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Modelling Of Various Facts Devices for Optimal Reactive Power Dispatch

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Abstract:- Optimal Reactive Power Dispatch (ORPD) has a conspicuous impact on minimizing the transmission system real power loss along with the deviation of voltage at buses in the system. ORPD utilizes many parameters such as transformer tap settings, generator output voltages and the control parameters of various compensating device such as capacitor banks and synchronous condensers. Flexible AC Transmission System devices are found to be efficient in achieving the above said goal of ORPD. In this paper, mathematical modelling of many FACTS devices is done for implementing the ORPD algorithm.

Keywords:- FACTS, TCSC, TCPAR,UPFC,ORPD

I. INTRODUCTION

The OPRD has an important impact on the secure and economic operation of power systems. The reactive power generation by itself has no cost but however it affects the total generation cost by decreasing the transmission loss. The ORPD algorithm basically executes the reactive power injection to reduce the power loss in the transmission network as well as lowers production cost while satisfying various limitations on various parameters. Environmental, cost problem are major hurdles for power transmission network expansion. Pattern of generation that results in heavy flows tends to incur greater losses and reducing the stability and security of the power system[1].

The electrical energy is very essential to cope up with the increased needs in day to day life because of the increasing Industrialization, urbanization of life style .This has resulted into expeditious growth in the of power networks . Due to this, few uncertainties have been developed in the system operation. Economy of the nation is mostly affected by the major problems in power sector such as power disruptions and individual power outages. Because of the rapid changes in the technology, many times transmission systems are being propelled to operating conditions approaching their stability limits as well as reaching their thermal limits because of the very cause to deliver increased demanded power[9]. The major issues that have to be faced by power industries in providing the balance between suppled power and demanded power are :
1. Transmission & Distribution of electric energy demand within the thermal limits of the transmission lines..
2. In large power system, tremendous loss encountered because of black outs and power disruptions causing stability problems.
These limitations mainly affect the delivered power quality[2]. However, by achieving the power system control these constraints can be suppressed. Implementation of FACTS devices in the system is found to be one of the best methods for reducing these constraints. Hence ,available resources are to be better utilized by installing Flexible AC Transmission System (FACTS) devices such as Thyristor controlled reactor(TCR),Thyristor Controlled Series Compensator (TCSC), Thyristor Controlled Phase Angel Regulator (TCPAR) , Unified Power Flow Controller (UPFC), Static Synchronous Compensator(STATCOM) and SVC which help in controlling the power flow in massively burdened lines and reinforce stability of the system.

In the recent years the fast development in the power electronics field has consequence to the FACTS devices . At present transmission and distribution of electric power has become more controllable and efficient because of these advanced devices For many years FACTS devices have been used to maximize the use of the available transmission lines, improving dynamic behaviour of transmission systems (stability problem) and solutions for loop flow problem and Sub Synchronous Resonance problem (SSR) [9]. However there were limited studies on the effect of use of FACTS devices for solving OPRD problem. In this study the FACTS devices have been considered as an additional control parameter in the ORPD problem. Power flow model of TCSC,TCPAR ,UPFC, STATCOM and SVC have been used in this study. In this investigate first the optimal location of each FACTS device in a network which the transmission power loss is minimized, is found

therefore the ORPD problem is solved considering the FACTS device as an additional parameter for each type of FACTS devices.
For many years the gradient–based optimization algorithm was used to solve ORPD problem [1],[4]. But ORPD is a global optimization problem with several local minimums that can lead the conventional optimization solutions to a local minimum[3]. In addition, in conventional methods to simplify the problem many mathematical assumptions, such as analytic and differential properties of the object function should be given. Otherwise it is difficult to calculate the gradient variables in the conventional method. During the last decade many stochastic algorithms were developed to solve the global optimization problem[5]. Simulated annealing, genetic algorithms and evolutionary programming. During the last decades evolutionary algorithms have found many applications in power systems, especially in economic operation areas [5],[7].

II. MATHEMATICAL MODELLING OF VARIOUS FACTS DEVICES

The power injection model is a desirable one for the ORPD analysis in this study as it is capable of handling the FACTS devices while performing the computations of power flows. The bus admittance matrix of Y_BUS matrix and the bus impedance matrix ,Z_BUS matrix of the power system is unaffected by using this model.. In fact, the power injection model is the most convenient and appropriate for power systems with FACTS devices. Above said FACTS devices are modelled using the power injection method [10]. For a transmission line connected between bus i and bus j, the voltages and angles at bus i and j are V_i, δ_i and V_j, δ_jrespectively. Therefore, complex power flow from bus I to bus j and vice versa are defined by the following equations:

$$P_{ij} = V_i^2 G_{ij} - V_i V_j [G_{ij} \cos \delta_{ij} + B_{ij} \sin \delta_{ij}$$
$$Q_{ij} = -V_i^2 (B_{ij} + B_{sh}) - V_i V_j [G_{ij} \sin \delta_{ij} - B_{ij} \cos \delta_{ij}] \qquad (1)$$

where

$$\delta_{ij} = \delta_i - \delta_j$$

Similarly the active and reactive power from bus j to bus i is given by

$$P_{ji} = V_j^2 G_{ji} - V_i V_j [G_{ji} \cos \delta_{ji} + B_{ji} \sin \delta_{ji}$$
$$Q_{ji} = -V_j^2 (B_{ij} + B_{sh}) - V_i V_j [G_{ji} \sin \delta_{ji} - B_{ji} \cos \delta_{ji}] \qquad (2)$$

A. TCPAR

The voltage angles between the buses i and j could be regulated by TCPAR. The block diagram model of TCPAR with transmission line is shown in Fig 1.

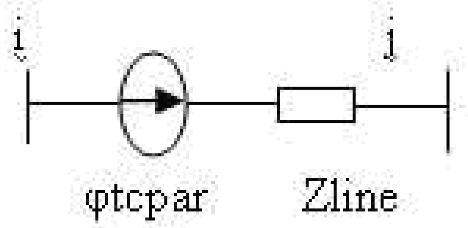


Fig.1 .TCPAR model

[1]The injected real and reactive power injected in buses i and j are :

$$P_{i(com)} = -V_i^2 S^2 G_{ij} - V_i V_j S [G_{ij} \sin \delta_{ij} + B_{ij} \cos \delta_{ij}]$$
$$P_{j(com)} = -V_i V_j S [G_{ij} \sin \delta_{ij} + B_{ij} \cos \delta_{ij}] \qquad (3)$$

$$Q_{i(com)} = -V_i^2 S^2 B_{ij} + V_i V_j S [G_{ij} \cos \delta_{ij} + B_{ij} \sin \delta_{ij}]$$
$$Q_{j(com)} = -V_i V_j S [G_{ij} \cos \delta_{ij} - B_{ij} \sin \delta_{ij}] \qquad (4)$$

where

$$S = tan\phi_{TCPAR}$$

B. UPFC

A series inserted voltage and phase angel of inserted voltage can model the affect of UPFC on the network. the inserted voltage has a maximum magnitude of V_t=0.1V_m, Where V_m is the rated voltage of the line, where the UPFC is connected. The block diagram model of UPFC with transmission line is shown in Fig 2.

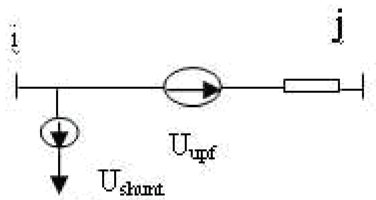


Fig.2 UPFC model

The real and reactive power injected at buses i and j are:

$$P_{i(com)} = -V_t^2 G_{ij} + V_i V_j[-2G_{ij}\cos(\phi_{UPFC} - \delta_{ij}) + G_{ij}\cos(\phi_{UPFC}) + B_{ij}\cos(\phi_{UPFC})]$$

$$Q_{i(com)} = V_i V_j[G_{ij} sin(\phi_{UPFC} - \delta_{ij}) + B_{ij}\sin(\phi_{UPFC} - \delta_{ij})] \quad (5)$$

$$P_{j(com)} = V_i V_t[G_{ij}\cos(\phi_{UPFC}) - B_{ij}\sin\phi_{UPFC})]$$

$$Q_{j(com)} = -V_i V_t[G_{ij}\sin(\phi_{UPFC}) + B_{ij}\cos\phi_{UPFC})] \quad (6)$$

C. TCSC

Series compensation is nothing but the control of transmission line impedance which can be either inductive or capacitive in nature. Series compensation aims at controlling active and reactive power flow through the transmission lines[9]. Thyristor Controlled Series Capacitor (TCSC) is a basically variable impedance type series compensator. It is connected in series with the transmission line to damp the system oscillations, minimize the transmission network loss and thus simultaneously increases the power transfer capability along with improvement in transient stability of the system. Here in the analysis, steady state operation of TCSC is considered.. The effect of a TCSC on the network can be seen as a controllable reactance inserted in series in the related transmission line for compensating transmission line reactance in which it is connected. It may have capacitive or inductive characteristics to decrease or increase the reactance of the line X_L respectively. Their values are functions of reactance of the line where the device is located [5]. Moreover, to avoid over compensation of the line, the working range of the TCSC is considered to be [-0.39X_L, 0.39X_L]. It increases the maximum power transfer in that line along with voltage profile improvement. A simple transmission line represented by its lumped Л equivalent parameters connected between bus i and bus j is shown in Fig.3. Where G_{ij} is the series conductance and B_{ij} is the series susceptance of a transmission line. B_{sh} is the shunt susceptance of a transmission line. The model of a transmission line with a TCSC connected between bus – i and bus- j is shown in Fig.4.

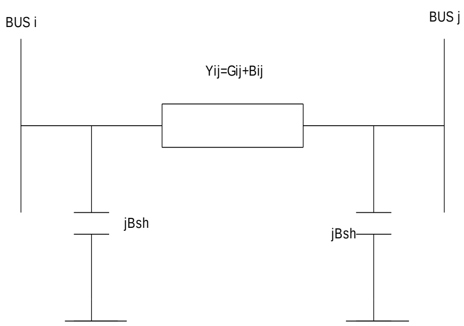


Fig.3 Transmission line model

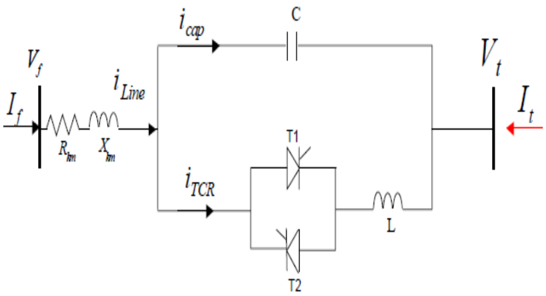


Fig. 4. Model of TCSC

According to the operating principle of the TCSC, it can control the active power flow for the line *l* (between bus- *i* and bus- *t* where the TCSC is installed).The fundamental frequency of TCSC equivalent reactance
as a function of the TCSC firing angle α is;

$$X_{TCSC} = X_C + K_1(2\sigma + sin^2_{\sigma}) - K_2 cos^2_{\sigma\omega r}(\tan(\sigma\omega r) - tan\sigma)) \tag{7}$$

where

$\sigma = \pi - \alpha$

$X_{TCSC} = X_C X_L/(X_L - X_C)$

$K_1 = (X_{LC} + X_C)/\pi$

$K_2 = \ 4X_{LC}^2 X_L/\pi$

$\omega_r = \dfrac{1}{2\pi\sqrt{LC}}$

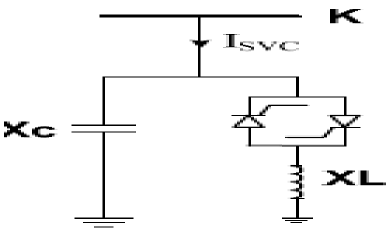
There exists a relation between the firing angle α and X_{TCSC}. The complex power injected by TCSC at bus i is given as follows

$$P_{TCSCfinj} = G'_{ij}V_i^2 \ + V_i V_t(G'_{ij}cos\delta_{it} + B'_{ij}sin\delta_{it})$$

$$Q_{TCSCfinj} = -B'_{ij}V_i^2 \ + V_i V_t(G'_{ij}sin\delta_{it} - B'_{ij}cos\delta_{it}) \tag{8}$$

D. STATIC VAR COMPENSATOR(SVC):

Static VAR Compensator (SVC) is a shunt connected FACTS controller whose main functionality is to regulate the voltage at a given bus by controlling its equivalent reactance. Basically it consists of a fixed capacitor (FC) and a thyristor controlled reactor (TCR) [7]. SVC has two configuration models, one is SVC Susceptance model as shown in Fig. 5a and later being Firing Angle model as shown in Fig. 5b.
A changing susceptance Bsvc represents the fundamental frequency equivalent susceptance of all shunt modules of the SVC .X_{SVC} equivalent reactance is controlled by changing firing angle α and is made up of the parallel combination of a thyristor controlled reactor (TCR) equivalent admittance and a fixed capacitive reactance as shown in Fig. 5 (b).



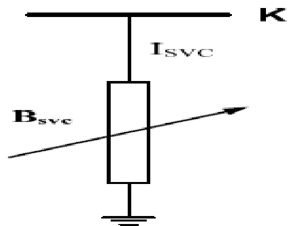


Fig.5a. SVC firing angle model **Fig.5b. SVC susceptance model**

Thus,[7]the model can be developed with respect to a sinusoidal voltage, differential and algebraic equations can be written as

$$I_{SVC} = -jB_{SVC}V_k \qquad (9)$$

The fundamental frequency TCR equivalent reactance

$$X_{TCR} = \pi X_L/(\sigma - sin\sigma) \qquad (10)$$

where
$\sigma = 2(\pi - \alpha)$
,α and σ are firing angle and conduction angle. The effective reactance of Static Voltage Compensator SVC X_{SVC} is determined by the parallel combination of X_C and X_{TCR} as

$$X_{SVC} = \frac{\pi X_C X_L}{X_C(2(\pi - \alpha) + sin2\alpha) - \pi X_L} \qquad (11)$$

E. The Static Synchronous Compensator (STACOM):

Iis a shunt compensation device of FACTS . It is based on power electronic devices to control voltage and improve the transient stability. Fig.6 shows the scheme of a STATCOM connected to a bus of the transmission system.

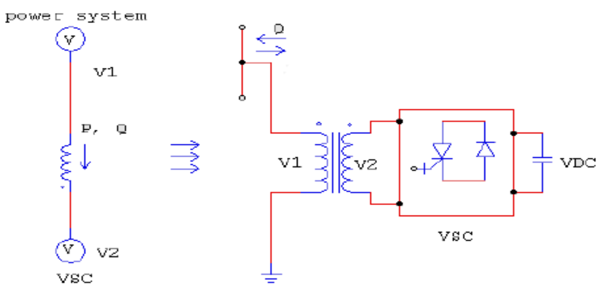


Fig. 6 STATCOM model

STATCOM consists of coupling transformer, Gate terminated Oscillator based voltage source converter VSC and a DC storage capacitor. By injecting the reactive power into the power network , it regulates the voltage magnitude at its terminals When the system voltage is high, it absorbs reactive power(STATCOM inductive) . When system voltage is low the STATCOM generates reactive power(STATCOM capacitive)[4].
The power balance equation of the STATCOM model is given by the following equation

$$P_{dc} + P_{loss} = P \qquad (12)$$

which represents the balance between the ac power P and dc power P_{dc} of the controller during balanced operation at fundamental frequency at steady state a condition . PWM controls are becoming a more practical option for transmission system applications of VSC-based controllers, due to some recent developments on power electronic switches that do not present the high switching losses of GTOs [8], which have typically restricted the use of this type of control technique to relatively low voltage applications. The steady state or "power flow" model Thus, the steady state equations for the STATCOM PWM controller are

$$V - V_{ref} \pm X_{SL}I = 0$$
$$V_{ref} - V_{dcref} = 0 \qquad (13)$$
$$P = GCV_{dc}^2 - RI^2 = 0$$
$$P - VIcos(\delta - \theta) = 0 \qquad (14)$$
$$Q - VIsin(\delta - \theta) = 0 \qquad (15)$$
$$P - V^2G + kV_{dc}V(Gcos(\delta - \alpha) + Bsin(\delta - \alpha)) = 0$$
$$Q + V^2B + kV_{dc}V(Gsin(\delta - \alpha) - Bcos(\delta - \alpha)) = 0 \qquad (16)$$

where on the first equation, the positive sign is used when the device is operating on the capacitive ($Q < 0$) and negative for the inductive mode($Q > 0$), since $I \geq 0$.

III. SIMULATION RESULTS

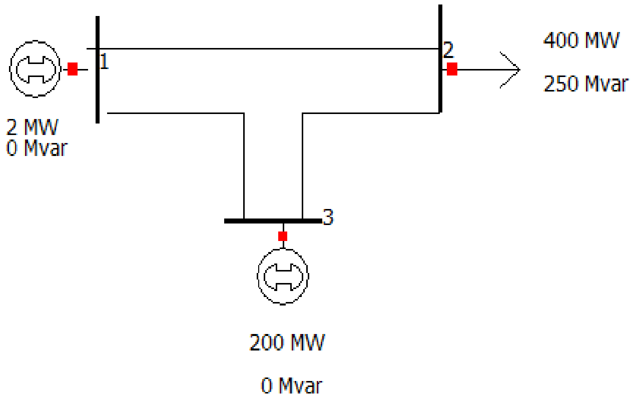


Fig. 7 Sample power system

For the power system shown in Fig.7 above the simulation is carried out with the insertion of TCSC and without TCSC for the ORPD using Power World Simulator software. TCSC is inserted in line between Bus 2 and Bus 3 either inductive or capacitive. The values of the reactance have been changed and the simulation is done using Power World Simulator software. The comparative results obtained for the complex power loss are given in the Table I. The results show that the real power loss without using TCSC for the system is found to be 20.7MW . Whereas the same have been found using inductive reactance of TCSC to be 21.5MW. And for the same system loading conditions the results have been found to be optimistic using capacitive reactance of TCSC. Thus , the power loss using capacitive reactance is found to be 20.5 MW.

Table I: Font Sizes for Papers

	P_L (MW)	Q_L (MVAR)
Without X_{TCSC}	20.7	41.6
With $+X_{TCSC}$	21.5	50.5
With $-X_{TCSC}$	20.5	31.4

IV. CONCLUSION

Thus the mathematical modelling of various FACTS devices has been done and the simulation of the sample power system using TCSC as variable inductive reactance or capacitive reactance is performed. From the results obtained using power world simulator software, it can be concluded that the TCSC being capacitive in nature reduces the power loss substantially.

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