. Unless specified the maximum power P^m and corresponding angle δ^M are determined for various values of location K.

The figure (5) to (9) shows the variation in maximum RE power $\left(P_R^m\right)$, maximum SE power $\left(P_S^m\right)$ and transmission angle $\left(\delta^m\right)$ with respect to degree of series compensation (%c).

From fig (5) it can be noted that when %C = 0, the value of $\left(P_S^m\right)$ increases as the value of k is increased from zero and reaches maximum value at 13.5 p.u. when % C = 15, the value of P_S^m increases, and reaches to 19.5 p.u. when %C=45 the value P_S^m increases and reaches maximum value 35 p.u. at k = 0.3.

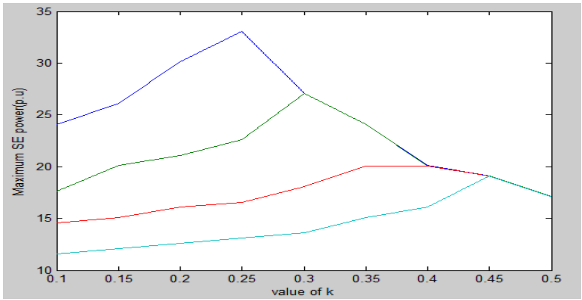

Figure 5: Variation in maximum sending end power for the different values of %c

Similarly for RE power $\left(P_R^m\right)$ can be observed in fig (6) when the series compensation in the line is taken into account. We observe that the optimal location of the shunt facts device will change and shift towards the generator side. It can observed that when %C = 45 we obtain the optimal location of shunt fact device at k = 0.225 and P_R^m increases to value of 22.5 p.u

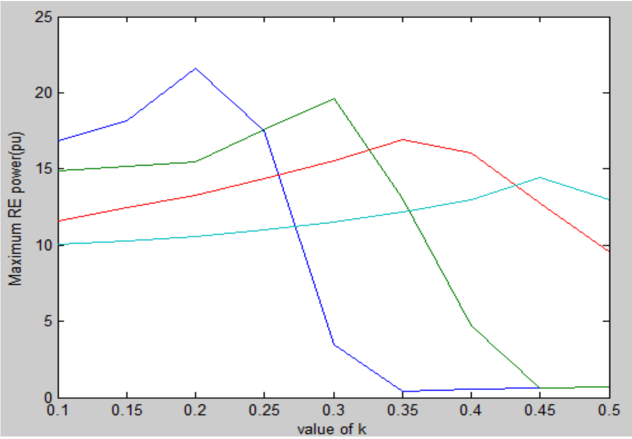

Figure 6: Variation in maximum receiving end power for the different values of %C

In figure (7), It can be observed by using both SVC and STATCOM, the angle at SE power increases when % C = 0 at k = 0 the value of δ^m increases from 96.7^0 to its maximum value 169^0 when % C=45 the value of δ^m increases 189.5^0 at k = 0.225. As the degree of series compensation increases, the stability, of the system increases and the optimal location of the shunt fact device changes.

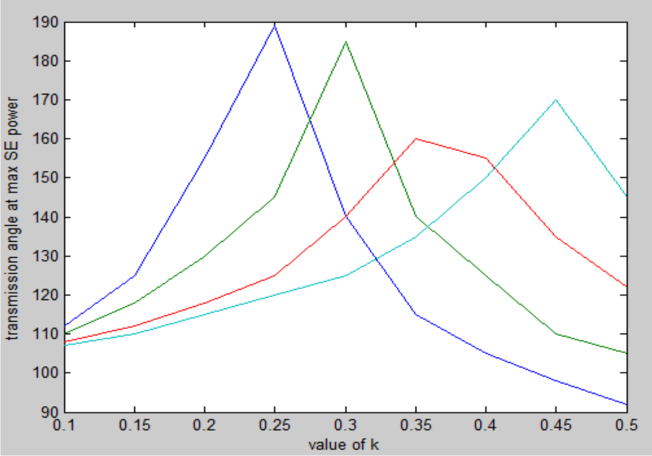

Figure 7: Variation in transmission angle at the maximum SE power for the different values of %c

Optimal location of shunt facts device

Fig (8) shows the variation of maximum RE power of section (1) $\left(P_{R1}^m\right)$ and maximum SE power of section (2) $\left(P_{S2}^m\right)$ against the value of K for different series compensation levels (%c). When %C =0 the value of k = 0.45 for uncompensated line similarly when %C = 45 the value of k = 0.25

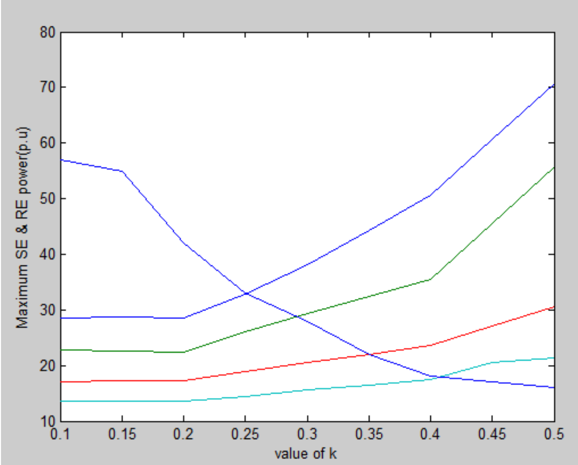

Figure 8: Variation in maximum RE power of section I and SE power of section II against k for different values of %c.

Figure (9) shows the variation in optimal off centre location of the shunt facts device against the degree of compensation level (%C) for the given R/X ratio of the line. It can be observed that the optimal off centre location increases linearly and reaches its highest value 55% for %c=45.

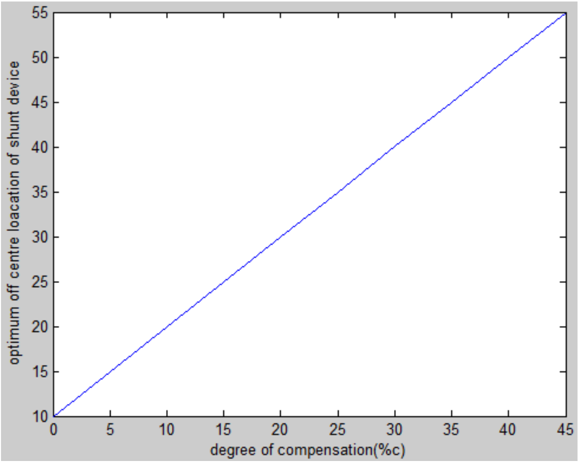

Figure 9: Variation in optimum off centre location of shunt facts device against %c

Optimal location using fuzzy control

The efficiency of methods prior to fuzzy logic, even though good, depends mainly on the goodness of data. Fuzzy logic provides a remedy for any lack of uncertainty in the data. Fuzzy logic has the advantage of including heuristics and representing engineering judgments into the optimal placement of shunt facts device. Further more, the solutions obtained from a fuzzy controller can be quickly assessed to determine their feasibility in being implement in the transmission systems.

Benefits of Fuzzy control

- Implementing 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.

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.

The two main objectives are considered mainly

1. To improve power transfer capability
2. To improve stability

Power angle and value of k (value of fraction of line length) are modelled 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. Now, a Fuzzy Inference System (FIS) is developed using MAT LAB 7.12 with two input and one output variables.

The inputs and outputs of FIS are modeled by fuzzy membership functions. Two inputs power angle δ^m and degree of compensation (%c) and one output for value of k are designed. The membership functions for $\left(\delta^m\right)$ are triangular and are denoted by L, LM, M, HM, H. The values of per unit ranges from [0-180^0].

The membership functions for (%c) are triangular and are denoted by , LM, M, HM, H, The values of per unit ranges from [0-0.45].

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.

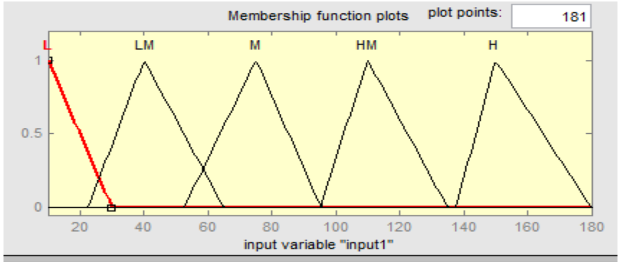

Figure 10: Membership functions for δ^m

The values of memebership functions are given below.

L	LM	M	HM	H
10-30	22-65	55-95	95-135	135-180

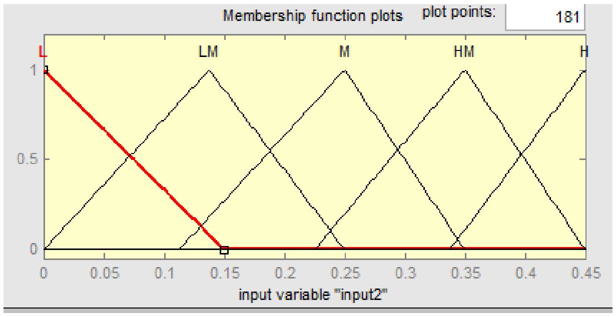

Figure 11: Membership functions for %c.

The values of membership function are given below

L	LM	M	HM	H
0-0.15	0-0.25	0.15-0.35	0.23-0.45	0.33-0.45

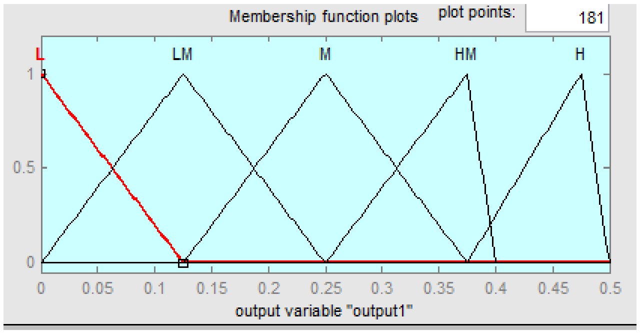

Figure 12: Membership functions for value of k

The values of membership function are given below

L	LM	M	HM	H
0-0.125	0-0.25	0.125-0.375	0.25-0.4	0.375-0.5

Rules are framed in the form “IF premise (or antecedent) THEN conclusion (or consequent)”. Are used to determine the suitability of a particulars location of shunt facts device.

Rules are framed we using decision matrix

1. If (input 1 is L) and (input 2 is L) then (output 1) is H (1).
2. If (input 1 is LM) and (input 2 is H) then output is (M).

Like this the 25 rules are framed by using decision matrix.

AND		Degree of compensation(%S)				
		L	LM	M	HM	H
Transmission angle(δm)	L	H	H	HM	HM	HM
	LM	H	HM	HM	HM	M
	M	H	HM	HM	M	M
	HM	M	M	M	LM	LM
	H	LM	LM	LM	L	L

After receiving the inputs the FIS, based on the rules framed in the decision matrix, calculates the suitability membership function of each value. This is then deffuzified in order to determine the optimal placement of shunt facts device.

Optimal location (Value of k)	
Conventional Method	**Fuzzy method**
0.25	0.205

Conclusion :

This paper has presented a novel method to determine the optimal placement of shunt facts device in a long transmission line by using conventional method and fuzzy method.

It has been found by conventional method the shunt fact devices has to be placed slightly off centre to get the highest possible benefit when the power flows in a particular direction the optimal location from the centre depends upon the line resistance, and it increases almost linearly as the R/X ratio of the line is increased. Both the power transfer capability and stability of the system can be further improved if the shunt fact device is placed at the new optimal location instead of at the midpoint of a line having non zero resistance. This paper also verifies the optimal location of the shunt facts device by using fuzzy control method and found that the optimal placement is at K =0.205 shifted towards the generator side and also improves the maximum power transfer capability of the transmission line

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