Innovative Systems Design and Engineering
ISSN 2222-1727 (Paper) ISSN 2222-2871 (Online)
Vol 3, No 3, 2012

Optimization of Loss Minimization Using FACTS in Deregulated Power Systems

Julluri Namratha Manohar[1*] Amarnath Jinka[2] Vemuri Poornachandra Rao[3]

1. Ellenki College of Engineering and Technology, Patelguda(V), Medak(Dist.), Hyderabad, Andhra Pradesh, India 502319

2. College of Engineering, Jawaharlal Nehru Technological University, Kukatpally, Hyderabad, Andhra Pradesh, India 500 085

3. TKR College of Engineering and Technology, Meerpet, Hyderabad

* E-mail of the corresponding author: jnm4607@yahoo.com

Abstract

Losses are an important parameter of consideration for mitigation and thereby enhancing the Available Transfer Capability of Power Systems. Loss mitigation is a two stage process – the first stage is the Planning phase and the second stage is the Operational phase. The paper discusses briefly the Planning phase activities. The various methods of mitigating the losses in the Operational phase have been presented in the paper with emphasis on one technique – the Flexible Alternating Current Transmission System devices. The Flexible Alternating Current Transmission System Devices are the latest power electronics devices by which losses can be reduced and transfer capability enhanced. Thyristor Control Series Compensator is used to reduce losses. The method is tested on IEEE 9 bus, 14 Bus and 30 bus systems and validated. Results have been presented and analyzed in this paper.
Keywords: Available Transfer Capability, B- Loss Coefficients, Flexible Alternating Current Transmission Systems, Thyristor Controlled Series Compensator.

1. Introduction

The primary objective of Power Systems design is to operate the systems economically at maximum efficiency and supply power on demand to various load centers with high reliability. The rising electric power demand in the 21st- century, has called for re-structuring of the electric power system. The restructuring is in two aspects – one is the technical aspect and the other the Management aspect. As regards the technical aspect the power systems are expanding in size to meet the huge power demand and are complex due to advancement of technology such as Hybrid-Generation, FACTS (Flexible Alternative Current Transmission Systems) etc. Management viewpoint, the deregulation of the power utility industry is resulting in significant regulatory changes. Deregulation has paved a path for the re-birth of distributed energy resources and continually emerging new and difficult issues of concern in the operation of power systems. In addition to modern power systems being highly interconnected over long distances to carry power from the sources to loads, there is an economic reason also. The interconnected systems benefit by (a) exploiting load diversity (b) sharing of generation reserves and (c) economy gained from the use of large efficient units without sacrificing reliability. Additionally, in deregulated circumstances of the power system, it has already become possible for the third party such as independent power producers and customers to access the transmission network for wheeling. Under the above condition, it becomes more and more important to enhance the reliability of the power system. An aspect of interest here is quantifying the loss accurately and adopting measures to minimize the loss, thereby resulting in improved power transfer capability. The electric power transmission efficiency-enhancing actions and technologies include:

• Distributed generation/Micro grids
• Intelligent grid design.
• Three phase design for distribution
• Distribution loss reduction via distribution automation.
•Higher transmission operating voltages.
• Reduction of overall Transmission and Distribution transformer Mega Volt-Ampere.
• Underground distribution lines.
• Energy storage devices.
• Ground wire loss reduction techniques.
• Power factor improvement.
Power electronic transformers

India's electricity grid has the highest transmission and distribution losses in the world – a whopping 27%. This is attributed to technical losses (grid's inefficiencies) and theft. Hence, Losses have always been a subject of interest to study.

The paper presents the interest of the authors in discussing few Planning techniques and determining the losses in the transmission system under various conditions and presenting an effective method of mitigating losses to enhance Available Transfer Capability.

The rest of the paper is organized as follows: Section 2. – Losses in Power System, Section 3. Management of Technical Losses, Section 4. Mathematical Modeling of Technical Losses, Section 5. FACTS Devices and its Implementation, Section 6. is Case Study and In Section 7. Results and Discussion have been presented. Conclusions in Section 8..

2. Losses in Power System

Losses in simple terms may be stated as the difference between the power generated and the power received.

$$\boldsymbol{P_{loss}} = P_G - P_R \tag{1}$$

where $\boldsymbol{P_{loss}}$ = Total Losses P_G = Power Generated P_R = Power Received

*2.1 **Categorization of Losses***

The losses are broadly classified into two categories:

i. Technical Losses:

The technical losses are internal to the Power system and occur due to the components in the system. They occur naturally and consist mainly of power dissipation in electrical system components such as transmission and distribution lines, transformers etc. Technical losses are a function of the system design parameters and the dynamic state of the power system. Technical losses can be controlled by two methods:

i) By proper design of the system parameters such as diameter of the conductor, length of the conductor, selection of the right material, operation voltage etc. This is an activity of the Planning Stage.

ii) Controlling the parameters during power system operation by use of devices such as FACTS etc. This is an activity of the Controlling Stage.

ii. Non-Technical Losses

Non-technical losses are caused by actions external to the power system and consist primarily of electricity theft, non-payment by customers, and errors in accounting and record-keeping.

3. Management of Technical Losses

Management of Technical Losses is a two stage process:

1. Planning Stage 2. Monitoring, Control and Maintenance Stage.

The stages are shown in Figure 1.

*3.1 **Planning to Minimize Losses***

The Technical losses can be calculated based on the natural properties of components in the power system: resistance, reactance, capacitance, voltage, current, and power, which are routinely calculated by utility companies as a way to specify what components can be added to the system, in order to reduce losses and improve the voltage levels and efficiency. Transmission losses in the network constitute economic loss providing no benefits. Transmission losses are construed as a loss of revenue by the utility. The magnitude of each of these losses needs to be accurately estimated and practical steps taken to minimize them. From the utility perspective, transmission losses need to be reduced to their optimal level. Before we begin to discuss the various steps in the planning of designing a power system that should operate with minimum losses, let us visit the major reasons for technical losses.

As per TERI (The Energy and Resources Institute) the major reasons for high technical losses in our country are due to inadequate planning: Inadequate investment on transmission and distribution (T&D), particularly in sub-transmission and distribution. While the desired investment ratio between generation and T&D should be 1:1, during the period 1956 -97 it decreased to 1:0.45. Low investment has resulted in overloading of the distribution system without commensurate strengthening and augmentation. Haphazard growths of sub-transmission and distribution system with the short-term objective of extension of power supply to new areas, large scale rural electrification through long 11kV(Kilo Volt) and Low Tension(LT) lines, Too many stages of transformations, Improper load management, Inadequate reactive compensation, Poor quality of equipment used in agricultural pumping in rural areas, Cooler, air-conditioners and industrial loads in urban areas. To overcome the above drawbacks, the various Modern Methods and Technology developed being implemented are: Implementation of rigid standards for various equipment such as transformers, High Voltage Direct Current Transmission (HVDC)**,** Placement **of** FACTS Devices, Gas Insulated Sub-Station (GIS)**,** Superconductors, Wide Area Monitoring System (WAMS) and Supervisory Control and Data Acquisition (SCADA).Planning also involves computation of the various losses for the design system parameters of resistance, reactance and capacitance of lines, operating voltages etc . This is discussed in the next section.

3.2 Monitoring, Control and Maintenance of the Electric Power Transmission Grid

Monitoring of the Electrical Power System requires recording of the various system parameters such as voltages, current, line flows, loads and generation and status of the various equipment. Controlling requires determining the deviation of the operating parameters from the standard and initiating corrective actions. In the context of the paper subject of study, we are to determine the losses and power flows on the various transmission lines at base state and after taking corrective action, and thereby compute the reduction in losses. The corrective action taken is placement of the FACTS device, Thyristor Controlled Series Capacitors (TCSC) in the lines having maximum active power loss.

4. Mathematical Modeling of Technical Losses

4.1 Fundamental method

Technical losses in power systems mean power losses incurred by physical properties of components in the power systems' infrastructure. A common example of such power loss is proportional to the resistance (R) of the wire and the square of the current (I) [1].

$$\boldsymbol{P_{loss} = RI^2} \tag{2}$$

For a system which delivers a certain amount of power *(P),* over a particular voltage *(V),* the current flowing through the cables is given by

$$I = \frac{P}{V}. \tag{3}$$

Thus, the power lost in the lines is

$$P_{loss} = RI^2 = R(\frac{P}{V})^2 = \frac{RP^2}{V^2} \tag{4}$$

Therefore, the power lost is proportional to the resistance and inversely proportional to the square of the voltage. Because of this relationship, it is favourable to transmit energy at voltages as high as possible. This reduces the current and thus the power lost during transmission. Thus High Voltage DC (HVDC) is used to transmit large amounts of power over long distances or for interconnections between asynchronous grids. When electrical energy is required to be transmitted over very long distances, it can be more economical to transmit using direct current (DC) instead of alternating current (AC). For a long transmission line, the value of the smaller losses, and reduced construction cost of a DC line, can offset the additional cost of converter stations at each end of the line. Also, at high AC voltages significant amounts of energy are lost due to corona discharge, the capacitance between phases or, in the case of buried cables, between phases and the soil or water in which the cable is buried. Since the power flow through an HVDC link is directly controllable, HVDC links are sometimes used within a grid to stabilize the grid against control problems with the AC energy flow. One prominent example of such a transmission line is the Pacific Intertie located in the Western United States. The two important modern technologies to boost efficiency of transmission are HVDC and FACTS. A study has been conducted on 9 Bus,14 Bus and 30 Bus system to determine the effect of FACTS devices in particular TCSC on i)reduction of losses ii) extent of loss reduction.

4.2 ***B-Coefficients***

Another interesting method is the B-Loss coefficients. B-Coefficients are the widely used conventional method to calculate the incremental losses. The B-Loss Coefficients express transmission losses as a function of the outputs of all generation plants. The B matrix loss formula was originally introduced in early 1950 as a practical method for loss calculations. Consider a simple three-phase radial transmission line between two points of generating/source and receiving/load as illustrated by Figure 2. We can deduce the line loss as:

$$\mathbf{P_{loss}} = 3\,I^{2}\,R \tag{5}$$

$$|I| = \frac{P_G}{(\sqrt{3})V_G \cos \emptyset_G} \tag{6}$$

V_G is the magnitude of the generated voltage (line-to-line)

$cos\varphi_G$ is the generator power factor

Combining the above two equations we have:

$$P_{Loss} = \frac{R}{|V_G|^2 cos^2 \emptyset_G}(P_G{}^2) \tag{7}$$

Assuming fixed generator voltage and power factor, we can write the losses as:

$$P_{Loss} = B\,P_G{}^2 \tag{8}$$

Losses are thus approximated as a second order function of generation. If a second power generation is present to supply the load as shown in the figure 3 we can express the transmission losses as a function of the two plant loadings. Losses can now be expressed by the equation:

$$P_L = P_1 B_{11} + 2P_1 P_2 B_{12} + P_2 B_{22} \tag{9}$$

We refer to *B* as the loss coefficient. The simplest form of the equationis called George's formula,which is given by:

$$P_L = \sum_{m=1}^{k} \sum_{n=1}^{k} P_m B_{mn} P_n \tag{10}$$

P_m, P_n is the power generation from all sources

The B coefficients are not truly constant but vary with unit loadings. Transmission losses become a major factor to be considered when it is needed to transmit electric energy over long distances or in the case of relatively low load density over a vast area. The active power losses may amount to 20 to 30 % of total generation in some situations. Finally we find out, that the real power losses are the function of the generation and B-loss coefficient. Varying the generations to fulfill the power demand would change the losses accordingly. If we will be able to minimize the B-losses, we will reduce the total losses also. B-loss coefficient is a function of resistances, voltages and power factors at each system state, while the resistances are the physical properties of the equipment and they are constant, improving the voltage would minimize the B-loss coefficient.

5. FACTS Devices and Its Implementation

The power electronic based FACTS have been developed and used as economical and efficient means to control the power transfer in the interconnected AC transmission systems. The benefit brought about by FACTS includes improvement of system dynamic behavior and thus enhancement of system reliability. The benefits due to FACTS controllers are many. They contribute to optimal system operation by reducing power losses and improving voltage profile. The power flow in critical lines can be enhanced as the operating margins can be reduced due to fast controllability. In general, the power carrying capacity of lines can be increased to values up to the thermal limits (imposed by current carrying capacity of the conductors). The transient stability limit is increased thereby improving dynamic security of the system and reducing the incidence of blackouts caused by cascading outages. The steady state or small signal stability region can be increased by providing auxiliary stabilizing controllers to damp low frequency oscillations. FACTS controllers such as TCSC can counter the problem of Sub-synchronous Resonance (SSR). The problem of voltage fluctuations and in particular, dynamic over-voltages can be overcome by FACTS controllers. However, their main function is to control power flows [2]. Provided optimally located, FACTS devices are capable of increasing the system load ability too. These aspects are playing an increasing and major role in the operation and control of competitive power systems.

*5.1 **Modeling of FACTS Devices***

Table 1 lists the several types of existing and proposed FACTS devices. These types are termed A, B, and C here for convenience [3]. Figure 4. depicts the block diagram of the FACTS devices (a) TCSC (b) TCPST (c) UPFC (d) SVC. As shown in Fig.4, the reactance of the line can be changed by TCSC. The afore-mentioned FACTS devices can be applied to control the power flow by changing the parameters of power systems so that the power flow can be optimized [4]. Moreover, in a multi machine network according to the different utilization of generation units, by use of FACTS, the generation costs can also be reduced.

5.2 Practical Implementation of TCSC

Series compensation, in its classical appearance, has been in commercial use since the 1960s. From its basic mechanism, a number of benefits are attainable, all contributing to reduction of losses and increase of the power transmission capability of new or existing transmission circuits. The rated value of TCSC is a function of the reactance of the transmission line where it is located. In power transmission applications, the degree of compensation is usually chosen somewhere in the range $0.7X_{Line}$ to $0.2\ X_{Line}$.

In India, two TCSCs have been installed on the Rourkela-Raipur twin circuit 400 kV power transmission inter-connector between the Eastern and Western regions of the grid. The length of the inter-connector is 412 km. The main purpose of this major AC inter-connector is to enable export of surplus energy from the Eastern to the Western regions of India during normal operating conditions, and also during contingencies. The TCSCs are located at the Raipur end of the lines.

The TCSCs enable damping of inter-area power oscillations between the regions, which would otherwise have constituted a limitation on power transfer over the inter-connector. Dynamic simulations performed during the design stage, and subsequently confirmed at the commissioning and testing stage, have proved the effectiveness of the Raipur TCSC as power oscillation dampers.

6. Case Study

6.1Optimal Location of TCSC Based On Real Power Loss

The static conditions are considered here for the placement of FACTS devices in the power system. The objectives for device placement may be one of the following: 1. Reduction in the real power loss of a particular line.2. Reduction in the total system real power loss 3. Reduction in the total system reactive power loss. 4. Maximum relief of congestion in the system. For the first objective the line with the maximum power loss may be considered for placement of TCSC. Methods based on the sensitivity approach may be used for the next three objectives. If the objective of FACTS device placement is to provide maximum relief of congestion, the devices may be placed in the most congested lines or, alternatively, in locations determined by trial-and-error.

6.2 ***Proposed Approach***

Power Flow studies were carried out by using Power World Simulator and MATLAB. First Base Case data was obtained for 9 – Bus, 14-Bus and 30 – Bus. The One-Line diagram of 9-Bus and 14-Bus Test systems is depicted **in** Figure 5 and 6 respectively. The lines having maximum losses were identified. TCSC FACTS device was placed in these lines. TCSC was implemented by increasing the reactance of the line by 20 % to 70%. .After placing of TCSC power flow data was obtained and compared with the base case values. The percentage reduction of losses was computed. The results are analyzed and discussed below.

7. Results and Discussions

1) The Power Flow study converged in 0.14sec with FACTS as compared to without FACTS. 2) Objective Function Value is reduced by 1.31 $/hr. **3)** For the 9 – Bus System Total MW Loss before placement of FACTS Devices is 10.6MW.The transmission line between buses 5 and 6 is having the maximum Loss of 7.6MW. Hence, TCSC was placed in the line between buses 5 and 6. Total MW Loss after placement of FACTS Devices is 9.9MW and the loss in the transmission Line between buses 5 and 6 is reduced to 6.3MW. Thus the total Loss reduction is 6.6%, with placement of FACTS Devices. The inductive reactance between 75% and 20% of the line reactance respectively were considered. In 14 Bus System line between buses 1 to 2 is having maximum MW loss. Hence the TCSC FACTS device was placed in this particular line; and the reduction in losses was observed to be 17%. In Case Study of 30 Bus System **also** the lines having maximum losses were identified and TCSC placed. The lines identified were between buses 1-3, 2-4, 2-6, 24-25, 25-27. The real Power Loss reduction was 9.4%. 4) The Table 2 below shows the percentage loss reduction with FACTS devices. 5) The graph of the Losses Vs Line No of 9 – Bus is depicted in Figure 7. **5)** The graph of the Losses Vs Line No of **30** – Bus in Figure 8.

8. Conclusion

FACTS devices have proved an effective method for Loss reduction .The effectiveness of TCSC is demonstrated on IEEE 9 bus, 14 bus system and 30 –Bus IEEE Power Systems. The main conclusions of the paper are: i) The time of convergence is less. ii) The placement of Facts devices enhances system ATC and mitigates real power loss. iii) The simple and direct method of placing TCSC in the lines having maximum power loss has shown effective results in loss reduction and enhancing ATC.

References

[1]Arai Sobhy M. Abdelkader, *Member, IEEE*, 2011, Characterization of Transmission Losses, 392 IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 26, NO. 1, FEBRUARY 2011

[2]Optimal Placement of FACTS Devices by Genetic Algorithm for the Increased Load Ability of a Power System A. B.Bhattacharyya, B. S.K.GoswamiWorld Academy of Science, Engineering and Technology 75 2011

[3] Optimal Location of FACTS Devices for Congestion Management in Deregulated Power Systems K.Vijayakumar,SRM University,Kattankulathur, Chennai, International Journal of Computer Applications (0975 – 8887), Volume 16– No.6, February 2011.

[4] K.Narasimha Rao, J.Amarnath “Enhancement of Available Transfer Capability with FACTS Devices”, Journal of Current Sciences, 2010.

[5] V.Kakkar and N.K.Agarwal, Recent Trends on FACTS and D-FACTS, Modern Electric Power Systems

2010, Wroclaw, Poland.
[6] Lana Wong, A Review of Transmission Losses in Planning Studies August 2011, http://www.energy.ca.gov/2011publications/CEC-200-2011-009/CEC-200-2011-009.pdf

J.Namratha Manohar has acquired her degree in Electrical Engineering from Osmania University in the year 1982, MCA from IGNOU in the year 2004, M.Tech from IASE in the year 2006.She is presently a Research Student in the Department of Electrical Engineering at J.N.T.U, Hyderabad and serving as Professor and Head of the Department of Electrical and Electronics Engineering at Ellenki College of Engineering and Technology,Patelguda. Her research areas include Power System, Performance Optimization Techniques.

J.Amarnath has acquired his degree in Electrical Engineering from Osmania University in the year 1982, M.E from Andhra University in the year 1984 and Ph.D from J.N.T. University, Hyderabad in the year 2001. He is presently Professor in the Department of Electrical and Electronics Engineering, JNTU College of Engineering, Hyderabad, India. He presented more than 60 research papers in various national and international conferences and journals. His research areas include Gas Insulated Substations, High Voltage Engineering, Power Systems and Electrical Drives.

Dr PC Rao Vemuri, a popular Professor of Computer Science worked at various capacities like General Manager (TECH), Vice President ,Director (Technical) and Chief Technology officer in IT industry. He is one of the team members who got transferred CYBER MAINFRAME computer technology from CDC (USA) to India. Dr PCRAO worked as a Principal and Professor of reputed colleges GNITS ,Karshak, Sri Indu, St Martin, IARE and Holy Mary Institute of Technology and Science from last 13 years. His areas of research are CPU scheduling models ,natural Language processing data bases ,data mining and software cost estimation .

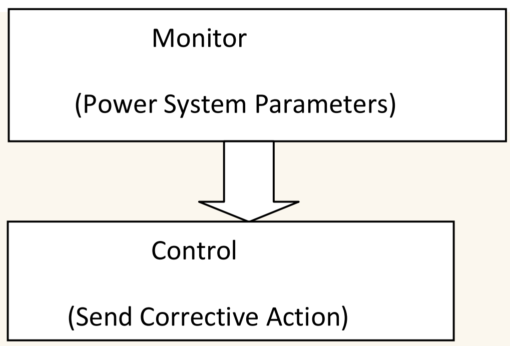


Fig. 1 Stages of Management of Technical Losses

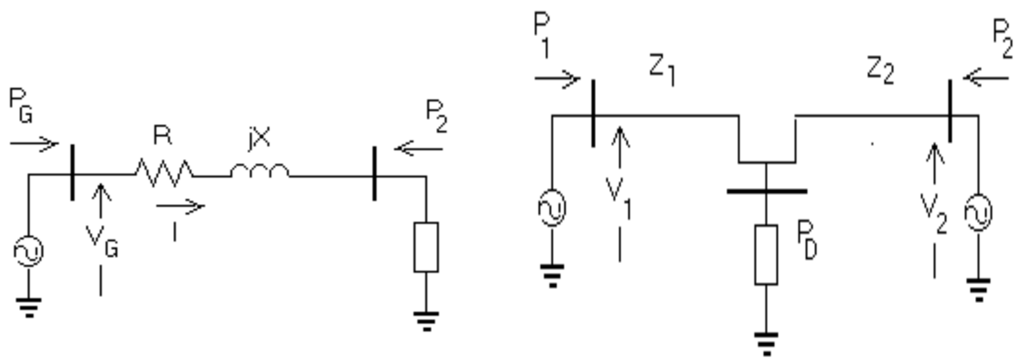


Figure 2 Radial Line with One Generation

Figure 3 Radial System with One Additional Generation

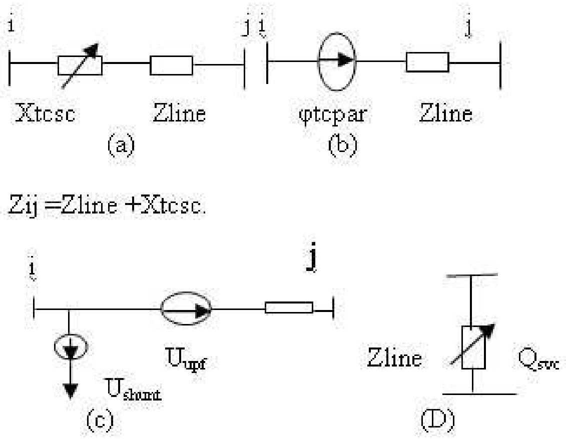
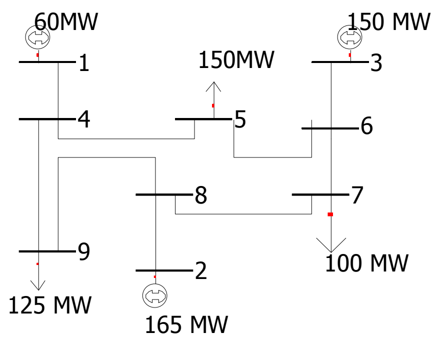


Fig. 4. Block diagram of the considered FACTS devices (a) TCSC (b) TCPST (c) UPFC (d) SVC



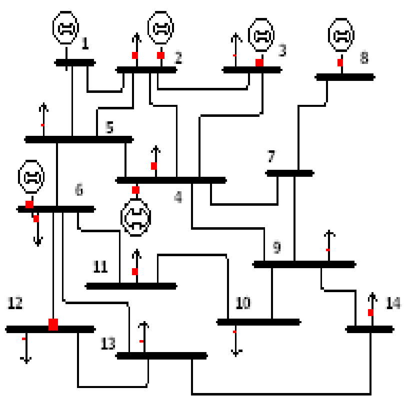
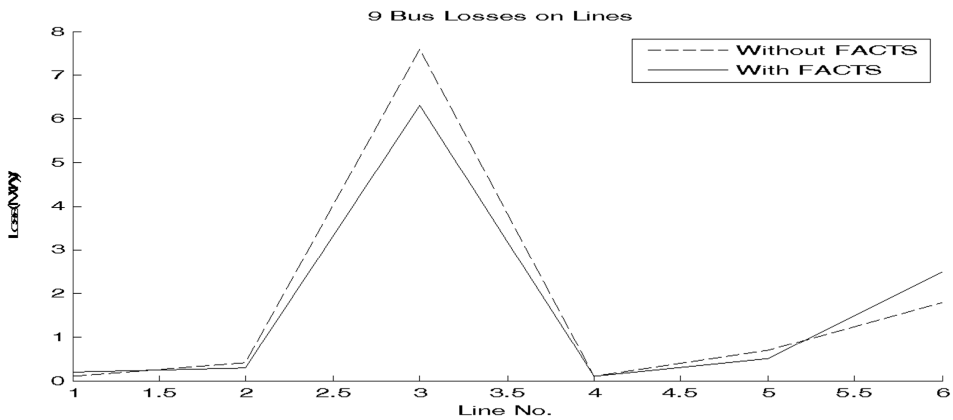


Figure 5 IEEE 9-Bus Test System

Figure 6 IEEE 14-Bus Test System



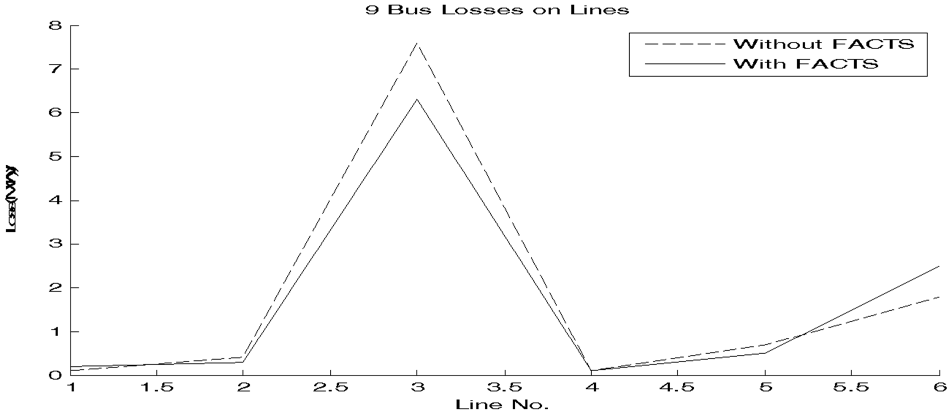


Figure 7 9 Bus System Losses Before and after Placing FACTS

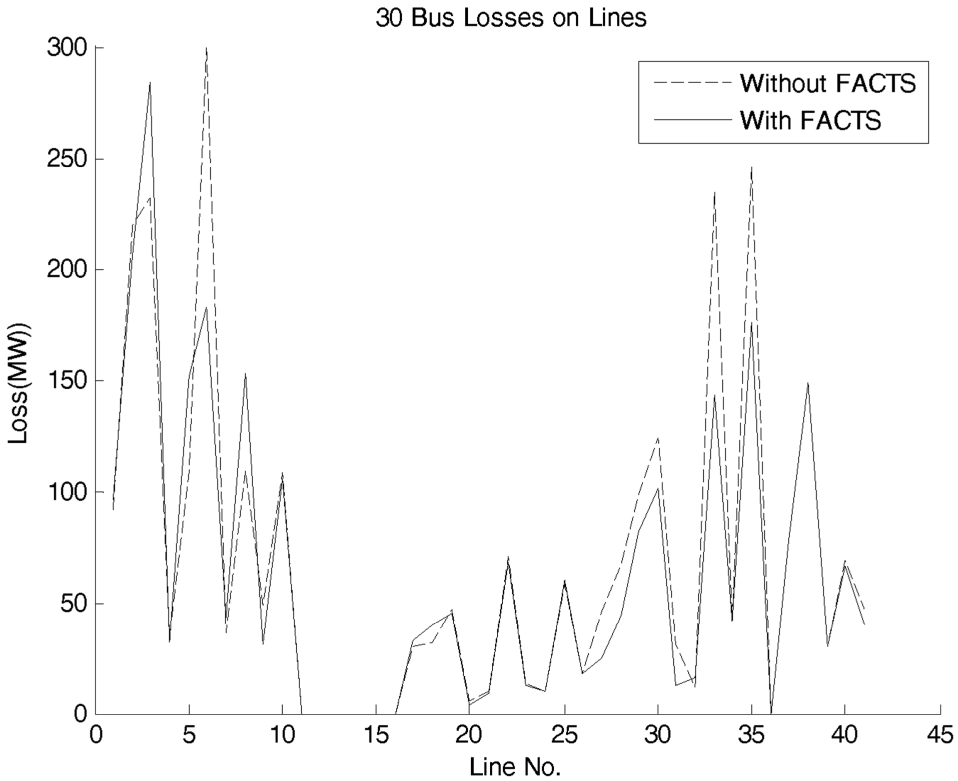


Figure 8 30 Bus System Losses Before and after Placing FACTS

TABLE 1 TYPES OF FACTS DEVICE MODELS

Type Designation	Parameter Controlled	FACTS Devices
Type A	Series P and Q	UPFC
Type B	Series P	TCSC,phase angle regulator
Type C	Series Q	SVC,STATCON

Table 2 % Loss Reduction with FACTS

Power System	Real Power Loss Reduction
9-Bus	6.6%
14-Bus	17%
30-Bus	9.4%