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Line Losses Minimization in Electrical Power Network Using Matlab

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ABSTRACT
With the increasing size of power system, there is a thrust on finding the solution to maximize the utilization of existing system and to provide adequate voltage support. For this the flexibility of power is needed. Flexible AC transmission system (FACTS) if placed optimally can be effective in providing voltage support, controlling power flow and in turn resulting into lower losses. The algorithm to find the optimal location of TCSC and STATCOM based on genetic algorithm has been developed. The effect of these devices on line flows and bus voltage profile has been studied by placing at random location and placing them optimally with optimal ratings dictated by genetic algorithm.
Keywords: Transmission, FACTS devices, Losses, optimization, compensator

INTRODUCTION

The increasing Industrialization, urbanization of life style has led to increasing dependency on the electrical energy. This has resulted into rapid growth of power systems. This rapid growth has resulted into few uncertainties. Power disruptions and individual power outages are one of the major problems and affect the economy of any country. In contrast to the rapid changes in technologies and the power required by these technologies,[1] transmission systems are being pushed to operate closer to their stability limits and at the same time reaching their thermal limits due to the fact that the delivery of power have been increasing. The major problems faced by power industries in establishing the match between supply and demand are:

i. Transmission & Distribution; supply the electric demand without exceeding the thermal limit.
ii. In large power system, stability problems causing power disruptions and blackouts leading to huge losses.

These constraints affect the quality of power delivered. However, these constraints can be suppressed by enhancing the power system control. One of the best methods for reducing these constraints are FACTS devices. With the rapid development of power electronics, *AC Flexible Transmission Systems* (FACTS) devices have been proposed and implemented in power systems. FACTS devices can be utilized to control power flow and enhance system stability. Particularly with the deregulation of the electricity market, there is an increasing interest in using FACTS devices in the operation and control of power systems. A better utilization of the existing power systems to increase their capacities and controllability by installing FACTS devices becomes imperative. FACTS devices are cost effective alternatives to new transmission line construction. Reactive power compensation is provided to minimize power transmission losses, to maintain power transmission capability and to maintain the supply voltage. Series compensation is control of line impedance of a transmission line; with the change of impedance of a line either inductive or capacitive compensation can be obtained thus facilitating active power transfer or control. Thyristor Controlled Series Capacitor (TCSC) is a variable impedance type series compensator and is connected in series with the transmission line to increase the power transfer capability, improve transient stability, reduce transmission losses and dampen power system oscillations. Shunt compensation is used to increase the steady-state transmittable power and to control the voltage profile along the line. Static compensator (STATCOM)[2] is a shunt compensator and one of the important

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members of FACTS family that are increasingly being applied to long transmission lines by the utility in modern power systems. They can have various applications concerned with operation and control of power system, such as scheduling power flow; decreasing unsymmetrical components damping the power oscillations and enhancing transient stability.

FLEXIBLE AC TRANSMISSION SYSTEM

The concept of Flexible AC Transmission Systems (FACTS) was first defined by N.G. Hingorani, in 1988. A Flexible Alternating Current Transmission System (FACTS) is a system comprised of static equipment used for the AC transmission of the electrical energy. It is meant to enhance controllability and increase power transfer capability of the network. It is generally a power electronic-based device. FACTS is defined by the IEEE as "a power electronic based system and other static equipment that provide control of one or more AC transmission system parameters to enhance controllability and increase power transfer capability [5]

The Flexible AC Transmission System (FACTS) is a concept that involves the application of high power electronic controllers in AC transmission networks which enable fast and reliable control of power flows and voltages. FACTS do not indicate a particular controller but a host of controllers which a system planner can choose, based on cost benefit analysis. The main objectives of a FACTS controller are as follows:

i. Regulation of power flows in prescribed transmission routes.
ii. Secure loading of lines near their thermal limits.
iii. Prevention of cascading outages by contributing to emergency control.
iv. Damping of oscillations which can threaten security or limit the usable line capacity.

v. Prevention of voltage collapse by providing reactive power support.

The active and reactive power flows in a transmission line can be precisely controlled by injecting a series voltage phasor with desirable magnitude and phase angle, leading to an improvement in system stability and system reliability and reduction in operating cost and new transmission line investment cost. It is also possible to force power flow through a specific line and regulate the unwanted loop and parallel power flows by varying the impedance of the line. FACTS controllers have a significant impact on damping power system oscillations and compensating dynamic reactive power. FACTS can be divided into four categories based on their connection in the network: Shunt controllers, Series controllers, Combined Series – Series controllers and Combined Series – Shunt controllers.

Optimal Placement of Facts Devices

During the outages of some of the critical lines/equipments, power system may become insecure and vulnerable to the voltage collapse/instability due to lack of reactive power support and/or overloading of the network. Generators may have limited reactive power capability and, sometimes, their reactive power cannot be efficiently used if the reactive power requirement in the network is far from their locations. 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. Moreover, low voltage profile in the system may cause load curtailment. Hence, reactive power compensators are required in the network to maintain the voltage profile and, thereby, improving the steady state and dynamic performances of the system.

Load Flow Solutions

Load flow studies are the backbone of power system analysis and design. Load flow studies are necessary for planning, economic scheduling and exchange of power between utilities [6]. In addition, power flow analysis is required for many analyses such as transient stability and contingency studies. The load flow solution gives the nodal voltages and phase angles and hence the power injection at all the buses and power flows through interconnecting transmission lines. Load flow equations are nonlinear and can be solved by an iterative method.

Evolutionary Algorithm

Evolutionary algorithms (EA) are search methods that take their inspiration from natural selection and survival of the fittest in the biological world. EAs differ from more traditional optimization techniques in that they involve a search from a "population" of solutions, not from a single point. In an EA a number of artificial creatures search over the space of the problem. EA also use objective function information, not derivatives or other auxiliary knowledge .Genetic Algorithm is one of the several evolutionary search methods. GA is search algorithms based on mechanics of natural selection and natural genetics. They emulate species evolution through generations. The main features of GA that differentiates it from other search methods are that it works with a coding of parameter instead of parameters themselves, it evaluates the fitness of each string to guide its search instead of the optimization function and is the algorithm is multipath search and hence reducing the possibility of local minimum trapping. The three most important aspects of GA are:

i. Definition of objective function
ii. Definition and implementation of genetic representation
iii. Definition and implementation of genetic operators

The Concept of Optimization in Power Systems

The brief review on the placement of FACTS devices is presented here. The concept of FACTS and FACTS devices was first defined by Hingorani, 1988 in. FACTS usually refer to the application of high-power semiconductor devices to control different parameters and electrical variables such as voltage, impedance, phase angles, currents, reactive and active power. FACTS can provide versatile benefits to transmission utilities such as control of power flow, increasing capabilities of lines to their thermal limits, reducing loop flows, providing greater flexibility. The value of FACTS application lies mainly in the ability of the transmission system to efficiently transmit power or to transfer power under contingency conditions. FACTS technology is a collection of controllers that can be applied to control electrical variables and parameters. In general FACTS controllers can be divided into four categories:

1) Series controllers mainly TCSC and SSSC
2) Shunt controllers mainly STATCOM and SVC
3) Series-series controllers such as IPFC and
4) Combined series-shunt controllers such as UPFC.

Reactive power compensation is an important issue in powers system. The purpose of reactive power compensation is mainly to improve the voltage profile in the system and to minimize the power loss.

FACTS Applications to Optimal Power Flow

In the last two decades, researchers developed new algorithms for solving the optimal power flow problem incorporating various FACTS devices [8]. Generally in power flow studies, the thyristor-controlled FACTS devices, such as SVC and TCSC, are usually modeled as controllable impedance. However, VSC-based FACTS devices, including IPFC and SSSC, shunt devices like STATCOM, and combined devices like UPFC, are more complex and usually modeled as controllable sources [9]. Padhy et al. have presented a new hybrid model for OPF incorporating FACTS devices to overcome the classical optimal power flow algorithm where load demands, generation outputs, and cost of generation are treated as fuzzy variables. In the solution process, GA coupled with full AC power flow, selects the best regulation to minimize the total generation fuel cost and keep the power flows within their secure limits. Shao and Vittal presented a linear programming (LP)—based OPF algorithm for corrective FACTS control to relieve overloads and voltage violations caused by system contingencies. The optimization objective was chosen to minimize the average loadability on highly loaded transmission lines.

Thyristor Controlled FACTS devices

This group employs reactive impedances or tap-changing transformer with thyristor switches working as the control elements. This group includes the Static Var Compensator(SVC),Thyristor Controlled Series Compensator-Switched capacitor(TCSC) and Thyristor controlled phase shifter(TCPS).They employ conventional thyristors in circuit arrangements which allows fast control response compared to the corresponding mechanical system .Each device can control one of the three power transmission control variables (bus voltage, transmission impedance and phase angle)

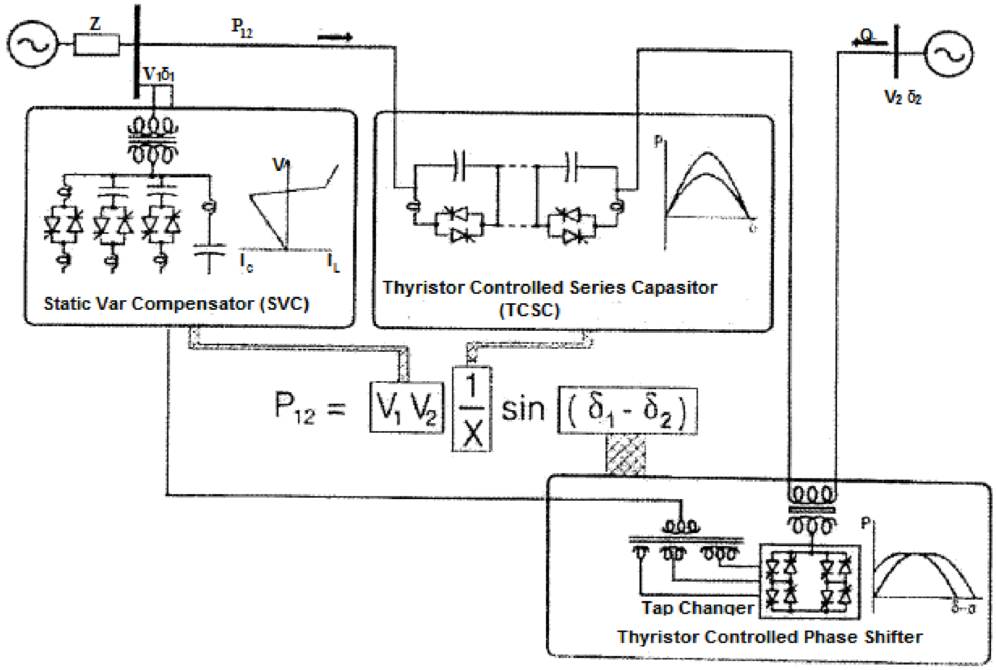

Fig1aThyristor controlled FACTS devices
Source: **[10]**

Stactic VAr Compensator (SVC)

The SVC is effectively a variable shunt reactance which is able to produce a compensating reactive current. It comprises a Thyristor Switched Capacitor (TSC) and a Thyristor Controlled Reactor (TCR).The device is operated to regulate the voltage at a selected terminal of the transmission system by a proper coordination of the capacitor switching and reactor phase angle control **[10]**.It may be controlled to improve the transient and dynamic stability of the transmission system. SVC may be controlled to damp power oscillation by adjusting its output between appropriate capacitive and inductive values to oppose the angular acceleration and deceleration of the involved synchronous machines **[10]**. SVC installations consist of a number of building blocks. The most important is the thyristor valve, that is, stack assemblies of series connected anti-parallel thyristors to provide controllability.

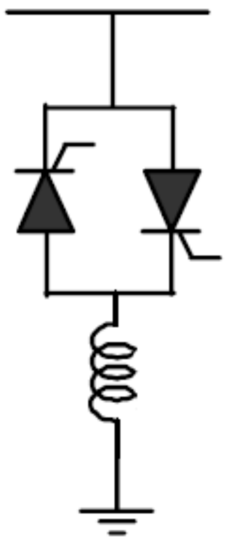

Fig1bThyristoControlled Reactor

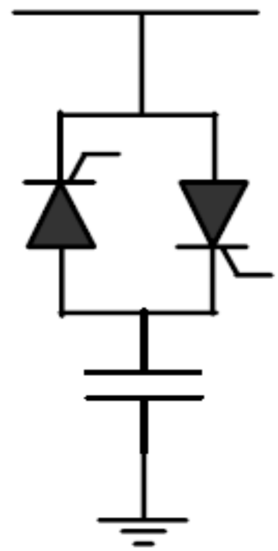

Fig1cThyristorSwitched Capacitor [11]

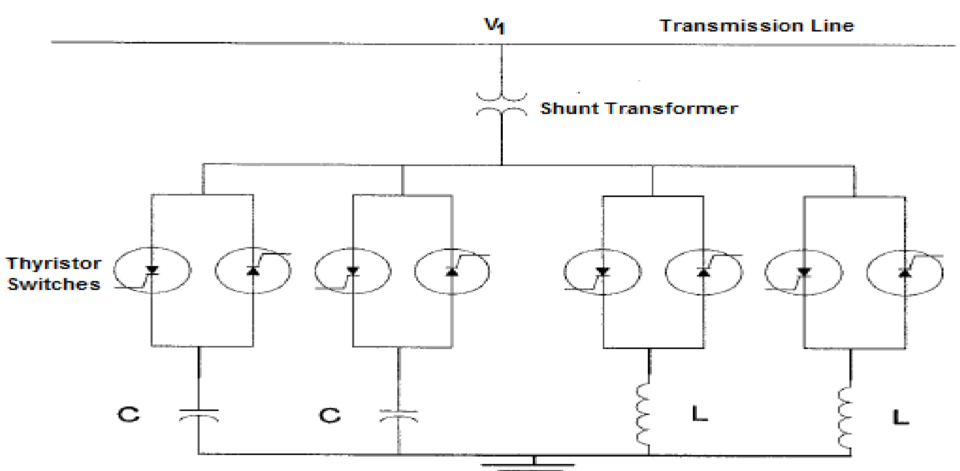

Fig1dStaticVArCompensator[10]

MATLAB 7.0

Matlab 7.0 was used to carry out this process. The scripts for these techniques are in Appendix One. Matpower is a prepared folder that operates with Matlab to execute power flow analysis. It uses an options vector to control the many options available. It is similar to the options vector produced by the f-options function in early versions of Matlab's Optimization Toolbox. The primary difference is that modifications can be made by option name, as opposed to having to remember the index of each option. Algorithms for the two techniques used are embedded in the Matpower folder and hence, invoked for the purpose of this analysis.

In Matpower, by convention, a single generator bus is typically chosen as a reference bus to serve the roles of both a voltage angle reference and a real power slack. The two techniques (Newton Raphson and Gauss-seidel) are used for the optimization of FACTS devices position and systems. Data and analysis were obtained. The voltage angle at the reference bus has a known value, but the real power generation at the slack bus is taken as unknown to avoid over specifying the problem. The remaining generator buses are classified as PV buses, with the values of voltage magnitude and generator real power injection given. Since the loads Pd and Qd are also given, all non-generator buses are PQ buses, with real and reactive injections fully specified. Table 1.0 shows the bus data of the power system for consideration. Table 1.1 shows the Generator data.

Table 1.0 Bus Data Of The Power System.

Bus no.	Bus Type	Pd	Qd	Gs	Bs	Area	V_m	V_a	Base KV	Zone	V_{max}	V_{min}
1	3	0	0	0	0	1	1	0	135	1	1.05	0.95
2	2	21.7	12.7	0	0	1	1	0	135	1	1.10	0.95
3	1	2.4	1.2	0	0	1	1	0	135	1	1.05	0.95
4	1	7.6	1.6	0	0	1	1	0	135	1	1.05	0.95
5	1	0	0	0	0.19	1	1	0	135	1	1.05	0.95
6	1	0	0	0	0	1	1	0	135	1	1.05	0.95
7	1	22.8	10.9	0	0	1	1	0	135	1	1.05	0.95
8	1	30	30	0	0	1	1	0	135	1	1.05	0.95
9	1	0	0	0	0	1	1	0	135	1	1.05	0.95

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10	1	5.8	2	0	0	3	1	0	135	1	1.05	0.95
11	1	0	0	0	0	1	1	0	135	1	1.05	0.95
12	1	11.2	7.5	0	0	2	1	0	135	1	1.05	0.95
13	2	0	0	0	0	2	1	0	135	1	1.1	0.95
14	1	6.2	1.6	0	0	2	1	0	135	1	1.05	0.95
15	1	8.2	2.5	0	0	2	1	0	135	1	1.05	0.95
16	1	3.5	1.8	0	0	2	1	0	135	1	1.05	0.95
17	1	9	5.8	0	0	2	1	0	135	1	1.05	0.95
18	1	3.2	0.9	0	0	2	1	0	135	1	1.05	0.95
19	1	9.5	3.4	0	0	2	1	0	135	1	1.05	0.95
20	1	2.2	0.7	0	0	2	1	0	135	1	1.05	0.95
21	1	17.5	11.2	0	0	3	1	0	135	0	1.05	0.95
22	2	0	0	0	0	3	1	0	135	1	1.10	0.95
23	2	3.2	1.6	0	0	2	1	0	135	1	1.10	0.95
24	1	8.7	6.7	0	0.04	3	1	0	135	1	1.05	0.95
25	1	0	0	0	0	3	1	0	135	1	1.05	0.95
26	1	3.5	2.3	0	0	3	1	0	135	1	1.05	0.95
27	2	0	0	0	0	3	1	0	135	1	1.10	0.95
28	1	0	0	0	0	1	1	0	135	1	1.05	0.95
29	1	2.4	0.9	0	0	3	1	0	135	1	1.05	0.95
30	1	10.6	1.9	0	0	3	1	0	135	1	1.05	0.95
TOTAL		189.20										

Bus data format to Table 1.0

1 bus number (positive integer)

2 bus type code number for Table One

PQ bus = 1

PV bus = 2

Reference bus = 3

Isolated bus = 4

3 Pd, real power demand (mw)

4 Qd, reactive power demand (Mvar)

5 Gs, shunt conductance (mw demanded at v = 1.0 p.u.)

6 Bs, shunt susceptance (mvar injected at v = 1.0 p.u.)

7 area number, (positive integer)
8 Vm, voltage magnitude (p.u.)
9 Va, voltage angle (degrees)
10 basekv, base voltage (kv)
11 zone, loss zone (positive integer)
12 maxvm, maximum voltage magnitude (p.u.)
13 minvm, minimum voltage magnitude (p.u.)

Table 1.1 GENARATOR DATA

Bus	Pg	Qg	Qmax	Qmin	Vg	MBase	Status	Pmax	Pmin
1	23.54	0	150	-20	1	100	1	80	0
2	60.97	0	60	-20	1	100	1	80	0
22	21.59	0	62.5	-15	1	100	1	50	0
27	26.91	0	48.7	-15	1	100	1	55	0
23	19.2	0	40	-10	1	100	1	30	0
13	37	0	44.7	-15	1	100	1	40	0
Total	189.2		405.9	-95					

Generator Data Format

1 bus number
2 Pg, real power output (MW)
3 Qg, reactive power output (MVar)
4 Qmax, maximum reactive power output (Mvar)
5 Qmin, minimum reactive power output (Mvar)
6 Vg, voltage magnitude setpoint (p.u.)
(remote controlled bus index)
7 mbase, total mva base of this machine, defaults to basemva
(machine impedance, p.u. On mbase)
(step up transformer impedance, p.u. On mbase)
(step up transformer off nominal turns ratio)
8 status, > 0 - machine in service
≤ 0 - machine out of service
(% of total var's to come from this gen in order to hold v at remote bus controlled by several generators)

9 Pmax, maximum real power output (mw)
10 Pmin, minimum real power output (mw)

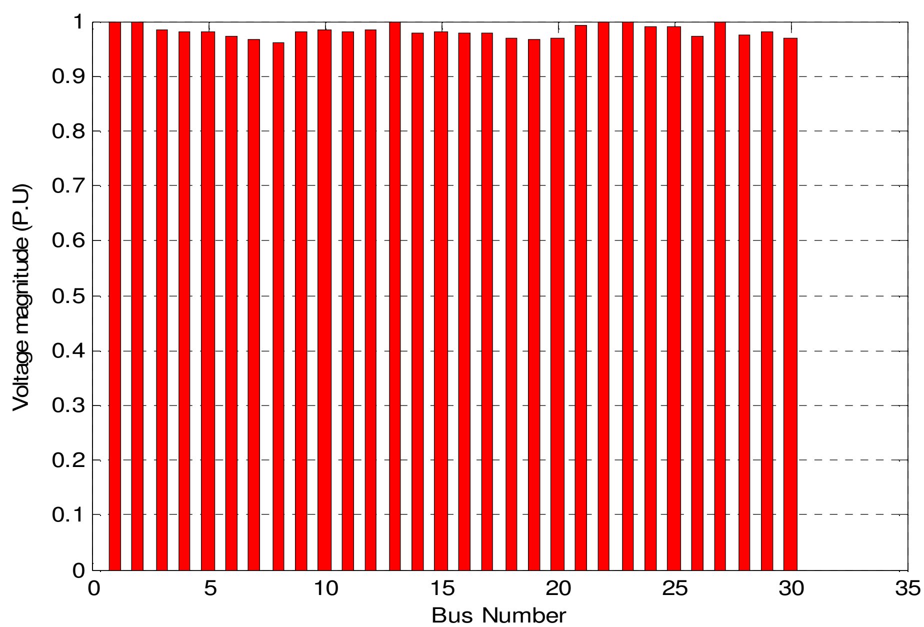
After the implementation of newton raphson's and Gauss-seidel technique, the following result in Table 4.2 was obtained.This result shows the voltage magnitude as well as angle on the buses. The system summary is as follows;

Buses: 30
Generators: 6
Loads: 20
Shunts: 2
Branches: 41
Total Generator Capacity: 335MW
On-line Capacity: 335MW
Load demand: 189MW

Table 1.2 Power flow details of the buses

BUS NO.	Voltage Mag(pu)	Voltage Angle(deg)	P_G	Q_G	P_D	Q_D
1	1.000	0.000	25.97	-1.00		-------
2	1.000	-0.415	60.97	32.00	21.70	12.70
3	0.983	-1.522	------	------	2.40	1.20
4	0.980	-1.795	------	------	7.60	1.60
5	0.982	-1.864	------	------	------	-------
6	0.973	-2.267	------	------	------	-------
7	0.967	-2.652	------	------	22.80	10.90
8	0.961	-2.726	------	------	30.00	30.00
9	0.981	-2.997	------	------	------	-------
10	0.984	-3.375	------	------	5.80	2.00
11	0.981	-2.997	------	------	------	-------
12	0.985	-1.537	------	------	11.20	7.50
13	1.000	1.476	37.00	11.35	------	------
14	0.977	-2.308	------	------	6.20	1.60
15	0.980	-2.312	------	------	8.20	2.50
16	0.977	-2.644	------	------	3.50	1.80
17	0.977	-3.392	------	------	9.00	5.80

18	0.968	-3.478	------	------	3.20	0.90
19	0.965	-3.958	------	------	9.50	3.40
20	0.969	-3.871	------	------	2.20	0.70
21	0.993	-3.488	------	------	17.50	11.20
22	1.000	-3.393	21.59	39.57	------	------
23	1.000	-1.589	19.20	7.95	3.20	1.60
24	0.989	-2.631	------	------	8.70	6.70
25	0.990	-1.690	------	------	------	------
26	0.972	-2.139	------	------	3.50	2.30
27	1.000	-0.827	26.91	10.54	------	------
28	0.975	-2.266	------	------	------	------
29	0.980	-2.128	------	------	2.40	0.90
30	0.968	-3.042	------	------	10.60	1.90
TOTAL			**191.64**	**100.41**	**189.20**	**107.20**



BUSES WITH VOLTAGE MAGNITUDE

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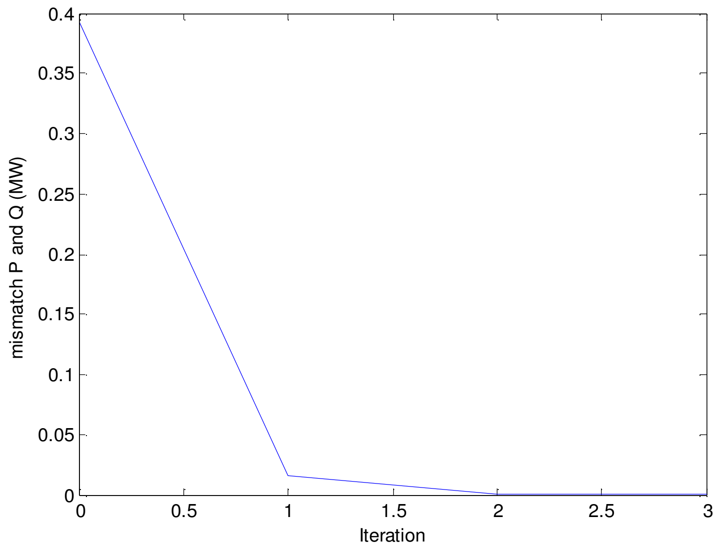

Fig4.1 Graph of Mismatch against iteration for the Newton Raphson's Technique

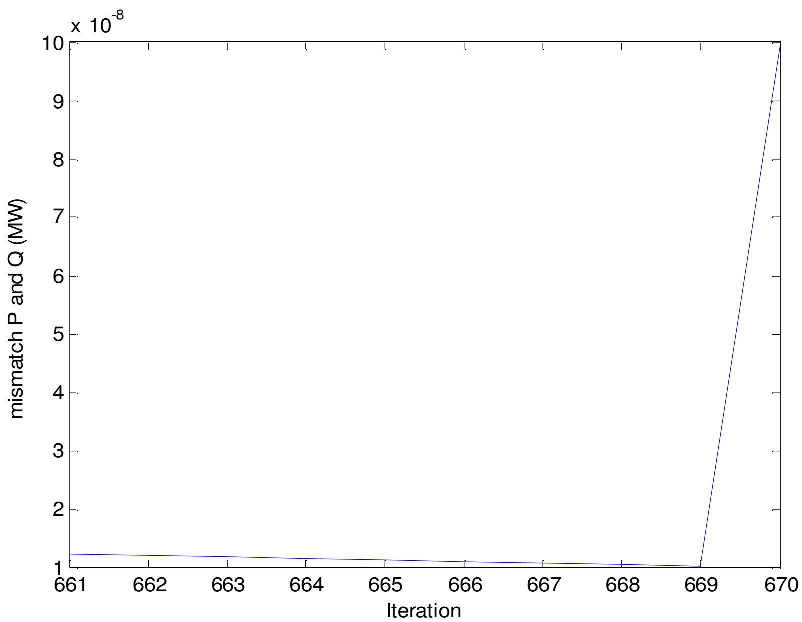

Fig 4.2 Graph of Mismatch against iteration for the Gauss-seidel's Technique

CONCLUSIONS

In this review, the current status of power system stability enhancement using FACTS controllers was discussed and scrutinized. The essential features of FACTS controllers and their potential to enhance system stability was addressed. The location and feedback signals used for design of FACTS-based damping controllers were discussed. The coordination problem among different control schemes was also considered. Performance comparison of different FACTS controllers has been reviewed. The likely future direction of FACTS technology, especially in restructured power systems, was discussed as well. In addition, utility experience and major real-world installations and semiconductor technology development have been summarized. A brief review of FACTS applications to optimal power flow and deregulated electricity market has been presented. About two hundred twenty seven research publications have been classified, discussed, and appended for a quick reference. For the readers' convenience and broad spectrum, different applications of the first and second generations of FACTS devices over the last two decades can be reviewed through the annotated bibliographies.

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