Reparation of Inductive Power in Power System by the use of FACTS devices

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ABSTRACT

This paper presents a shunt type FACTS device connected across the load to improve the power flow and to maintain the reactive power in real data transmission line power system using MiPower software. The main objective of this work is to maintain the voltage stability of steady-state bus voltages and reactive power flows in transmission system with and without FACTS controller. FACTS devices are capable of controlling the active and reactive power flows in a transmission line by controlling its series and shunt parameters. This paper presents a steady state model of Static VAR Compensator (SVC) controller in the power system for stability enhancement. Benefits of FACTS controllers to power system are also discussed. In this work real data system has been considered for load flow analysis and also to incorporate the SVC controller in the system.

KEYWORDS: *Reactive power compensation, Static VAR Compensator (SVC), load flow analysis, MiPower software.*

I. INTRODUCTION

Due to increase in demand, the transmission system becomes more stressed, which in turn, makes the system more vulnerable to voltage instability. Voltage stability has become an increasingly important phenomenon in the operation and planning of the present day power systems. Voltage collapse is a process in which the appearance of sequential events together with the voltage instability in a large area of system can lead to the case of unacceptable low voltage condition in the network. Increasing load can lead to excessive demand of reactive power and system will show voltage instability [1]. If additional resources provide sufficient reactive power support, the system will be established in a stable voltage level. If there are not sufficient reactive power resources and the excessive demand of reactive power can lead to voltage collapse.

A number of methods for voltage stability analysis have been suggested such as P-V curves, QV curves, Modal analysis etc. A number of voltage stability indices such as Voltage Collapse Proximity Indicator (VCPI), the minimum singular value of power flow Jacobian matrix, the loading margin, minimum eigen value of reduced Jacobian Matrix have been proposed in the literature to estimate the proximity of the power system to voltage stability and voltage collapse [2]. The application of PV curves is to evaluate the voltage stability of a power system for various loading conditions and contingencies.

FACTS controllers are used to enhance power system performance. These controllers can reduce electrical distances, modify power flows and absorb or provide reactive power. It increases all types of stability of the system. FACTS controllers provide fast and reliable control over the three main transmission parameters, i.e. voltage magnitude, phase angle and line impedance [3].

This paper presents the modeling of Newton Raphson Power flow method for estimating the voltage stability of a system with and without SVC FACTS controller using Mipower software

II. CONVENTIONAL POWER FLOW

A. *Electrical Transmission Networks*

The main objective of a power flow study is to determine the steady-state operating condition of the electrical power network. The steady-state may be determined by finding out, for a given set of loading conditions, the flow of active and reactive powers throughout the network and the voltage magnitudes and phase angles at all buses of the network [4]. The information conveyed by such studies indicates whether or not the nodal voltage magnitudes and active and reactive power flows in transmission a line is within prescribed operating limits. If the study predicts that the power flow in a given transmission line is beyond the power carrying capacity of the line, then control action is taken.

B. *Power Flow Equations*

A popular approach to assess the steady-state operation of a power system is to write equations stipulating that at a given bus the generation, load, and powers exchanged through the transmission elements connecting to the bus must add up to zero[5]. This applies to both active power and reactive power. These equations are termed 'mismatch power equations' and at bus k they take the following form:

$$\Delta P_k = P_{Gk} - P_{Lk} - P_k^{cal} = P_k^{sch} - P_k^{cal} = 0 \qquad -1$$

$$\Delta Q_k = Q_{Gk} - Q_{Lk} - Q_k^{cal} = Q_k^{sch} - Q_k^{cal} = 0 \qquad -2$$

The terms ΔP_k and ΔQk are the mismatch active and reactive powers at bus k, respectively.

P_{Gk} and Q_{Gk} represent, respectively, the active and reactive powers injected by the generator at bus k.

P_{Lk} and Q_{Lk} represent the active and reactive powers drawn by the load at bus k, respectively.

The scheduled active and reactive powers:

$$P_k^{sch} = P_{Gk} - P_{Lk} \qquad -3$$

$$Q_k^{sch} = Q_{Gk} - Q_{Lk} \qquad -4$$

The transmitted active and reactive powers, P_k^{sch} and Q_k^{sch} , are functions of nodal voltages and network impedances and are computed using the power flow equations.

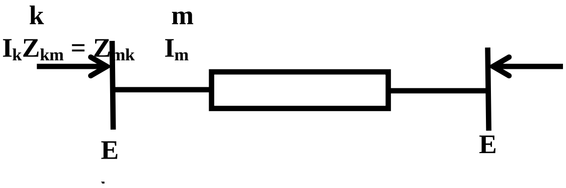

Figure1.Equivalent impedance

In order to develop suitable power flow equations, it is necessary to find relationships between injected bus currents and bus voltages. Based on Fig.1 the injected complex current at bus k, denoted by I_k, may be expressed in terms of the complex bus voltages E_k and E_m as follows:

$$I_k = \frac{1}{Z_{km}}(E_k - E_m) = y_{km}(E_k - E_m) \qquad -5$$

Similarly for bus m

$$I_m = \frac{1}{Z_{mk}}(E_m - E_k) = y_{mk}(E_m - E_k) \qquad -6$$

The above equations can be written in matrix form as,

$$\begin{bmatrix} I_k \\ I_m \end{bmatrix} = \begin{bmatrix} y_{km} & -y_{km} \\ -y_{mk} & y_{mk} \end{bmatrix} \begin{bmatrix} E_k \\ E_m \end{bmatrix} \qquad -7$$

or

$$\begin{bmatrix} I_k \\ I_m \end{bmatrix} = \begin{bmatrix} y_{kk} & y_{km} \\ y_{mk} & y_{mm} \end{bmatrix} \begin{bmatrix} E_k \\ E_m \end{bmatrix} \qquad -8$$

Where the bus admittances and voltages can be expressed in more explicit form:

$$Y_{ij} = G_{ij} + jB_{ij} \qquad -9$$

$$E_i = V_i e^{j\theta_i} = V_i(\cos\theta_i + j\sin\theta_i) \qquad -10$$

Where i = k, m and j =k, m.

The complex power injected at bus k consists of an active and a reactive component and may be expressed as a function of the nodal voltage and the injected current at the bus:

$$S_k = P_k + jQ_k = E_k I_k^* \qquad -11$$

$$= E_k (Y_{kk} E_k + Y_{km} E_m)^*$$

Where I_k^* is the complex conjugate of the current injected at bus k.

The expressions for P_k^{cal} and Q_k^{cal} can be determined by substituting Equations (9) and(10) into Equation (11), and separating into real and imaginary parts:

$$P_k^{cal} = V_k^2 G_{kk} + V_k V_m (G_{km}\cos(\theta_k - \theta_m) + B_{km}\sin(\theta_k - \theta_m)) \qquad -12$$

$$Q_k^{cal} = -V_k^2 B_{kk} + V_k V_m (G_{km}\cos(\theta_k - \theta_m) - B_{km}\sin(\theta_k - \theta_m)) \qquad -13$$

For specified levels of power generation and power load at bus k, and according to Equations (1) and (2), the mismatch equations may be written down as

$$\Delta P_k = P_{Gk} + P_{Lk} - \{V_k^2 G_{kk} + V_k V_m [G_{km}\cos(\theta_k - \theta_m) + B_{km}\sin(\theta_k - \theta_m)]\} = 0 \quad -14$$

$$\Delta Q_k = Q_{Gk} + Q_{Lk} - \{-V_k^2 B_{kk} + V_k V_m [G_{km}\cos(\theta_k - \theta_m) - B_{km}\sin(\theta_k - \theta_m)]\} = 0 - 15$$

Similar equations may be obtained for bus m simply by exchanging subscripts k and m in Equations (14) and (15). It should be remarked that Equations (12) and (13) represent only the powers injected at bus k through the ith transmission element, that is, $P_k^{i\ cal}$ and $Q_k^{i\ cal}$. However, a practical power system will consist of many buses and many transmission elements. This calls for Equations (12) and (13) to be expressed in more general terms, with the net power flow injected at bus k expressed as the summation of the powers flowing at each one of the transmission elements terminating at this bus, the active and reactive powers, respectively.

The generic net active and reactive powers injected at bus k are:

$$P_k^{cal} = \sum_{i=1}^{n} P_k^{i\ cal} \qquad -16$$

$$Q_k^{cal} = \sum_{i=1}^{n} Q_k^{i\ cal} \qquad -17$$

Where $P_k^{i\ cal}$ and $Q_k^{i\ cal}$ are computed by using Equations (12) and (13), respectively. As an extension, the generic power mismatch equations at bus k are:

$$\Delta P_k = P_{Gk} - P_{Lk} - \sum_{i=1}^{n} P_k^{i\ cal} = 0 \qquad -18$$

$$\Delta Q_k = Q_{Gk} - Q_{Lk} - \sum_{i=1}^{n} Q_k^{i\ cal} = 0 \qquad -19$$

III. POWER FLOW INCLUDING FACTS CONTROLLERS

A. *FACTS Technology*

In an A.C power flow, the electrical generation and load must be balanced all the times. Since the electrical system is self-regulating, therefore, if one of the generators supplies less power than the load, the voltage and frequency drop, thereby load goes on decreasing to equalize the generated power by subtracting the transmission losses. However there is small margin of self-regulating. If voltage is dropped due to reactive power, the load will go up and frequency goes on decreasing and the system will collapse ultimately. Also the system will collapse if there is a large reactive power available in it. In case of high power generation the active power flows from surplus generating area to the deficit area [5].

Recent development of power electronics introduces the use of FACTS controllers in power systems. FACTS controllers are capable of controlling the network condition in a very fast manner and this feature of FACTS can be exploited to improve the voltage stability, and steady state and transient stabilities of a complex power system [6]. This allows increased utilization of existing network closer to its thermal loading capacity, and thus avoiding the need to construct new transmission lines. The well known FACTS devices are namely SVC, STATCOM, TCSC, SSSC and UPFC.

B. *Shunt Compensation*

The steady state transmittable power can be increased and the voltage profile along the line can be controlled by appropriate reactive shunt compensation. To change the natural electrical characteristics of the transmission line and to make it more compatible with prevailing load demand. Under the shunt compensation, the shunt connected, fixed or mechanically switched reactors are applied to minimize line over voltage under light load conditions. Shunt connected fixed or mechanically switched capacitors are applied to maintain voltage levels under heavy load conditions. The basic consideration/objective is to increase the transmittable power by shunt connected VAR-Compensation. VAR-Compensation is also used for voltage regulation at the mid-point to segment the transmission line. VAR-compensation is also used at the end of the line to prevent voltage instability and also to improve dynamic voltage control to increase the transient stability and damped power

C. *Static VAR Compensator*

SVC is a static Var compensator which is connected in parallel to transmission line. SVC acts as a generator/load, whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific power system variables [7]. Static Var systems are applied by utilities in transmission applications for several purposes. The primary purpose is usually for rapid control of voltage at weak points in a network. SVC is similar to a synchronous condenser but without rotating part in that it is used to supply or absorb reactive power. The basic structure of SVC is shown in Fig. 2. The SVC is connected to a coupling transformer that is connected directly to the ac bus whose voltage is to be regulated. From Fig. 1, SVC is composed of a controllable shunt reactor and shunt capacitor(s). Total susceptance of SVC can be controlled by controlling the firing angle of thyristors. However, the SVC acts like fixed capacitor or fixed inductor at the maximum and minimum limits

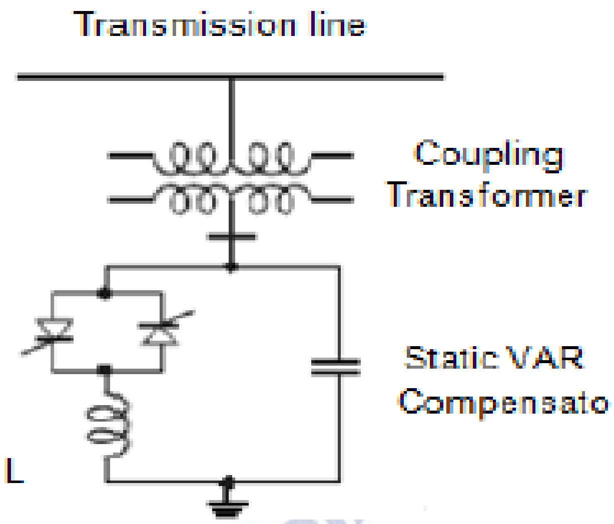

Figure 2.Static VAR Compensator

C.1. Shunt Variable Susceptance Model

In practice the SVC can be seen as an adjustable reactance with either firing-angle limits or reactance limits [8]. The equivalent circuit shown in Figure is used to derive the SVC nonlinear power equations and the linearised equations required by Newton's method.

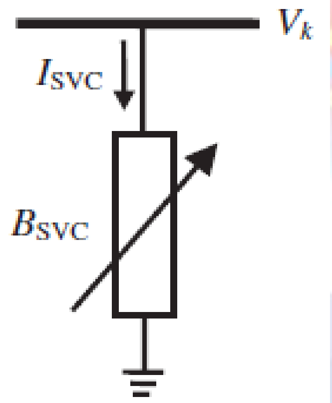

Figure 3.Variable shunt susceptance

With reference to Fig. 3, the current drawn by the SVC is

$$Z_{SVC} = jB_{SVC}V_k \qquad -20$$

and the reactive power drawn by the SVC, which is also the reactive power injected at bus k, is

$$Q_{SVC} = Q_k = -V_k^2 B_{SVC} \qquad -21$$

The linearised equation is given by Equation (5.6), where the equivalent susceptance BSVC is taken to be the state variable:

$$\begin{bmatrix} \Delta P_k \\ \Delta Q_k \end{bmatrix}^{(i)} = \begin{bmatrix} 0 & 0 \\ 0 & Q_k \end{bmatrix}^{(i)} \begin{bmatrix} \Delta \theta_k \\ \Delta B_{SVC} / B_{SVC} \end{bmatrix}^{(i)} \qquad -22$$

At the end of iteration (i), the variable shunt susceptance BSVC is updated according to

$$B_{SVC}^{(i)} = B_{SVC}^{(i-1)} + \left(\frac{\Delta B_{SVC}}{B_{SVC}} \right)^{(i)} B_{(SVC)}^{(i-1)} \qquad -23$$

The changing susceptance represents the total SVC susceptance necessary to maintain the nodal voltage magnitude at the specified value. Once the level of compensation has been computed then the thyristor firing angle can be calculated. However, the additional calculation requires an iterative solution because the SVC susceptance and thyristor firing angle are nonlinearly related.

IV. METHODOLOGY

A. Load Flow

One of the most common computational procedures used in power system analysis is the load flow calculation. The planning, design, and operation of power systems require such calculations to analyze the steady-state (quiescent) performance of the power system under various operating conditions and to study the effects of changes in equipment configuration. These load flow solutions are performed using computer programs designed specifically for this purpose [9]. The basic load flow question is this: Given the load power consumption at all buses of a known electric power system configuration and the power production at each generator, find the power flow in each line and transformer of the interconnecting network and the voltage magnitude and phase angle at each bus.

Analyzing the solution of this problem for numerous conditions helps to ensure the power system is designed to satisfy its performance criteria while incurring the most favorable investment and operation costs. Computer programs to solve load flow studies are divided into two types: static (offline) and dynamic (real time). Most load flow studies for system analysis are based on static network models. Real time load flows (online) that incorporate data input from the actual networks are typically used by utilities in Automatic Supervisory Control and Data Acquisition (SCADA) systems. Such systems are used primarily as operating tools for optimization of generation, VAr control, dispatch, losses, and tie line control. This report is concerned on static network models and their analysis only [10].

B. Problem formulation

In order to conduct load flow studies, a practical system has been considered based on the inputs provided by PRDC, India. In this case Bhutan power system has been considered for analysis. The system consists of 220kV and 400 kV voltage levels, one ICT (Inter Connecting Transformer) of 315 MVA, 400/220 kV Transformer, seven numbers of 220/66 kV transformers with different MVA ratings, six numbers of 212.5 MVA, 13.8/400 kV GSU Transformers, four numbers of 105 MVA, 11/220 kV GSU Transformers, two numbers of 30 MVA, 11/220 kV GSU Transformers, two numbers of 15 MVA, 11/66 kV GSU Transformers, nineteen numbers of 66 kV feeders with different lengths, seven numbers of 220 kV zebra lines, three numbers of 400 kV lines with different lengths, seventeen numbers of loads at 66 kV voltage levels, one load at 11kV and one load at 220kV and one interconnection point to Indian grid of Siliguri400 kV substation. The network diagram considered for load flow study has shown in Fig. 4. The element data considered for different types of power systems components are given as follows. As shown in network diagram, the different transformers data, bus data and transmission line data considered for load flow study are presented in the following Tables.

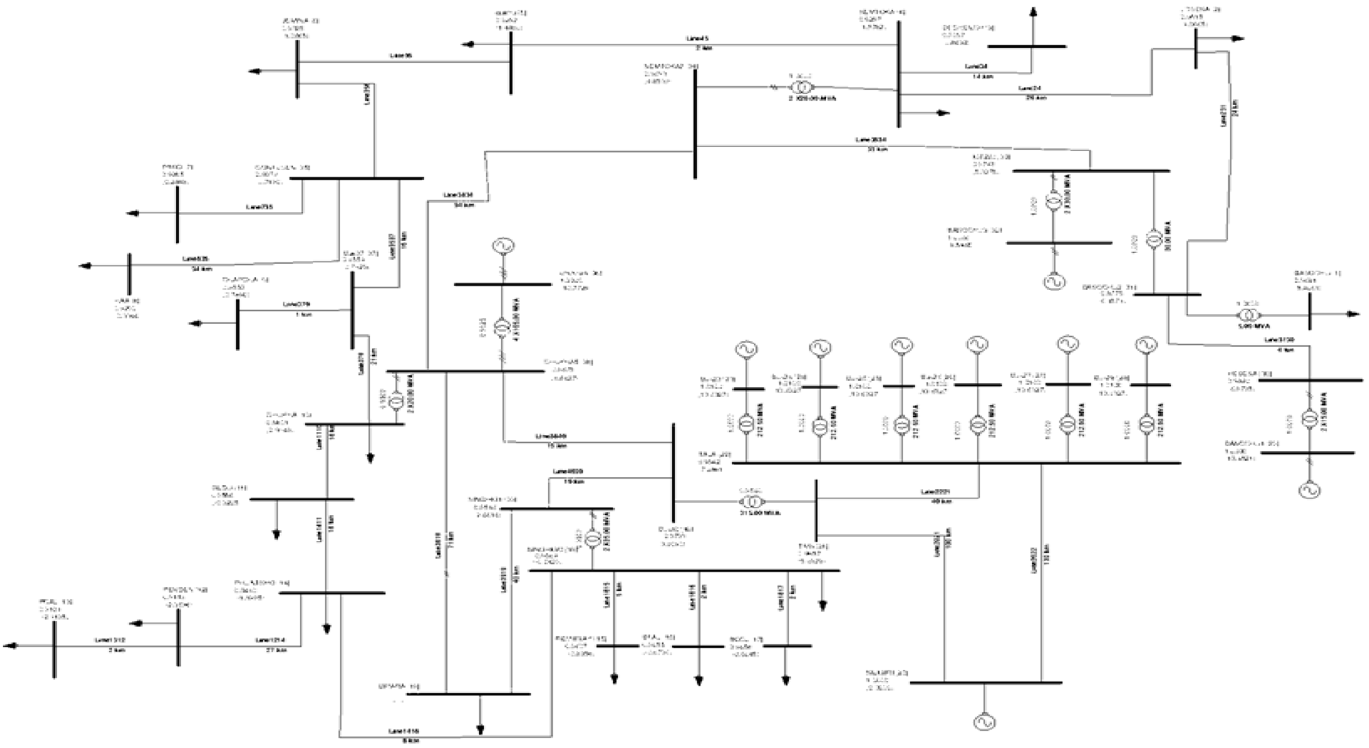

Figure: 4. Single line diagram considered for load flows studies

Table1. Transformers data

Sl no.	HV (kV)	LV (kV)	MVA	% Impedance on itsMVA rating	Minimum Tap	Maximum Tap	Set tap
1	66	11	5	14	0.95	1.05	1.00
2	220	11	30	14	0.95	1.05	1.00
3	400	13.8	212.5	14	0.95	1.05	1.00
4	400	220	105	12	0.95	1.05	0.95
5	220	66	315	10	0.95	1.05	0.95

Table: 2. Bus Data along with Scheduled Power, Specified Voltage and Load Details

Bus No.	Bus kV	Bus Type	Specified Voltage (p.u.)	P_{GEN} (MW)	Machine MVA	P_{LOAD} (MW)	Load Power Factor
1	11	PQ	-	-	-	0.6	0.9
2	66	PQ	-	-	-	2	0.9
3	66	PQ	-	-	-	12	0.9
4	66	PQ	-	-	-	16	0.9
5	66	PQ	-	-	-	5	0.9
6	66	PQ	-	-	-	1.5	0.9
7	66	PQ	-	-	-	4.2	0.9
8	66	PQ	-	-	-	2.5	0.9
9	66	PQ	-	-	-	1	0.9
10	66	PQ	-	-	-	3.67	0.9
11	66	PQ	-	-	-	6.3	0.9
12	66	PQ	-	-	-	5.1	0.9
13	66	PQ	-	-	-	5.1	0.9
14	66	PQ	-	-	-	18.5	0.9
15	66	PQ	-	-	-	10	0.9
16	66	PQ	-	-	-	4	0.9
17	66	PQ	-	-	-	2.8	0.9
18	66	PQ	-	-	-	3	0.9
19	220	PQ	-	-	-	330	0.9
20	400	SLAK	-	-	-	-	-
21	400	PQ	-	-	-	-	-
22	400	PQ	-	-	-	-	-
23	13.8	PV	1.01+j0.00	170	212.5	-	-
24	13.8	PV	1.01+j0.00	170	212.5	-	-
25	13.8	PV	1.01+j0.00	170	212.5	-	-
26	13.8	PV	1.01+j0.00	170	212.5	-	-
27	13.8	PV	1.01+j0.00	170	212.5	-	-
28	13.8	PV	1.01+j0.00	170	212.5	-	-
29	11	PV	1.00+j0.00	2*12	2*15	-	-
30	66	PV	1.00+j0.00	2*12	2*15	-	-
31	66	PQ	-	-	-	-	-
32	11	PQ	-	-	-	-	-
33	220	PQ	-	-	-	-	-
34	220	PQ	-	-	-	-	-
35	66	PQ	-	-	-	-	-
36	11	PV	1.03+j0.00	4*84	4*105	-	-
37	66	PQ	-	-	-	-	-
38	220KV	PQ	-	-	-	-	-

Table 3.Transmission Line Library Data

Sl. No.	Conductor Type	Library Code	R1 (ohm/km)	X1 (ohm/km)	B1/2 (mho/km)
1	Drake	1001	0.278	0.4056	2.29e-6
2	Zebra	1002	6.99e-2	3.98e-1	1.46e-6
3	Moose	1003	1.97e-2	3.06e-1	1.9e-6

Table: 4. Transmission line element data

Si.No.	From Bus	To Bus	No. Circuits	Length (km)	Voltage (kV)
1	30	31	1	4	66
2	31	2	1	23.8	66
3	4	2	1	26	66
4	4	3	1	14	66
5	4	5	1	1.4	66
6	5	6	1	12	66
7	6	35	1	12.5	66
8	35	7	1	24	66
9	35	8	1	36.6	66
10	35	37	1	16	66
11	37	9	1	1	66
12	10	11	1	18	66
13	11	14	1	17.7	66
14	14	12	1	27	66
15	12	13	1	2	66
16	14	18	1	8.44	66
17	18	15	1	5	66
18	18	16	1	2	66
19	18	17	1	2	66
20	34	33	1	34.5	220
21	34	38	1	54.4	220
22	38	39	2	71	220
23	39	19	1	39.6	220
24	40	39	1	19	220
25	38	40	1	15	220
26	20	22	1	130	400
27	20	21	1	100	400
28	22	21	1	40	400

C. Load flow results without SVC

In order to conduct load flow studies, a practical system has been considered based on the inputs provided by PRDC. In this case Bhutan power system has been considered for analysis. There are three reasons why it is necessary to manage reactive power and control voltage. First, both customer and power system equipment are designed to operate within a range of voltages, usually within ±5% of the nominal voltage. At low voltages, many types of equipment perform poorly, light bulbs provide less illumination, induction motors can overheat and be damaged, and some electronic equipment will not operate at. High voltages can damage equipment and shorten their lifetimes. Second, reactive power consumes transmission and generation resources. To maximize the amount of real power that can be transferred across a congested transmission interface, reactive power flows must be minimized. Similarly, reactive power production can limit a generator's real power capability. Third, moving reactive power on the transmission system incurs real power losses. Both capacity and energy must be supplied to replace these losses.

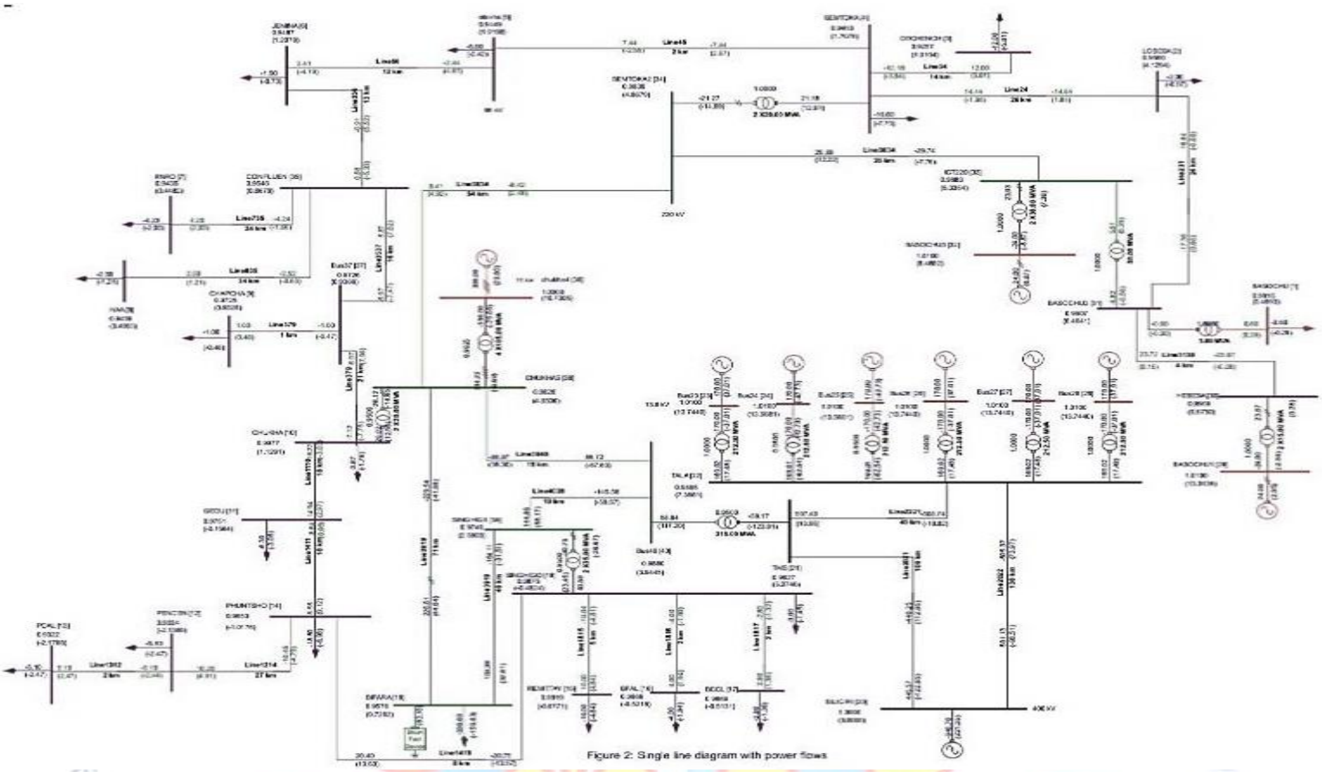

Figure5. Single line diagram considered for load flows with Static VAR Compensation

Table: 5. Load flow results without SVC

Total Real Power Generation	Total Reactive Power Generation	Total Real Load	Total Reactive Power Generation	Total Real Power Losses	Total Reactive Power Losses
1404 MW	16.5 MVAr	433.27 MW	209.84 MVAr	25.18 MW	206.65 MVAr

D. Load flow analysis with SVC

A static var compensator connected to a line having a capacitor (+100,var) and a reactor (-100 Mvar) for producing and absorbing reactive power, respectively, capacitor for providing, in combination with the capacitor and the reactor, a maximum leading reactive capacity so as to effectively reduce the capacities of the elements and for compensating for changes in reactive power resulting from a current fluctuation in response to a load fluctuation. The reactor increases the reactive power produced by the capacitor when the reactive power absorbed by the reactor is low and decreases the reactive power produced by the capacitor when the reactive power absorbed by reactor is high. Here SVC is connected at bus number 19 with load 19 having 330MW as shown in fig. 6.

Table: 6. Load flow results with SVC

Total Shunt SVC injection: 83.181 MVAr					
Total Real Power Generation	Total Reactive Power Generation	Total Real Load	Total Reactive Power Generation	Total Real Power Losses	Total Reactive Power Losses
1404 MW	16.5 MVAr	433.27 MW	209.84 MVAr	24.03 MW	198.09 MVAr

V. CONCLUSION

In this paper presents a shunt type FACTS device SVC connected across the load to improve the power flow and to maintain the reactive power in real data transmission line power system using MiPower software. The power flow for the real data system is analyzed without and with FACTS devices performing the Newton-Raphson method using MiPower software. The largest power flow takes place in the transmission line connecting the bus is identified and SVC is connected to that bus.

Thus SVC upholds its target value and as expected identical power flows and bus voltages are obtained for a shunt variable susceptance Model.

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