

Optimal Location of Shunt FACTS Devices using Genetic Algorithm for Transmission Line Model

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Abstract

FACTS devices are used for controlling transmission voltage, Power flow, dynamic response and reducing reactive losses in transmission lines. It has been proven that the midpoint of a transmission line is the optimal location for shunt FACTS devices and is based on the simplified line model, which is not valid practically. In this paper, the optimal location of static VAR compensator which is a shunt FACT device has been investigated for both maximum power transfer and stability, considered the actual line model by using Genetic Algorithm. In most of the cases, the faults occurred at source end bus, considered fix load at receiving end. However the optimality changes if fault occurred at load end bus and load is variable. In this paper, fault location at both ends and load variation are considered for searching optimal location of SVC using GA. It is found that the static VAR compensator should be placed slightly off center to get the maximum power.

Keywords: Genetic Algorithm, line Compensation, SVC

1. Introduction

In modern power systems, power quality is a major concern. The electric utilities are expected to provide continuous and quality electric service to their customers at a reasonable rate within specified voltage and frequency limits. To maintain voltage within specified limits, power system should have enough reactive power supplies [1]. Also during the outages of some critical lines, power system may become insecure and vulnerable to the voltage collapse due to lack of reactive power support. Generators may have limited reactive power capability. Further, these generators may have to reduce their real power output to fulfill the reactive power demand of the system, resulting in loss of opportunity in the electricity market. Proper selection and coordination of equipment for controlling reactive power and voltage are among the major challenges of power system engineering. An in-depth analysis of the options available for maximizing existing transmission assets, with high levels of reliability and stability, has pointed in the direction of power electronics. There is general agreement that novel power electronics equipment and techniques are potential substitutes for conventional solutions, which are normally based on electromechanical technologies that have slow response times and high maintenance costs.

Flexible AC Transmission System (FACTS), a power electronic device is technology-based concept that can provide a full dynamic control over active and reactive power flow on transmission systems based on the key control variables such as transmission line impedance, phase angle and voltage. They are certainly playing an important and a major role in the operation and control of modem power systems. Shunt FACTS controllers, such as static VAR compensator (SVC) and static synchronous compensator (STATCOM), are capable of effectively controlling the voltage profile by dynamically adjusting the reactive power output at the point of connection [2-3]. However, these controllers are very expensive and, hence, their optimal locations in the network must be ascertained. Among these two FACTS controllers, SVC is more popular due to its lower cost as compared to the STATCOM.

In literature, several methods have been suggested to optimally place these controllers in the system. Previous works on the topic prove that shunt FACTS devices give maximum benefit from their stabilized voltage support when sited at the mid-point of the transmission line [4-8]. The proof of maximum increase in power transfer capability is based on the simplified model of the line neglecting line resistance and capacitance. However, for long transmission lines, when the actual model of the line is considered, the results may deviate significantly from those found for the simplified model [9].

2. Transmission Line model

By considering the transmission line parameters uniformly distributed, the line can be modeled by a two-port, four-terminal network as shown in Fig. 1.

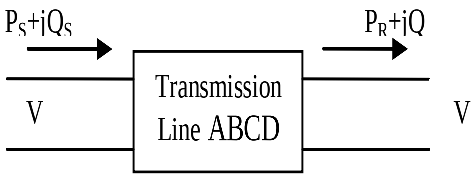

Figure 1. Two port, four terminal of a Transmission Line

This represents the actual model of the line. The relationship between the sending end (SE) and receiving end (RE) quantities of the line can be written as

$$V_S = A V_R + B I_R \tag{1}$$

$$I_S = C V_R + D I_R \tag{2}$$

The *ABCD* constants of a line of length *l*, having a series impedance of impedance of z Ω /km and shunt admittance of yS/km are given by

$$A = D = cosh(\gamma\ell) \qquad B=Z_C\, sinh(\gamma\ell)$$

$$C= sinh(\gamma\ell)/Z_C \text{ , } \quad \text{where} \quad y = \sqrt{zy} \quad \text{and} \quad Zc = \sqrt{z/y}$$

The active and reactive power flows at the SE and RE of the line can be written as

$$P_S = C_1\, cos(\beta-\alpha) - C_2\, cos(\beta+\delta) \tag{3}$$

$$Q_s = C_1\, sin(\beta-\alpha) - C_2\, sin(\beta+\delta) \tag{4}$$

$$P_R = C_2\, cos(\beta-\delta) - C_3\, cos(\beta-\alpha) \tag{5}$$

$$Q_R = C_2\, sin(\beta-\delta) - C_3\, sin(\beta-\alpha) \tag{6}$$

where $C_1=AV_S^2/B$, $C_2=V_SV_R/B$, $C_3=AV_R^2/B$ and $A=A\ \angle\alpha$, $B=B\angle\beta$, $V_R=V_R\ \angle 0$, $V_S=V_S\ \angle\delta$

It is clear from (3) and (5), that the RE power P_R reaches the maximum value when the angle δ becomes β. However, the SE power *Ps* becomes maximum at $\delta=(\pi-\beta)$. For the simplified model of the line, the resistance and capacitance are neglected. For such a model, the *ABCD* constants of the line become

$$A = D = 1\angle 0 \qquad B = x\ell\angle 90^0 \qquad C=0$$

Here x is the series reactance of the line in Ω /km. In this case, the line is represented by only it lumped series reactance $X = x\ell$, and both *Ps* and P_R become maximum at δ =90 Such a simplified model may provide reasonably good results for a short line for which the power transfer capability is normally dictated by its thermal limit. When a FACTS device is connected to a long line to increase the power transfer capability, the use of simplified line model may provide erroneous results.

3. *Mid Point Compensation*

For a Simplified Line Model the power transfer through the line for given values of sending end and receiving end voltages is given by

$$P = P_{max} \sin\delta$$

where $P_{max} = V_S V_R / X$ and occurs at $\delta_{max} = 90^0$.

When a shunt FACTS device is connected to the line, both P_{max} and δ_{max} are increased and their values depend on the k factor. For k = 0.5 and $V_S = V_R = Vm$, both P_{max} and δ_{max} become double When k exceeds 0.5, both P_{max} and δ_{max} decrease after reaching the maximum value. It is an established fact that, for the simplified line model, the optimal location of shunt FACTS device or reactive power support is at the midpoint (k = 0.5).
However, for the actual line model, the power flow is given by (3) to (6) and thus the above results may not be considered as accurate. Objective of this paper is to find the maximum power and the corresponding location of the shunt FACTS device when the actual line model is considered and load is varied.

4. *Transmission Line with Shunt FACT Device*

The SVC uses conventional thyristors to achieve fast control of shunt connected capacitors and reactors. The configuration of the SVC is shown in Fig.1, which basically consists of a fixed capacitor (C) and a thyristor controlled reactor (L). The firing angle control of the thyristor banks determines the equivalent shunt admittance presented to the power system. The accuracy, availability and fast response enable SVC's to provide high performance steady state and transient voltage control compared with classical shunt compensation.

Consider that the line is transferring power from a large generating station to an infinite bus and equipped with a shunt FACT device at point m as shown in the Fig.3. The transmission line is divided into two sections and 'k' is used to show the fraction of line length at which shunt FACT Device is placed. The shunt FACT Device used in this case is SVC, connected to the line through a step-down transformer. For the simplified line model, sections 1 and 2 are represented by lumped series reactance of $kx\ell$ and $(1-k)x\ell$ respectively. It is considered that the rating of the SVC is large enough to supply the reactive power required to maintain a constant voltage magnitude at bus m and the device does not absorb or supply any active power. The voltage magnitude Vs=Vr=Vm is required to maintain constant (these voltages are assumed to be maintained by terminal generators) during maximum power transferring capability study in line. Vs is the sending end voltage, Vr is the receiving end voltage and Vm is the voltage at the SVC location. MATLAB is used for simulation of shunt FACTS devices.

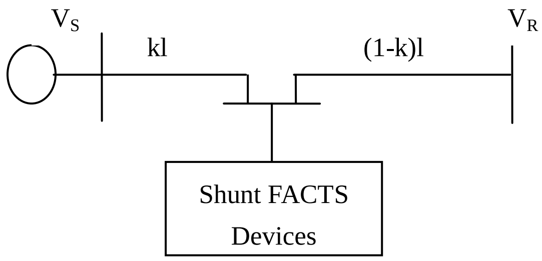

Figure .2 Transmission Line with a Shunt FACT Device

5. *MATLAB Simulation*

Transmission line system as proposed in Section 3 is modeled with one generating unit of 1000 MVA at the source end, connected via a 700 km long transmission line to the fixed voltage bus bar. Load of 100 MVA, 100 MVAR is connected through transformer as shown in Fig. 3. The machine is equipped with a hydraulic turbine and governor (HTG), excitation system and power system stabilizer (PSS). SVC used for this model has the rating of ±200 MVA and the reference voltage is set to 1 pu. Initial power outputs of the generators are P1 = 0.7 pu and P2 = 0.5 pu . A three phase fault occurs at sending end bus at time t = 0.1 s. The original system is restored upon the clearance of the fault. Simulink model of system is given in Fig.4

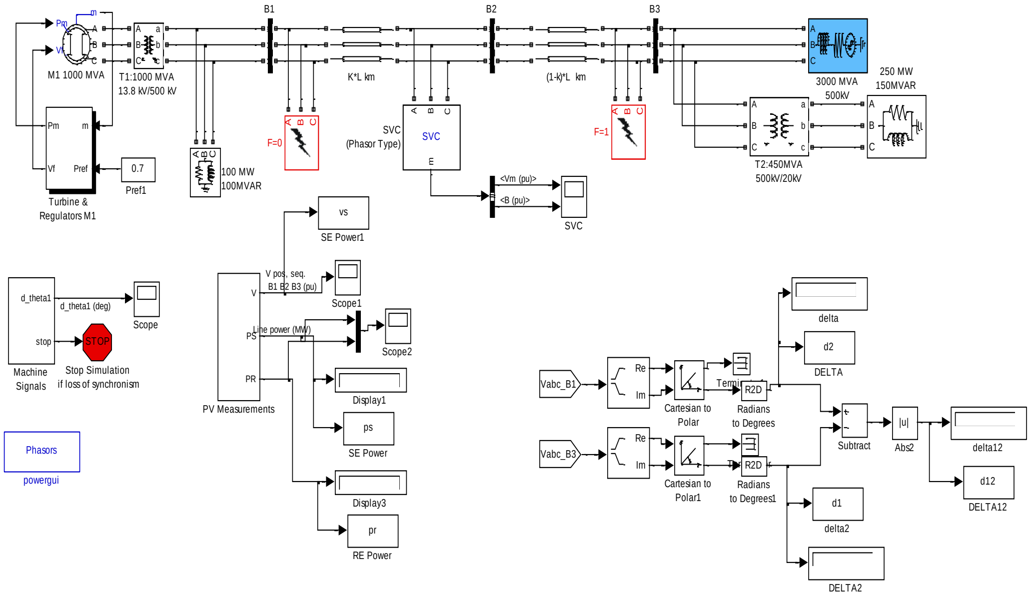

Figure .3 simulation model of transmission line system with shunt FACTS devices

6. *Ga Algorithm Based Optimal Location*

The main objective of the paper is to find the maximum power and the corresponding location of the shunt FACTS device for the line. Genetic algorithms are stochastic search algorithm inspired by the principles of natural selection and natural genetics. Genetic Algorithm has considerably broadened the scope of optimization in engineering. In this paper, Genetic Algorithm has been used to search for optimal location of SVC.GA is always an effective tool for searching of optimal values in case of multi variable optimization. In most of the cases for searching the optimal position of SVC faults are considered at source end bus, however if fault are considered at load end bus , the optimality will change. One of the most important things while searching for optimal location of SVC is that, its performance should not degrade in variable load condition. In this paper both fault location and load variation are considered for searching optimal location of SVC. Load connected to transformer is varied, sending end and receiving end power are calculated to calculate loss index (lindex)

$$lindex = \frac{P_s - P_r}{P_s}$$

Objective function of GA is to minimize the loss index.

P_s=Sending end power

P_r=Receiving end power

F=fault location index (F=1 correspond to fault at load side)

L=load (100-300 MW)

Initially F is kept at 0 (means fault considered at source side).Each chromosome in GA is 32 bit string .Upper 16 bit correspond to load (at transformer T2) and lower 16 bit correspond to k. Search space for k is [0.1 0.9] while a variable inductive load for L form 10Mvar to 100Mvar.Optimal value of found with GA was checked with fault at load end (F=1),if there is large difference in power.

7. Results And Conclusions

The results shown in Fig. 5 indicate that optimal value of SE power is obtained for value of k=0.55 by using GA which is greater than k=0.5. Thus to get the highest possible benefit in terms of the power transferring capability and stability, the shunt FACTS devices must be placed at k=0.55 which is slightly off the center. Fig.5 shows Maximimn receiving end power with different shunt FACT locations k. The power-angle curve for receiving end and sending end power is as shown in Fig.6, it indicates that the SE power reaches to maximum with FACTS devices for k=0.55 for power angle $\delta = 74$ deg. and power approaches to zero at $\delta = 147$ deg and RE power reaches to maximum value for the same FACT location for $\delta = 63$ deg and approaches to zero at 125 deg. Fig.7 shows the voltage profile for SE, RE and Mid point and and Fig.8 shows the power transfer capability of line It is a common practice to consider the centre or midpoint of a line as the optimal location of reactive power support or shunt FACTS devices considering the faults occurred.

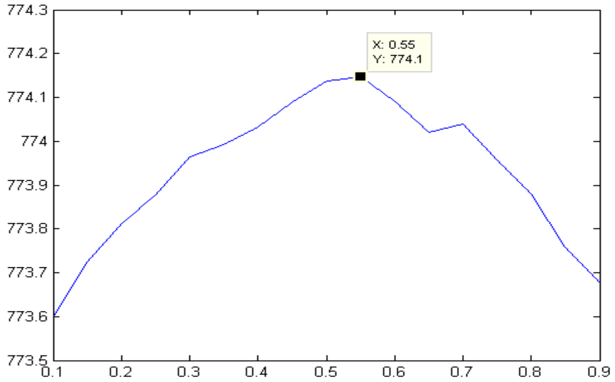

Figure.4. Maximimn receiving end power with different shunt FACT devices location (k)

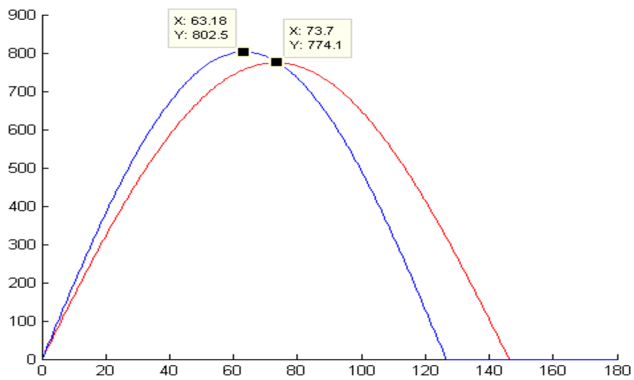

Figure.5. Power characteristics of Receiveing end and Sending end Power

at source end bus and fix load at receiving end. This is true only when the simplified line model is considered. This paper investigates the effects of the actual line model on the optimal location of shunt FACTS devices considering the fault occurred at source end as well as load end and the load is variable, to get the highest possible benefit. It has been found that the shunt FACTS device may need to be placed slightly off-centre to get the highest possible benefit when the fault occurred at souce end as well as load end and load is variable.

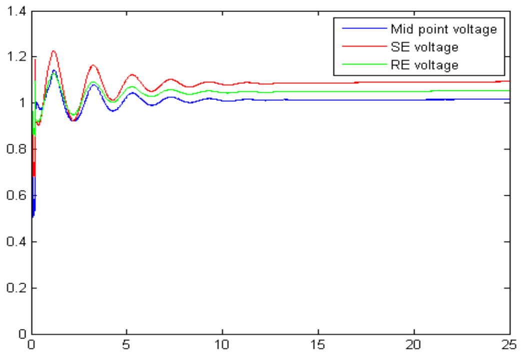

Fig.6. Sending end, Receiving end and Mid point Voltages

APPENDIX

The data for various components used in the MATLAB model of Fig. 3.

Generator parameters: M=1000MV, V=13.8KV, f=60 Hz, Xd=1.305, X1d=0.296, X″d=0.255, Xq=0.474, X″q = 0.243, X1=0.18

Transformer parameters: T1=1000 MVA, 13.8/500 KV,

R2=0.002, L2=0.12,Rm=500,Xm=500.

T2=450 MVA, 500/220KV, R2=0.00149, L2=0.1,Rm=450, Xm=500.

Transmission line parameters per km: R1=0.1755, R0= 0.2758, L1=0.8737mH, L0=3.22mH, C1=13.33nF, C0 = 8.297 nF.

SVC parameters: 500KV, ±200MVAR, Td=4 ms.

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