IDENTIFICATION OF WEAK BUSES AND IMPROVING VOLTAGE PROFILE UNDER VARING LOAD CONDITIONS USING STATCOM IN IEEE-14 BUS POWER SYSTEM

DISSERTATION
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Submitted by:

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CERTIFICATE

I, OM PRAKASH SINGH, Roll No. 2K12/PSY/27 student of M. Tech. (POWER SYSTEM), hereby declare that the dissertation/project titled **"IDENTIFICATION OF WEAK BUSES AND IMPROVING VOLTAGE PROFILE UNDER VARING LOAD CONDITIONS USING STATCOM IN IEEE-14 BUS POWER SYSTEM"** under the supervision of Dr. NARENDRA KUMAR Professor of Electrical Department, Delhi Technological University in partial fulfillment of the requirement for the award of the degree of Master of Technology has not been submitted elsewhere for the award of any Degree.

Place: Delhi **(OM PRAKASH SINGH)**

Date: 31.07.2014

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DR. NARENDRA KUMAR

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ABSTRACT

The whole world faces energy shortages, power scenario in present. There is a deficit between energy demand and energy supplied. The per capita energy consumption indicates the living standard of the society of the country and also it shows the development of the country. Every country is trying to harness the energy obtained from natural resources and maximize it, due to the limited resources of the fossil fuels. The major issue in these problem is the voltage collapse of transmission system which is most suffered by the frequent variations load. In this project, we focus on the detection and identification of weakest busses under variation load. Voltage variation problem increase day-by-day with increasing load demand power. Therefore the efficiency and power quality of power is become poor for consumer service due to increasing load demand, voltage goes down. Thus the system stability or voltage profile is poor at various buses in an interconnected power system under varying load conditions (varying load 0 to 50% increasing). Hence the voltage magnitudes and angles also change which are responsible for voltage instability which have major result in blackout.

For the continuation power flow voltage magnitude, angle, real and reactive power should be maintained so that voltage stability improved.

Finding the weakest buses during increasing load by Newton-Raphson method with MATLAB programming and compare all results with original results with and without STATCOM in an interconnected in IEEE 14 bus power system. As the results the voltage at the buses goes below to specified voltage profile lower limit 0.98 p.u. during heavy load conditions or voltage may exceed voltage profile upper limit 1.0 p.u. during light load conditions, at there identified weakest buses allocation for the adjusted FACTS controllers to improve voltage profile limit (0.98 p.u or 1.0 p.u) of IEEE-14 bus power system to maintained reactive power in IEEE-14 power system.

CONTENTS

CHAPTER 1

INTRODUCTION

1.1 GENERAL

In present scenario the whole world faces energy shortages. There is a deficit between energy demand and energy supplied. The per capita energy consumption indicates the living standard of the society of the country and also it shows the development of the country. Every country is trying to harness the energy obtained from natural resources and maximize it. Due to the limited resources of the fossil fuels (coal, natural gas, oil, nuclear fuel etc.) the world is exploring renewable energy sources such as solar, wind, tidal, hydro, geothermal, biomass etc. However, problems such as high per unit cost act as major deterrents to the complete switchover to renewable energy.

Power engineers and researchers are now a days concentrating in the area of power electronics and power quality so that energy deficit problem can be overcome and good quality of power supply can be provided to the consumers at the least cost. Many devices such as FACTS (Flexible AC Transmission System) Devices and Custom Power Devices are in use at transmission and distribution level respectively. Literature review in this field, points to a number of solutions for mitigation of power quality issues.

This chapter highlights the power scenario in the world and India in particular. Facts and figures related to the different energy sources, installed capacity and contribution from renewable energy sources are provided for 2013-14. The next section lists the power quality problems in details and custom power devices.

1.1.1 Power Scenario in the World

The total installed capacity in the whole world is nearly equal to 5,144 GW (Giga Watt) as per 2013. China, U.S., Japan, Russia and India are the Top five countries in the list of installed generating capacity as it is shown in the Table 1.1. India holds the fifth position in the world. 55.75% of the total electricity of the world is produced by these five countries [1].

Ranking list of countries on the basis of installed generating capacity in year-2013.

Country	Global Ranking	Installed Capacity (in GW)
China	1	1146
United States	2	1025
Japan	3	284.5
Russia	4	223.1
India	5	189.3
Germany	6	153.2
Canada	7	131.5
Italy	8	122.3
France	9	119.1
Brazil	10	106.2
Spain	11	102.5
United Kingdom	12	88.02
Korea	13	80.59
Mexico	14	59.33
Australia	15	56.94

Table 1.1

1.1.2 Power Scenario in India

In India, the total installed capacity is 248.51 GW till the end of May 2014. Out of this total installed capacity, the non-renewable sources account for 87.55% and renewable sources constitute the remaining 12.45% of total installed capacity [2-4]. The state wise distribution of the total installed capacity (MW) is given in Table 1.2.

Ranking list of 20 Indian states on the basis of installed generating capacity as of 31-Dec-2013.

Ranking	**State/Union Territory**	**Total Installed Capacity (MW)**
1	Maharashtra	32,505.98
2	Gujarat	26,269.12
3	Tamil Nadu	20,716.52
4	Andhra Pradesh	17,285.48
5	Uttar Pradesh	14,274.57
6	Rajasthan	14,059.12
7	Karnataka	13,940.66
8	Madhya Pradesh	12,902.35
9	West Bengal	8,708.82
10	Haryana	8,251.81
11	Punjab	7,614.95
12	Delhi Territory	7,500.79
13	Odisha	7,381.79
14	Chhattisgarh	6,864.91
15	Kerala	3,875.20
16	Himachal Pradesh	3,824.96
17	Uttarakhand	2,588.01
18	Jharkhand	2,579.86
19	Jammu and Kashmir	2,524.96
20	Bihar	2,198.13

Table 1.2

Table 1.3 and Figure 1.1 give the breakup of total installed capacity of India as on 31 December 2013. Thermal sources contribute 68%, hydro has a share of 17% and the renewable source amounts to 13%. The remaining 2% of share is met by nuclear power sources.

List of installed capacity from all the different energy sources as of 31 December 2013.

Energy Resource		**Installed Capaci1ty (MW)**
Thermal (Total)		159,793.99
	Coal	138,213.39
	Gas	20,380.85
	Diesel	1,199.75
Hydro		39,893.40
Nuclear		4,780.00
Renewable		29,462.55
Total		**233,929.94**

Table 1.3

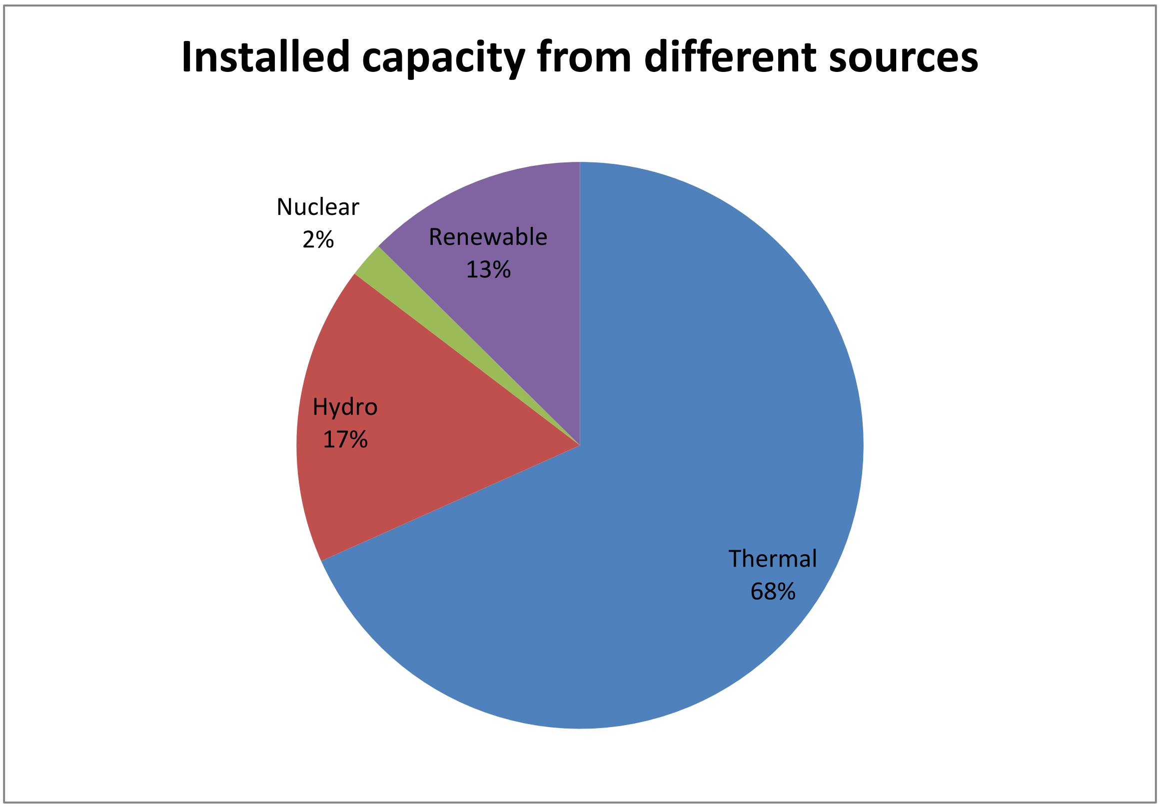

Figure 1.1: Breakup of electricity distribution in point of different resources in India.

Total Renewable Energy Installed Capacity in India as of December 2013.

Renewable Energy Resource	**Installed Capacity (MW)**
Wind Power	20,149.50
Solar Power (SPV)	2,180.00
Small Hydro Power	3,763.15
Biomass Power	1,284.60
Bagasse Cogeneration	2,512.88
Waste to Power	99.08
Total	**29,989.21**

Table 1.4

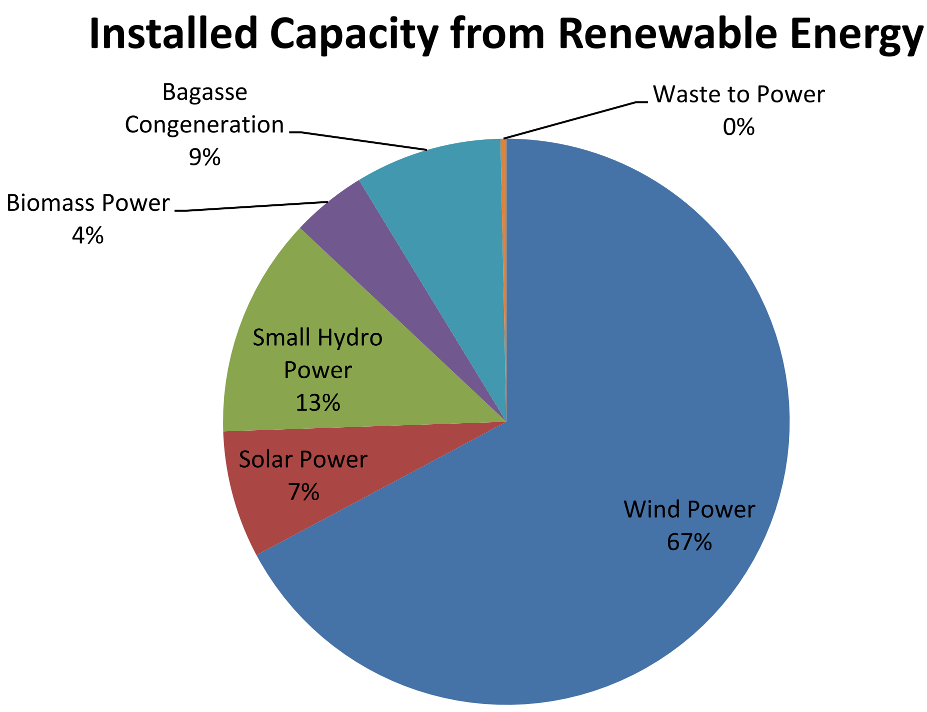

Figure 1.2: Breakup of installed capacity from renewable energy resources in India.

Table 1.4 and Figure 1.2 give a detailed distribution of renewable energy resources such as wind, solar power, small hydro, biomass etc. and their contribution in MW as well as percentage. The total installed capacity of renewable energy is 29,462 MW as per 31 December 2013 figures.

1.2 POWER SYSTEM LAYOUT AT DISTRIBUTION LEVEL

Figure 1.3 shows a typical power system network, in which generator/alternator, transmission lines, sub-transmission lines, transformers, loads are shown [5-7]. Different sections of the power system operate at different voltage levels due to transformer action. However, the entire power system operation and control takes place at a constant frequency of 50 Hz. T1 represents a step-up transformer and T2 &T3 represent step-down transformers. The entire power system is protected from faults & large transient conditions with the help of circuit breakers, relays and other protection devices.

At the distribution level, power generation generally takes place at 6 kV – 31 kV AC rms (phase to phase). It is then boosted up for transmitting the power through power transformer (T1) to a high voltage level typically 220kV, 400kV, 760kV etc. Then it is stepped down through power transformer (T2) at sub-transmission level i.e. 32kV to 132kV for the large factories and industrial customers. These industrial consumers have their own internal power distribution system to step down the voltage to 11kV, 3.3kV and 440V levels. The voltage is again stepped down through power transformer (T3) for transmitting power to the commercial and domestic consumers. The domestic and commercial consumers finally receive 440V (3-phase) or 230V (1-phase) power. The next section discusses power quality problems and some of the indexes for measurement of these.

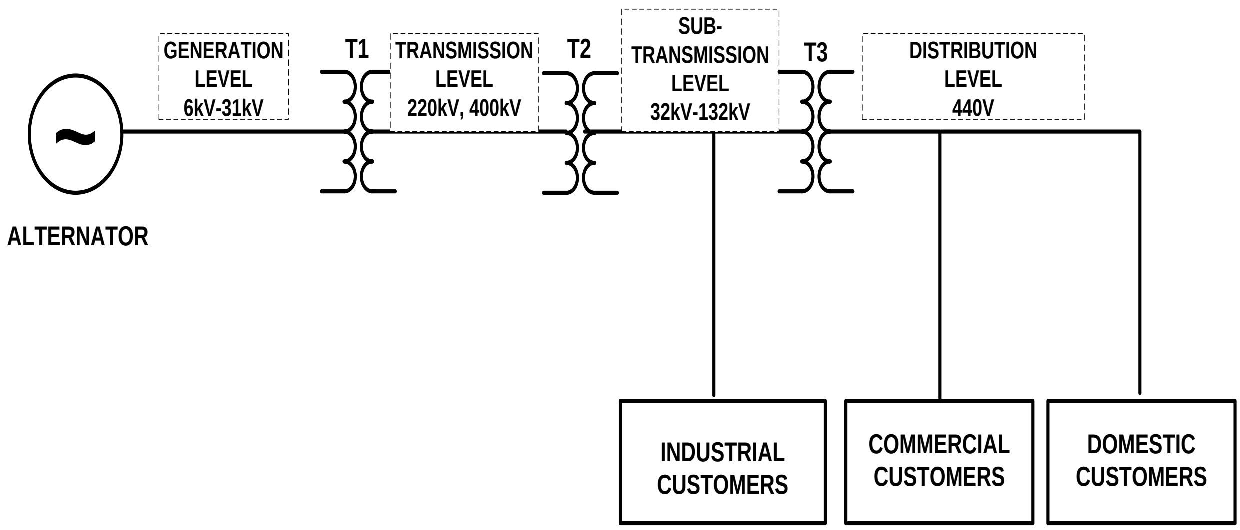

Figure 1.3: Layout of a typical power system layout.

1.2.1 Objective and solution domain

MODERN, power systems are prone to prevalent failures. With increased loading of existing power transmission systems, operation of power system becomes more complex and power system will become less secure. Operating environment, conventional planning and operating methods can leave systems exposed to instabilities. Voltage instability is one of the phenomena which have result in a major blackout which is most suffered by the frequent variations load. In this project, we focus on the detection and identification of weakest busses under variation load increased load data by 0% to 50% in 5% interval and so on then we have compared all the result with the original power flow results of IEEE-14 bus system for identified weakest buses in IEEE – 14 bus system. [1] – [4]. Power flow solution is prefer to a solution of the network under steady state conditions subjected to certain constraints under which the system operates. The power flow solution gives the nodal voltages and phase angles given a set of power injections at buses and specified voltages and angle [5].

Power flow in lines and transformers should not be allowed to exceed a particular level. But the increased transactions may lead to the operation of power system closer to the operating limit and result in congestion [6]. Power flows in some of the transmission lines are well below their normal limits, other lines are overloaded, which has an overall effect on deteriorating voltage profiles and decreasing system stability and security [7]. For transmission network security & failure point of view it is quite important to calculate the **most sensitive node in the network. Sensitivity terms are used to find which nodes to generate** a minimum voltage as compared. The active and reactive power demands, the losses and the voltage magnitudes are also affected due to infrastructure of network and variation in load. Overall voltage profiles are deteriorated and system stability and security are decreased due to the reason that, transmission line powers flows are not uniform. The effects quantities are mainly taken into account for getting faster and accurate results. The results improve the quality of all following system studies that use the same load flow analysis for further calculations [8].

Conventional techniques for solving the load flow problem are iterative using the Newton-Raphson Method or Gauss -Seidel methods Load flow analysis, for identification of weakest buses of large power systems with MATLAB Programs and voltage magnitude and phase angle and reactive power controlled by FACTS controller [9] - [14].

FACTS devices have been defined by the IEEE as “AC transmission system incorporating power electronic-based and other static controllers to enhance controllability and increase power transfer capability”. They are able to provide rapid active and reactive power compensations to power systems, and therefore can be used to provide voltage profile, phase angle and power flow control [10] [15]. Using FACTS controllers one can control the variables such as voltage magnitude and phase angle at chosen bus and line impedance where a voltage collapse is observed [17].

With FACTS technology, such as Static Var Compensator (SVC), Static Synchronous Compensator (STATCOM), Static Synchronous Series Compensator (SSSC) and Unified Power Flow Controller (UPFC) etc., bus voltages, line impedances and phase angles in the power system can be regulated rapidly and flexibly. In this project we focus on STATCOM there are used FACTS controllers based on voltage source converters [7]-[18]. Which is placed at weakest buses to improved voltage profile and angles under various load conditions.

1.2.2 POWER FLOW OVERVIEW

The objective of the whole project is to developed a programming that allow user to crack power flow problems. However the other objective that needed to complete as following are:

- Power flow analysis is very important in scheduling stages of new networks or addition to existing ones like adding new generator sites, meeting increase load demand an locating new transmission sites.
- 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 power channels.
- It determines the voltage of the buses. The voltage level at the certain buses must be kept within the closed tolerances.
- line flows can be known. This line, we should not close to its stability or thermal limits, means to be overloaded.
- Steady-state condition, transmission lines, transformers and generators to study the performance.
- For the purposes of education and training to write a program for power flow analysis
- MATLAB simulation analysis by the power flow to achieve

1.3 Short Duration Voltage Variations

This category of disturbances can be mainly subdivided into sag, swell and interruptions. [9]

1.3.1 Voltage Sag (Dip)

It took a minute for a few cycles of 10 ms at a frequency of at least 0.9 m for power RMS voltage level is reduced.

1.3.2 Voltage Swell

It is defined as the increase in rms voltage level from 1.1 to 1.8 pu at the power frequency for few cycles ranging from 10 ms to 1 min.

1.3.3 Interruption

It is defined as the decrease in supply rms voltage to a level less than 0.1 pu for a duration not more than 1min.

These disturbances i.e. voltage sags, voltage swells and interruptions may further be classified [8] into three groups based on their duration.

- Instantaneous: 0.5–30 cycles
- Momentary: 30 cycles – 3 s
- Temporary: 3 s–1min

1.4 Long Duration Voltage Variations

Under this category of disturbances, three problems are listed.

1.4.1 Undervoltage

It is a reduction in rms voltage level to a value less than 0.9 pu at power frequency for duration more than 1 min. This effect is also referred to as Brownout.

1.4.2 Overvoltage

More than a minute at a frequency of power for a period of 1.1 to 1.8 m RMS voltage is increase in the level.

1.4.3 Interruption

When the supply rms voltage goes down to a level less than 0.1 pu for a duration of more than 1min, interruption is said to take place.

1.4.4 Voltage Imbalance

It is a condition, when the rms voltages of the three phases do not have equal magnitude.

1.5 CONCLUSION

In this chapter, the energy scenario of the world and India in particular has been discussed. A typical power distribution structure layout is explained at generation, transmission, sub-transmission and distribution level. Power quality problems are mentioned and some of them include transients, short duration and long duration voltage variations, voltage imbalance also discussed operation, parameters and controlling of STATCOM for maintained voltage profile limit.

CHAPTER 2

Literature Review

2.1 General

In this section, many research papers, journal papers and books have been reviewed on many emerging areas of the power system. Mainly focused on the voltage profile limit, phase angle and reactive power problems and possible solutions, custom power devices (STATCOM) or FACTS controller, some conventional algorithms load flow solution by N-R method and some the generating the reference voltage and currents.

2.2 Literature Survey

Pushpendra Mishra and H.N. Udupa [1] has presented the detection of weakest bus in IEEE- 14 bus power system, at where voltage profile goes down, during load increased upto 40% in 5% interval and results evaluate up to with original results done through MATLAB (PSAT) for applied protection scheme at weakest bus to prevent voltage collapse in IEEE-14 bus power system.

Bindeshwar Singh, N. K. Sharma, A. N. Tiwari [2] has the models developed utilized for Eigen-value analysis of IEEE 9-bus 3-machinepower systems. There are many commercial packages available for transient simulation and analysis of power systems. for enhancement of voltage stability by FACTs controllers. And presents a systematic modular approach to incorporate series and shunt FACTS controllers in DAE (Different algebraic equation) model of multi-machine power systems in coordinated control manner for enhancement of voltage stability of the systems.

S. Choudhary and S.P. Choudhary [3] has presented in this paper a novel method for dip voltage detection in IEEE-9 bus system using Artificial neural network.

H.R. Baghaee, M. Jannati, B. Vahidi [4] has presented In this paper a novel approach for optimal placement of Multi-type FACTS devices based on Genetic algorithm (GA) is presented. Simulation of IEEE 30 bus test system for different scenarios shows that the placement of Multi-type FACTS devices leads to improve in voltage stability margin of power system and reduce losses with the increase in power demand, operation and planning of large interconnected power system.

G.Ravi Kumar and R.Kameswara Rao [5] has presented In this paper a model has been included in a Newton-Raphson load flow algorithm, which is capable of solving large power networks reliably. The Voltage regulation is achieved by controlling the production, absorption and flow of reactive power throughout the network. Reactive power flows are minimized so as to reduce system losses of 5-bus has been used of the SVC. This method has been extended to 30-bus practical system to test the performance of the SVC and TCSC at different locations of the bus system.

Ajilly Ann John and Tibin Joseph [6] has presented, an approach based on PSO has been presented and applied to find out the optimal location of TCSC and SVC. The problem is formulated as an optimization problem to minimize the real power losses and voltage variations in a system. The particle swarm optimization algorithm has been used to obtain the optimal location of TCSC and SVC with minimum active power losses and without voltage violations in IEEE-14 bus power system.

D. Murali and M. Rajaram [7] has presented, the control and performance of UPFC intended for installation on atransmission line is presented. Simulation results show the effectiveness of UPFC on controlling the power angle oscillations , real and reactive power flow through the line in IEEE- 9 bus.

Renu Yadav, Sarika Varshney and Laxmi Srivastava [8] has presented in this paper, The nature of voltage stability can be analyzed by the production, transmission and consumption of reactive power, unbalancing which occurs in stressed condition of power system line stability index, reactive power VAR loss, performance index are computed to determine the optimal location of TCSC and can be employed to reduce the flows in heavily loaded lines, resulting in a low system loss and improved stability of network in IEEE- 30 bus power system**.**

Baochun Lu, Baoguo Li , and Yi Liu, [9] discusses in this paper the effect of SVC controller on voltage stability Based on Generalized Tellegen's Theorem. Meanwhile a practical criterion for static voltage stability is presented, The method determines the maximum power transfer limit by finding the critical value of equivalent impedance model by the reactive compensation of an IEEE-14 30 bus power system.

F.U Rong and SUN Wanpeng [10] has presented in this paper as a renewable clean energy in smart grid on power system, wind farm causes negative influences such as voltage dip and voltage collapse in power system. Static synchronous Compensator (STATCOM) is introduced into system and used to improve the voltage stability on the basic of analyzing impact of wind power integration on voltage stability of the grid. In order to assess accurately the voltage stability of each bus in wind farm incorporated system an improve voltage profile, by adopting plan for the optimal location of STATCO based on the evaluatio index.

Noha H. El-Amary, Mohamed El Fakharany [11] has describe in this paper, a smart electrical power grid is represented to save the power flow continuity with minimum power losses in case of any abnormal condition. The optimum power continuity is achieved utilizing a developed Particle Swarm Optimization (PSO) technique. This technique is programmed to fulfil two main tasks. The buses voltages angles can be modified using static VAR compensators, capacitor banks, or Flexible AC Transmission System devices (FACTs) technology.

Paramjeet Kaur and Poonam [12] has presented the incoming of interline power flow controller IPFC can increase the bus voltage to which IPFC converters are connected and there is a significant change in the system voltage profile at the neighbouring buses, increase in active power flow and decrease in reactive power flow through the lines .Also, the effect of IPFC parameters on active and reactive power flows through the lines in which IPFC and FACTS device is placed in IEEE-14 bus system.

Dharamjit and D.K.Tanti [13] has described the Voltage magnitude and angles of a 30 bus system were observed for different values of increasing the reactance loading resulted in an increased voltage regulation. Gauss-Siedel has simple calculations and is easy to execute, but as the number of buses increase, number of iterations increases

Abdel Moamen M. A and Narayana Prasad Padhy [14] has presented a Newton-Raphson load flow algorithm to solve power flow problems in power system with unified power flow controller (UPFC). This algorithm is capable of solving power networks very reliably. The IEEE 30 bus system has been used to demonstrate the proposed method over a wide range of power flow variations in the transmission system.

H. Omidi B. Mozafari, and A. Parastar [15] has presented in order to improve voltage stability margin of power system in contingency condition based on reactive power generation management of shunt capacitors along with active and reactive power generation management of each unit. This technique is useful especially in contingency conditions leading to restriction of voltage stability margin between zero and 5 percent.

I.Sai Ram and J. Amarnath [16] has proposed approach was implemented and the performance is evaluated with system Initially, the voltage collapse rating of the system is analyzed and the optimal location of UPFC is determined. From the location, injected power rating of UPFC is determined by GA and GSA algorithm depends on the voltage magnitude and angle. Then, UPFC is placed on that location and the stability of sthe system is analyzed.

Nimit Boonpirom and Kitti Paitoonwattanakij [17] has proposed based on TCSC comparison with STATCOM compensation to increase the steady state voltage stability margin of power capability.

G Naveen Kumar and M Surya Kalavathi [18] has presented voltage profile at different buses has been improved by the placement of FACTs efficiently following a large disturbance to get the system back to its pre-disturbance values. This has been tested on modified 9 and 6 bus systems.

A. Kazemi1, A. Parizad1 [19] has presented In this paper Harmony search algorithm has applied to determine optimal location of FACTS devices in a power system to improve power system security. Three types of FACTS devices have been introduced. Line overload and bus under voltage has been solved by controlling active and reactive power of series and shunt compensator,

D.B. Bedoya C.A. Castro L.C.P. da Silva [20] has proposed method in a fast, accurate and efficient tool for voltage stability analysis, being appropriate for online applications such as power systems monitoring and control.

2.3 Conclusion

In this chapter, the energy scenario of the world and India in particular has been discussed. A typical power system is explained at generation, transmission, sub-transmission and distribution level. Power blackout and voltage stability problems are mentioned and some of them include transients, short duration and long duration voltage variations, voltage imbalance also discussed operation, parameters and controlling of FACTS controllers (STATCOM) with different techniques for maintained voltage profile limit in chapter 1 and chapter 2.

CHAPTER 3

POWER FLOW CONCEPTS

GENERAL

The power flow Problem, is solved to determine the steady-state complex voltages at all buses of the network, from which the active and reactive power flows in every transmission line and transformer are calculates. The set of equations representing the power system are non-linear. For most practical purposes, all power flow methods exploits the well – confirmed nodal properties of equipment owing to the non-linear nature of the power flow equations, the numerical solution is reached b iteration.

3.1 BASIC FORMULATION

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 the zero, which applies to both active power and reactive power. These equations are termed mismatch power equations and at bus k they take the following form.

$$\Delta P_K = P_{GK} - P_{LK} - P_K^{cal} = P_K^{sch} - P_K^{cal} = 0 \quad \text{... ... (3.1)}$$

$$\Delta Q_K = Q_{GK} - Q_{LK} - Q_K^{cal} = Q_K^{sch} - Q_K^{cal} = 0 \quad \text{... ... (3.2)}$$

The terms ΔP_K and ΔQ_K 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, which are assumed to be controll by the plant operator. P_{LK} and Q_{LK} represent the active and reactive powers drawn by the load at bus k, respectively. Under normal operation the customer has control of these variables, and in the power flow formulation they are assumed to be known variables.

In principles, at least, the generation and the load at bus k may be measured by the electric utility and, in the parlance of power system engineers, their net values are known as the scheduled active and reactive powers.

These scheduled active and reactive powers are :-

$$P_K^{sch} = P_{GK} - P_{LK} \quad \text{... ... (3.3)}$$

$$Q_K^{sch} = Q_{GK} - Q_{LK} \quad \text{... ... (3.4)}$$

The transmitted active and reactive powers, P_K^{cal} and Q_K^{cal} are functions of nodal voltages and network impedances and are computed using power flow equations. Provided the nodal voltages throughout the power network are known to a good degree of accuracy then the transmitted powers are easily and accurately calculated. In this situation, the corresponding mismatch powers are zero for any practical purpose and the power balance at each bus of the network is satisfied. However, if the nodal voltages are not known precisely then the calculated transmitted powers will have only pproximates values and the corresponding mismatch powers are not zero. The power flow solution takes the approach of successively correcting the calculated nodal voltages and, hence, the calculated transmitted powers until values accurate enough are arrived at, enabling the mismatch powers to be zero or fairly close to be zero. In modern power-flow computer programs, it is normal for all mismatch equations to satisfy a tolerance as tight as 1e -12 before the iterative solution can be considered successful. Upon convergence, the nodal voltage magnitude and angles yield useful information about the steady-state operating conditions of the power system and are known as state variables.

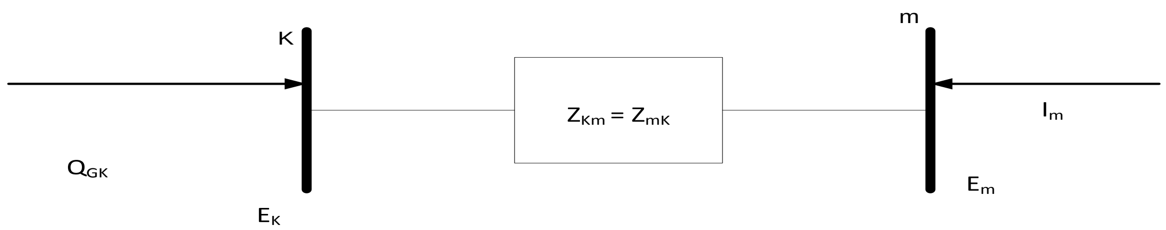

Fig. 3. 1 Equivalent Impedanc

In order to develop suitable power flow equations, it is necessary to find relationships between injected bus currents and bus voltages , Based on Fig. 3.1 the injected complex current at bus k, denoted by l $_k$ may be expressed in terms of the complex bus voltages V $_k$ and V $_m$ as follows:

$$I_K = \frac{1}{Z_{Km}}(V_K - V_m) = Y_{Km}(V_K - V_m) \qquad \text{... ... (3.5)}$$

At bus m,

$$I_m = \frac{1}{Z_{mK}}(V_m - V_k) = Y_{mk}(V_m - V_k) \qquad \text{... ... (3.6)}$$

From equations (3.6) ,

$$\begin{bmatrix} I_K \\ I_m \end{bmatrix} = \begin{bmatrix} Y_{KK} & Y_{Km} \\ Y_{mK} & Y_{mm} \end{bmatrix} \begin{bmatrix} V_m \\ V_k \end{bmatrix} \qquad \dots\dots (3.7)$$

where , Just admittances and voltages can be expressed more clearly:

$$Y_{ij} = G_{ij} + jB_{ij} \qquad \dots\dots (3.8)$$

$$E_i = V_i e^{j\theta_i} = V_i(\cos\theta_i + \text{ jsin}\,\theta_i) \qquad \dots\dots (3.9)$$

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

An active and reactive power injected into the components are complex and expressed as a function of the nodal voltage and current to be injected into decline

$$S_K = P_K + jQ_K = V_K I_K^*$$

$$S_K = V_K\,(Y_{KK}V_K + Y_{Km}V_k) \qquad \dots\dots (3.10)$$

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

The expression for P_K^{cal} and Q_K^{cal} can be determined by substituting Equation (3.8) and (3.9) into Equation (3.10), and separating into real and imaginary parts :

$$P_K^{cal} = \mathrm{V_K^2\ G_{KK} + V_K\,V_m} \left[\mathrm{G_{Km}}\cos(\theta_\mathrm{K} - \theta_\mathrm{m}) + \mathrm{B_{Km}}\sin(\theta_\mathrm{K} - \theta_\mathrm{m})\right] \qquad \dots (3.11)$$

$$Q_K^{cal} = -\mathrm{V_K^2\ B_{KK} + V_K\,V_m} \left[\mathrm{G_{Km}}\sin(\theta_\mathrm{K} - \theta_\mathrm{m}) + \mathrm{B_{Km}}\cos(\theta_\mathrm{K} - \theta_\mathrm{m})\right] \qquad \dots (3.12)$$

For specified levels of power generation and power load at bus k, and according to Equation (3.1) and (3.2), the mismatch equations may be written down as:

$$\Delta P_K = P_{GK} - P_{LK} - \left\{-\mathrm{V_K^2\ B_{KK} + V_K\,V_m}\ \left[\mathrm{G_{Km}}\cos(\theta_\mathrm{K} - \theta_\mathrm{m}) + \mathrm{B_{Km}}\sin(\theta_\mathrm{K} - \theta_\mathrm{m})\right]\right\} = 0 \qquad \dots (3.13)$$

$$\Delta Q_K = Q_{GK} - Q_{LK} - \left\{\mathrm{V_K^2\ G_{KK} + V_K\,V_m} \left[\mathrm{G_{Km}}\sin(\theta_\mathrm{K} - \theta_\mathrm{m}) + \mathrm{B_{Km}}\cos(\theta_\mathrm{K} - \theta_\mathrm{m})\right]\right\} = 0 \qquad \dots (3.14)$$

Similar equations may be btained for bus m simple by exchanging subscripts k and m in Equations (3.13) and (3.14).

It should be marked that Equations (3.11) and (3.12) represent only the powers injected at bus k through it transmission element, that is, $P_K^{i..cal}$ and $Q_K^{i..cal}$. However, a practical power system will consists of many buses and many transmission elements, This calls for Equations (3.11) and (3.12) to be expressed in more general terms, with net power flowing at each one of the transmission elements terminating at this bus. This is illustrated in Fig. 3.2(a) and 3.2(b) for cases of active and reactive powers, respectively.

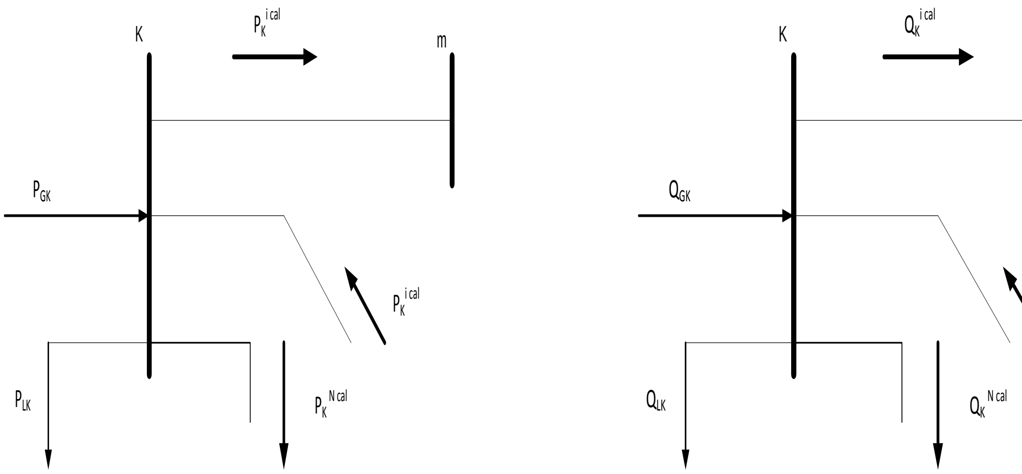

Fig. 3.2 power balance at bus k: 3.2(a) active power, 3.2(b) reactive power.

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

$$P_K^{cal} = \sum_{i=1}^{n} P_K^{i\,cal} \qquad \ldots..(3.15)$$

$$Q_K^{cal} = \sum_{i=1}^{n} Q_K^{i\,cal} \qquad \ldots..(3.16)$$

Where $P_K^{i..cal}$ and $Q_K^{i..cal}$ are computed by using Equations (3.11) and (3.12), respectively. As an extension, the genetic power mismatch equations at bus k are:

$$\Delta P_K = P_{GK} - P_{LK} - \sum_{i=1}^{n} P_K^{i\,cal} = 0 \qquad \ldots..(3.17)$$

$$\Delta Q_K = Q_{GK} - Q_{LK} - \sum_{i=1}^{n} Q_K^{i\,cal} = 0 \qquad \ldots..(3.18)$$

3.2 VARIABLES

In conventional power flow theory each bus is described by four ariables: net active power, net reactive power, voltage magnitude and voltage phase angle. Since there are only two equations per bus, two out of four variables must be specified in each bus in order to have a solvable problem. From purely mathematical viewpoint, any two variables can be specified, however, in engineering terms the choice is based on which variables at the bus can be physically controlled through the availability of a nearby controller. In the broades sense, one can think of voltage magnitudes and phase angles as the state ariables, and active and reactive powers as control variables.

3.3 BUS CLASSIFICATION

Buses are classified according to which two out of the four variables are specified:

1. Load (PQ) Bus: No generator is connected to the bus; hence the controlled variables P_G and Q_G are zero. Furthermore the active and reactive powers drawn by the load P_L and Q_L are known by available measurements. In these type of buses net active power and the net reactive power are specified, and voltage, V and phase angle, θ are computed.

2. Generator (PV) Bus: A generator source is connected to the bus; the nodal voltage magnitude V is maintained at constant value by adjusting he field current of the generator and hence it generates and absorbs reactive power. Moreover, the generated active power P_G is also set at a specified value. The other two quantities phase angle, θ and generated reactive power Q_G are computed. Constant oltage operation is possible only if the generator reactive power design limits are not violated, that is,

$$Q_{G..max} > Q_G > Q_{G..min.}$$

3. Generator (PQ) Bus: If the generator cannot provide the necessary reactive power support to constrain the voltage magnitude at the specified value then the reactive power is fixed at the violated limit and the voltage magnitude is freed. In this case, the generated active power P_G and the reactive power Q_G are specified, and the nodal voltage magnitude V and the phase angle are computed.

4. Slack (swing) Bus: One of the generator bus is chosen to be the slack bus where the nodal voltage magnitude, V_{slack} ' and phase angle, θ_{slack} are specified. There is only one slack bus in the power system and the function of the slack generator is to produce sufficient power to provide for any unmet system load and for system losses.That are not known in advance of the power flow calculation. The voltage phase angle at the slack bus θ_{slack} is chosen as the reference against which all other voltage phase angles in the system are measured. It is normal to fix its value to zero.

3.4 CONCLUSION

In this chapter the concept of load flow and mathematical model for bus voltage magnitude and phase angle also determined active and reactive power for injected at weakest buses and compare to original specified power units..

CHAPTER 4

METHODS OF POWER FLOW SOLUTION

4.1 EARLY POWER FLOW ALGORITHM:

From the mathematical modelling point of view, a power flow solution consists of solving the set of nonlinear algebraic equations that describes the electrical power network under steady-state conditions. Over the years, several approaches have been put forward for the solution of the power flow equations. Early approaches were based on loop equations and numerical methods using Gauss- type solutions. The method was laborious because the network loops have to be specified beforehand by the system engineer. Improved techniques saw the introduction of nodal analysis in favour of loop analysis, leading to a considerable reduction in data preparation, nevertheless, reliability towards convergence was still the main concern. Further developments led to the introduction of the Gauss-Seidel method with acceleration factors. The appeal of this generation power flow methods is their minimum storage requirements and the fact that they are easy to comprehend and to code in the computer programs. The drawback is that these algorithms exhibit poor convergence characteristics when applied to the solution of the networks of realistic size. Power flow solutions based on the nodal impedance matrix were briefly experimented with, but problem with computer storage and speed became insurmountable issues at the time. To overcome such limitations, the Newton-Raphson method and derived formulations were developed in the early 1970s and have since become firmly established throughout the power system industry.

4.2 THE NEWTON-RAPHSON ALGORITHM:

In large-scale power flow studies the Newton-Raphson method has proves most successful owing to its strong convergence characteristics. This approach uses iteration to solve the following set of nonlinear algebraic equations:

$$f_1(x_1, x_2, \dots\dots, x_N) = 0$$

$$f_2(x_1, x_2, \dots\dots, x_N) = 0$$

$$f_N(x_1, x_2, \dots\dots, x_N) = 0$$

Or

$$F(X) = 0 \qquad \ldots\ldots\ldots (4.1)$$

Where F represent the set of N nonlinear equations and X is the vector of n unknown state variables. The essence of the method consists of determining the vector of state variables X by performing a Taylor series expansion of F(X) about an initial estimate $X^{(0):}$

$$F(X) = F\,[X^0] + J\,[X^0][X - X^0] + higher\ terms \qquad \ldots\ldots\ldots (4.2)$$

where J [$X^{(0)}$] is a matrix of first-order partial derivatives of F(X) with respect to X, termed the Jacobin, evaluated at X = $X^{(0)}$. This expansion lends itself to a suitable formulation for calculating the vector of state variables X by assuming that $X^{(1)}$ is the value is sufficiently close to the initial estimate $X^{(0)}$. Based on this premise, all higher-order derivative terms in equation (4.2) may be neglected. Hence,

$$\mathrm{F}(\mathrm{X}^{(1)}) \approx \mathrm{F}(\mathrm{X}^{(0)}) + \mathrm{J}(\mathrm{X}^{(0)})\{X^{(1)} - X^{(0)}\} \qquad \ldots\ldots\ldots\ldots\ldots. \ (4.3)$$

$$\begin{bmatrix} \mathrm{f}_1\,(\mathrm{X}^{(1)}) \\ \mathrm{f}_2\,(\mathrm{X}^{(1)}) \\ \vdots \\ \mathrm{f}_n\,(\mathrm{X}^{(1)}) \end{bmatrix} \approx \begin{bmatrix} \mathrm{f}_1\,(\mathrm{X}^{(0)}) \\ \mathrm{f}_2\,(\mathrm{X}^{(0)}) \\ \vdots \\ \mathrm{f}_n\,(\mathrm{X}^{(0)}) \end{bmatrix} + \begin{bmatrix} \frac{\partial \mathrm{f}_1\,(\mathbf{X})}{\partial x_1} & \frac{\partial \mathrm{f}_1\,(\mathbf{X})}{\partial x_2} & \cdots & \frac{\partial \mathrm{f}_1\,(\mathbf{X})}{\partial x_n} \\ \frac{\partial \mathrm{f}_2\,(\mathbf{X})}{\partial x_1} & \frac{\partial \mathrm{f}_2\,(\mathbf{X})}{\partial x_2} & \cdots & \frac{\partial \mathrm{f}_2\,(\mathbf{X})}{\partial x_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial \mathrm{f}_n\,(\mathbf{X})}{\partial x_1} & \frac{\partial \mathrm{f}_n\,(\mathbf{X})}{\partial x_2} & \ddots & \frac{\partial \mathrm{f}_n\,(\mathbf{X})}{\partial x_n} \end{bmatrix} \begin{bmatrix} X_1^{(1)} - X_1^{(0)} \\ X_2^{(1)} - X_2^{(0)} \\ \vdots \\ X_n^{(1)} - X_n^{(0)} \end{bmatrix} \qquad \ldots\ldots\ldots (4.4)$$

In compact form, and generalising the power expression for the case of iteration (i),

$$\mathrm{F}(\mathrm{X}^{(\mathrm{i})}) \approx \mathrm{F}(\mathrm{X}^{(\mathrm{i}-1)}) + \mathrm{J}(\mathrm{X}^{(\mathrm{i}-1)})\{X^{(i)} - X^{(i-i)}\} \qquad \ldots\ldots\ldots\ldots\ldots. \ (4.5)$$

Where I = 1,2, … furthermore, if it is assumed that $X^{(I)}$ is sufficiently close to the solution $X^{(*)}$ then F($X^{(I)}$)= F($X^{(*)}$)=0,

Hence, equation (4.4) becomes

$$\mathrm{F}(\mathrm{X}^{(\mathrm{i}-1)}) + \mathrm{J}(\mathrm{X}^{(\mathrm{i}-1)})\{X^{(i)} - X^{(i-i)}\} = 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots.. (4.6)$$

And solving for $X^{(I)}$,

$$X^{(i)} = (\mathrm{X}^{(\mathrm{i}-1)}) - J^{-1}(\mathrm{X}^{(\mathrm{i}-1)})\mathrm{F}(\mathrm{X}^{(\mathrm{i}-1)}) \qquad \ldots\ldots\ldots\ldots\ldots\ldots(4.7)$$

The iterative solution can be expressed as a function of correction vector $\Delta X^{(I)} = X^i - X^{(i-1)}$,

$$\Delta X(I) = -J^{-1}(\mathrm{X}^{(\mathrm{i}-1)})\mathrm{F}(\mathrm{X}^{(\mathrm{i}-1)}) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.8)$$

And the initial estimates are updated using the following relation:

$$X^{i} = X^{(i-1)} + \Delta X^{(I)}, \qquad \ldots\ldots\ldots\ldots (4.9)$$

The calculations are repeated as many times as required using the most up –to-date values of X in equation (4.8). This is done until the mismatches ΔX are within a prescribed small tolerance (i.e.1e-12). In order to apply the Newton- Raphson method to the power flow problem, the relevant equations must be expressed in the form of Equation (4.8) where X represents the set of unknown nodal voltage magnitudes and phase angles. The power mismatch equations ΔP and ΔQs are expanded around a base point $(^{(0)},V^{(0)})$ and, hence, the power flow Newton-Raphson algorithm is expressed by the following relationship:

$$\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix}^{(i)} = -\begin{bmatrix}\frac{\partial P}{\partial \theta} & \frac{\partial P}{\partial V}V\\ \frac{\partial Q}{\partial \theta} & \frac{\partial Q}{\partial V}V\end{bmatrix}^{(i)} \begin{bmatrix}\Delta\theta\\ \frac{\Delta V}{V}\end{bmatrix}^{(i)} \qquad \ldots\ldots(4.10)$$

The various matrices in the Jacobin may consist of up to (nb-1)*(nb-1) elements of the form:

$$\left.\begin{matrix}\frac{\partial \mathrm{P_k}}{\partial \theta_\mathrm{m}}, & \frac{\partial \mathrm{P_k}}{\partial \mathrm{V_m}}\mathrm{V_m}\\ \frac{\partial \mathrm{Q_k}}{\partial \theta_\mathrm{m}}, & \frac{\partial \mathrm{Q_k}}{\partial \theta_\mathrm{m}}\mathrm{V_m}\end{matrix}\right\} \qquad \ldots\ldots\ldots\ldots(4.11)$$

Where k = 1, … , nb ,and m=1, … ,nb but omitting the slack bus entries. Also the rows and columns corresponding to the reactive power and voltage magnitude for the PV buses are discarded Furthermore, when buses k and m are not directl linked by a transmission element, the corresponding m-m entry in the Jacobin is null. Owing to the low degree of connectivity that prevails in practical power systems, the Jacobin power flows are highly sparse. An additional characteristics is that they are symmetric in structure but not in value. It must be pointed out that the correction terms ΔV_m are divided by V_m to compensate for the fact that Jacobin terms $\left(\frac{\partial P_k}{\partial P_m}\right)V_m$ and $\left(\frac{\partial Q_k}{\partial V_m}\right)V_m$

Are multiplied by V_m. it is shown in the derivative terms given below that this artifice yields useful simplifying calculations. Conside the It element connected between the buses k and m in figure 1, for which self and mutual Jacobin terms are given below:

For k ≠ m:

$$\frac{\partial P_{k,l}}{\partial \theta_{m,l}} = \mathrm{V_K\,V_m\,[G_{Km}\sin(\theta_K - \theta_m) - B_{Km}\cos(\theta_K - \theta_m)]} \quad \ldots\ldots(4.12)$$

$$\frac{\partial P_{k,l}}{\partial V_{m,l}}\mathrm{V_{m,l}} = \mathrm{V_K\,V_m\,[G_{Km}\cos(\theta_K - \theta_m) + B_{Km}\sin(\theta_K - \theta_m)]} \quad \ldots\ldots(4.13)$$

$$\frac{\partial Q_{k,l}}{\partial \theta_{m,l}} = -\frac{\partial P_{k,l}}{\partial V_{m,l}}\mathrm{V}_{\mathrm{m},l} \quad \ldots\ldots(4.14)$$

$$\frac{\partial Q_{k,l}}{\partial V_{m,l}}\mathrm{V}_{\mathrm{m},l} = \frac{\partial P_{k,l}}{\partial \theta_{m,l}} \quad \ldots\ldots(4.15)$$

For k = m

$$\frac{\partial P_{k,l}}{\partial \theta_{k,l}} = -Q_K^{cal} - \mathrm{V_K^2\,B_{KK}} \quad \ldots\ldots(4.16)$$

$$\frac{\partial P_{k,l}}{\partial V_{k,l}}\mathrm{V}_{\mathrm{k},l} = P_K^{cal} + \mathrm{V_K^2\,G_{KK}} \quad \ldots\ldots\ldots(4.17)$$

$$\frac{\partial Q_{k,l}}{\partial \theta_{k,l}} = P_K^{cal} - \mathrm{V_K^2\,G_{KK}} \quad \ldots\ldots\ldots(4.18)$$

$$\frac{\partial Q_{k,l}}{\partial V_{k,l}}\mathrm{V}_{\mathrm{k},l} = Q_K^{cal} - \mathrm{V_K^2\,B_{KK}} \quad \ldots\ldots(4.19)$$

In general, for a bus k containing n transmission elements I, the bus self-elements take the following form:

$$\frac{\partial P_k}{\partial \theta_k} = \sum_{l=1}^{n}\frac{\partial P_{k,l}}{\partial \theta_{k,l}} \quad \ldots\ldots(4.20)$$

$$\frac{\partial P_k}{\partial V_k}\mathrm{V_k} = \sum_{l=1}^{n}\frac{\partial P_{k,l}}{\partial V_{k,l}}\mathrm{V}_{\mathrm{k},l} \quad \ldots\ldots(4.21)$$

$$\frac{\partial Q_k}{\partial \theta_k} = \sum_{l=1}^{n}\frac{\partial Q_{k,l}}{\partial \theta_{k,l}} \quad \ldots\ldots(4.22)$$

$$\frac{\partial Q_k}{\partial V_k}\mathrm{V_k} = \sum_{l=1}^{n}\frac{\partial Q_{k,l}}{\partial V_{k,l}}\mathrm{V}_{\mathrm{k},l} \quad \ldots\ldots\ldots(4.23)$$

The mutual elements given by equation (4.12) & (4.15) remain the same whether we have one transmission element or m transmission elements terminating at bus k. after the voltage magnitudes and phase angles have been calculated by iteration, active and reactive power flows throughout the transmission system are determined quite straightforwardly. An important point to bear in mind is that the mismatch power equations ΔP *and* ΔQ of the slack bus are not included in the equation (4.10) and the unknown variables P_{slack} *and* Q_{slack} are computed once the system power flows and power losses have been determined. Also, Q_G in PV buses are calculated in each iteration in order to check if the generators are within reactive power limits. However, the mismatch reactive power equations ΔQ of PV buses are not included in equation (4.10). One of the main strengths of the Newton-Raphson method is its reliability towards convergence. For most practical situations, and provided the state variables, $X^{(0)}$, are suitably initialised, the method is said to exhibit a quadratic convergence characteristic; for example,

$$f(X^{(1)}) = 1e - 1,$$
$$f(X^{(2)}) = 1e - 2,$$
$$f(X^{(3)}) = 1e - 4,$$
$$f(X^{(4)}) = 1e - 8,$$

For the maximum mismatch. Contrary to the non-Newton-Raphson solutions, such a characteristic is independent of the size of the network being solved and the number and the kinds of control equipment present in the power system. Aspects that may dent its quadratic convergence performance are reactive power limit violations in generator PV buses and extreme loading conditions.

4.3 STATE VARIABLE INITIALISATION:

The effectiveness of the Newton-Raphson method to achieve feasible iterative solution is dependent upon the selection of suitable initial values for all the state variables involved in the study. The power flow solution of the networks that contain only conventional plat components is normally started with voltage magnitudes of 1 P.U. at all PQ buses. The slack and PV buses are given their specified values, which remain constant throughout the iterative solution if no generator reactive power limit are violated. The initial voltage phase angles are selected to be zero at all buses.

4.4 GENERATOR REACTIVE POWER LIMITS:

Even though the mismatch reactive power equation ΔQ k of PV bus k is not required in equation (4.9), solution of equation (3.16) for the PV bus is still carried out at each iterative step to assess whether or not the calculated reactive power Q_K^{cal} is within the generator reactive power limits:

$$Q_{G..\min K} < Q_{GK} < Q_{G..\max K.} \quad \dots\dots\dots\dots (4.24)$$

If either of the following conditions occur during the iterative process:

$$\left.\begin{array}{l} Q_K^{cal} \leq Q_{G..\max K,} \\ Q_K^{cal} \geq Q_{G..\min K,} \end{array}\right\} \quad \dots\dots (4.25)$$

Bus k becomes a generator PQ bus with either of the following mismatch power equations incorporated in equation (4.10):

$$\left.\begin{array}{l} \Delta Q_K = Q_{G..\max K.} - Q_{LK} - Q_K^{cal}, \\ \Delta Q_K = Q_{G..\min K} - Q_{LK} - Q_K^{cal}, \end{array}\right\} \quad \dots\dots\dots (4.26)$$

depending on the violated limit, together with the relevant Jacobin entries. The nodal voltage magnitude at bus k is allowed to vary and V k becomes a state variables. It should be remarked sthat bus k may revert to being a generator PV bus at some point during the iterative process if better estimates of Q_K^{cal} , calculated with more accurate nodal voltages, indicate that the reactive power requirements at bus k can, after all be met by the generator connected at bus k. hence reactive power limit checking is carried out at each iteration. Programming wisdom indicates that limit checking should start after the first or second iteration, since nodal voltage values computed at the beginning of the iterative process may be quite inaccurate leading to misleading reactive power requirements. The switching of buses from PV to PQ and vice versa impose additional numerical demands on the iterative solution and retard convergence.

4.5 CONCLUSION

The effectiveness of the N-R method to achieve feasible iterative solution is dependent upon the selection of suitable initial values for all the state variables involved in the study. The power flow solution of the networks that contain only conventional plat components is normally started with voltage magnitudes of 1 P.U. at all PQ buses.

CHAPTER 5

MODELING AND REPRESENTATION OF STATCOM

5.1 GENERAL

The STATCOM an acronym for STAtic COMpenstor is one of most popular FACTs device which is used to narrow the gap between uncontrolled and controlled power system mode of operation with providing additional degrees of freedom to control power flow and voltages at identified weakest bus of power system. The numbers of FACTs controller have commissioned. Most of them perform a useful role during steady-state and transient operation or system instability, but some are specially designed to operate only under transient conditions. The various FACTs controllers other than STATCOM are listed below

1. Thyristor- controlled phase shifter (PS)
2. Load tap changer (LTC)
3. Thyrister-controlled reactor (TCR)
4. Thyristor controlled series capacitor (TCSC)
5. Inter phase power controller (IPC)
6. Solid state series capacitor (SSSC)
7. Unified power flow controller (UPFC)
8. Static VAR compensator (SVC)

5.2 REPRESENTATION OF STATCOM

The static synchronous compensator is main member of FACTs devices family which consists of one shunt transformer, one voltage converter source , a dc capacitor . It is a solid state synchronous condenser connected in shunt with AC network system at the identified weakest bus. The output current adjusted. It is not capable of absorbing or generating real power so that only operating in reactive power domain. The regulating output voltage magnitude and phase angle or reactive power fluctuated of the power system during varying load condition which are control by STATCOM in the power system. If the magnitude of system voltage is increased, current flow through the shunt transformer from STATCOM to power system, then devices generate reactive power or maintain voltage profile and phase angle of identified weakest buses.

A schematic representation of the STATCOM is shown figure. DC link and voltage source converter block provide current I_{vR} and voltage E_{vR} injected reactive power or maintain voltage profile at weakest bus of power system.

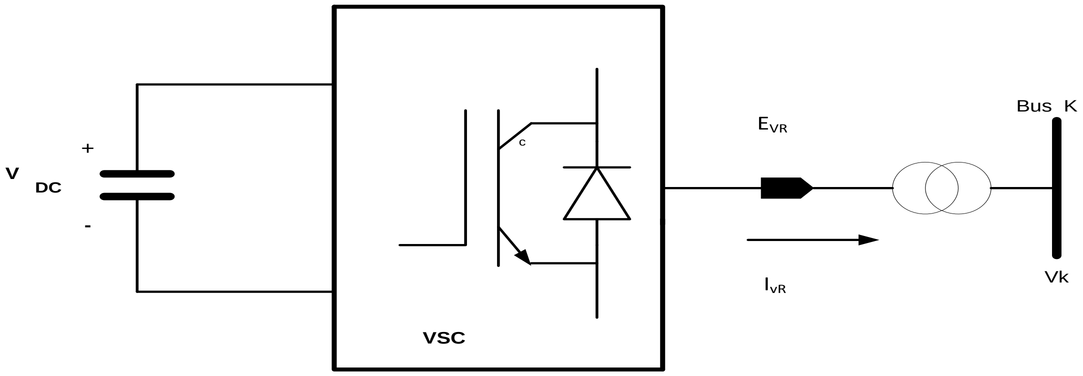

Fig. 5.1 STATCOM (VSC)

In steady state fundamental frequency studies STATCOM may be represent in the same way as a synchronous condenser which most case is the model of synchronous generator with zero active power generation. A more flexible model may be realised by representing the STATCOM as a variable voltage source., for adjusted voltage magnitude and phase angle, using a suitable iterative algorithm to satisfy specified voltage magnitude.

$$E_{vR} = V_{vR}\angle\delta_{vR}^{\circ}$$

$$E_{vR} = V_{vR}\left(cos\delta_{vR}^{\circ} + jsin\delta_{vR}^{\circ}\right) \qquad \text{... ... (5.0)}$$

The voltage magnitude V_{vR} is given maximum and minimum limit which are the function of STATCOM rating. However δ_{vR}° may take any value between -90 to 90 degree.

5.2.1 EQUIVALENT CIRCUIT OF STATCOM

Following on the STATCOM operation l characteristics as discussed in previous pera, it is reasonable to expect that for the purpose of positive sequence power flow analysis the STATCOM will be well represented by a synchronous voltage source with maximum and minimum voltage magnitude limits. The STATCOM equivalent circuit corresponds to the thevenin equivalent as seen bus k, with voltage source E_{vR} being the fundamental frequency component of voltage source converter output voltage and angle δ°_{vR}.

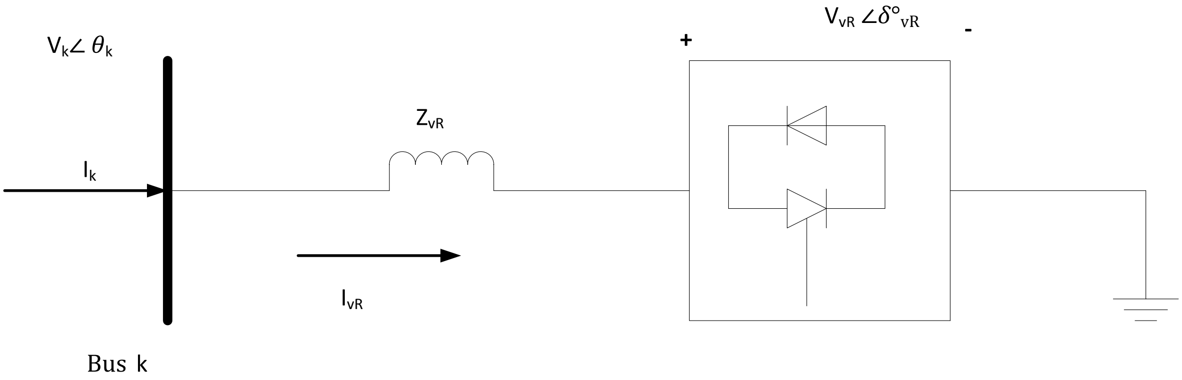

Fig. 5.2 STATCOM is represent as a PV bus

The connected STATCOM is representing as a PV bus which may change to a PQ bus in the events of limits being violated. In such a case the generated or absorbed reactive power would correspond to the violated limit. The STATCOM is represent as voltage source for the full range of operation, enabling a more robust voltage suppor mechanism.

5.2.2 DESCRIPTION OF STATCOM OPERATION

The DC to AC converter produces the output voltage at the terminal of STATCOM with the energy storage capacitor. The DC voltage at the converter produces a set of controllable three phase output voltages at the power frequency. The reactive power exchange between the PCC and STATCOM is controlled by changing the magnitude of the voltage produced. STATCOM is a shunt compensator which can be controlled so that it can inject suitable compensation currents. As compared to conventional static var compensator (SVC), it responses faster and produces reactive power at low voltage.

The energy E_{dc} required by the DC link capacitor to charge from actual voltage V_{dc} to the reference value V_{dcref} can be computed from equation (5.1) below

$$E_{dc} = 0.5 * C_{dc}\left(V_{dcref}^2 - V_{dc}^2\right) \quad (5.1)$$

where, C_{dc} is the capacitance of dc link capacitor.

DC Power (P_{dc}) required from the capacitor is calculated as

$$P_{dc} = K_P\left(V_{dcref}^2 - V_{dc}^2\right) + K_i \int\left(V_{dcref}^2 - V_{dc}^2\right)dt \quad \ldots\ldots (5.2)$$

5.2.3 Design Of Statcom

The performance of VSC is depends upon the parameters of the components associated with the VSC [15-17]. Here some of the related parameters are discussed, such as DC bus voltage V_{dc} , DC storage capacitance C_{dc} and interfacing inductance Lf.

5.2.4 Reference DC Link Voltage

Capacitor is used as the energy storage device and its voltage is decided according to the working voltage level of the ac distribution system. DC voltage level is selected for achieving good tracking performance. The DC link voltage is maintained at $1.3V_m$, where V_m (i.e. 110V) is maximum value of line to line voltage of the 3-phase system. The reference DC link voltage is taken as 200V for the study.

$$V_{dcref} = 1.3V_m \quad \text{... (5.3)}$$

5.2.5 Storage Capacitance

At the time of transients the dc capacitor supplies or demands energy from the ac system to maintain the quality of source power. For calculating the capacitance value, suppose controller works after the n cycles, so nST is the maximum possible energy capacity of the capacitor. This much energy can be supplied to or absorbed from the system. Where S is the maximum load rating and T is system time period. Hence,

$$\frac{1}{2} C_{dc} \left(V_{dcref}^2 - V_{dcm}^2\right) = nST \quad \text{... ... (5.4)}$$

$$C_{dc} = \frac{2nST}{(V_{dcref}^2 - V_{dcm}^2)} \quad \text{... ... (5.5)}$$

where, V_{dcm} is the maximum allowable voltage.

5.2.6 Interfacing Inductance

Neglecting the resistance of the interfacing inductors, inductors are designed to provide good performance at maximum switching frequency, at which the HCC is operated. So considering these aspects interfacing inductance Lf [15] is given by,

$$L_f = \frac{V_{dcref}}{(4hf_{max})} \quad \text{... ... (5.5)}$$

where, 2h is ripple in the current and f_{max} is maximum switching frequency achieved by Hysteresis Current Control (HCC).

5.2.7 V-I characteristics

The STATCOM is essentially an alternating voltage source behind coupling reactance with the corresponding V-I characteristics shown in figure. This show that the STATCOM can operated over its full output current range even at very low about 0.2 p.u. system voltage level.

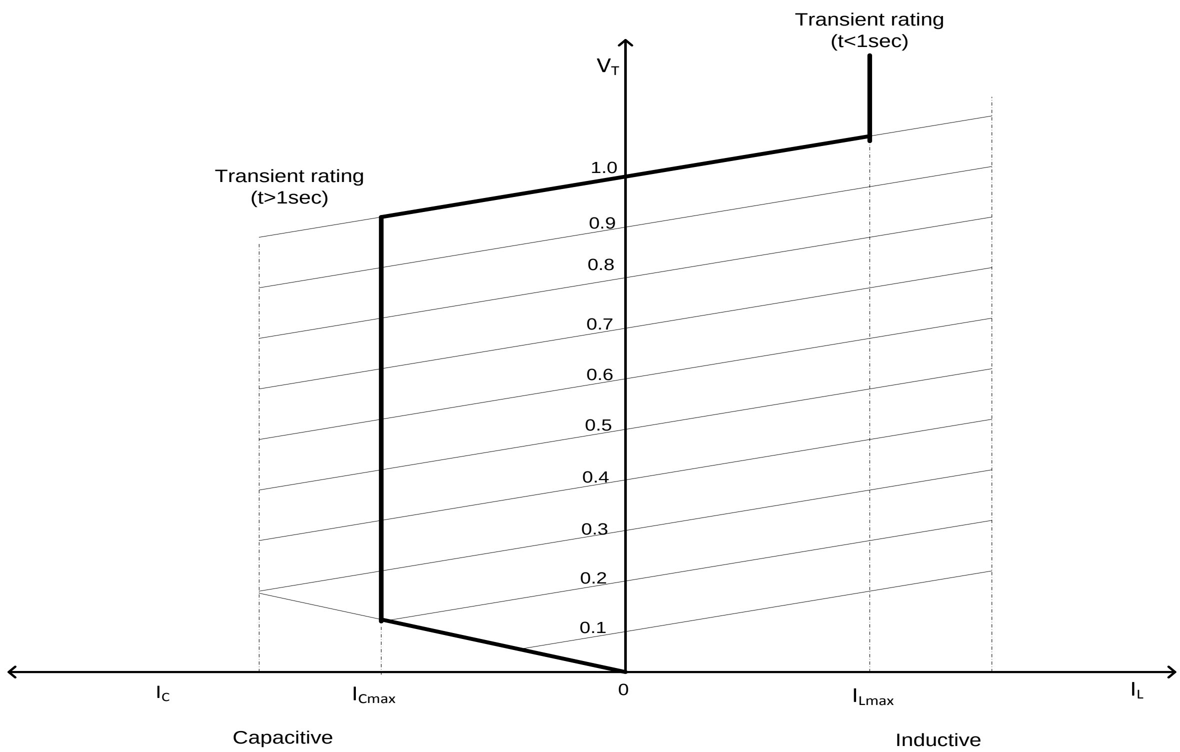

Fig. 5.3 V-I characteristics of STATCOM

In other words, the maximum inductive (I_{LMAX}) or capacitive (I_{CMAX}) output current of the STATCOM can be maintain independently of the AC system voltage, and the maximum VAR generation or absorption change linearly with the AC system voltage. As the fig. 3, the STATCOM has increased transient rating in both inductive and capacitive operating regions which depending on power semiconductors. The maximum attainable transient over current of the STATCOM in the capacitive region is determine by the maximum current turn off capability of power semiconductors used (i.e IGBT, GTO)

5.3 ASUMPTION FOR DERIVATION OF STATCOM

1. Device adjusted at midpoint of transmission line.

2. The sending end voltage and receiving end voltage in installation.

Following models are used to derive mathematical model of the controller for inclusion in power flow algorithm. The voltage and power equations for STATCOM are driven below.

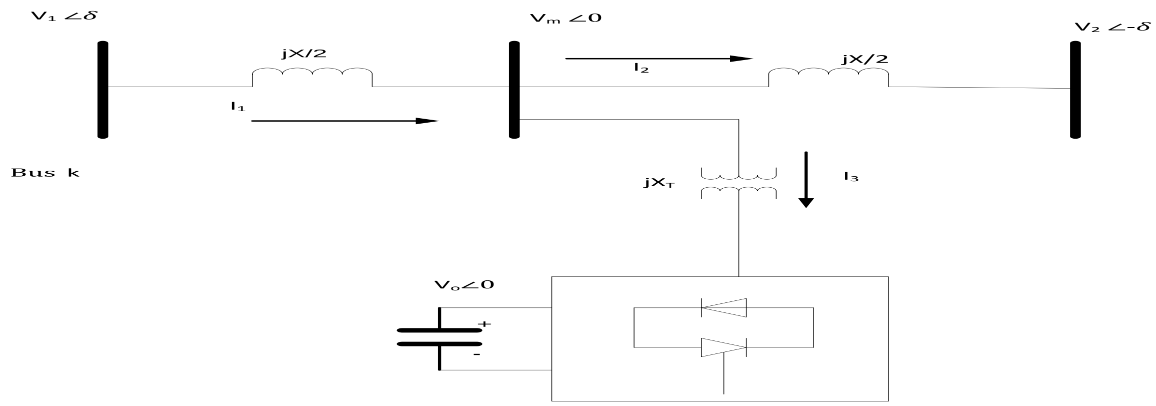

Fig. 5.4 STATCOM at midpoint of transmission

Where I_1, I_2, I_3 are passing current in equivalent circuit of STATCOM at midpoint of transmission line of power system.

$V_m \angle 0$, $V_o \angle 0$, and $V_1 \angle\delta$, $V_3 \angle -\delta$ are regulated voltage with angle δ and jX_T, X reactance of the circuit I_1, I_2 and I_3 current passing through transmission line and STATCOM controlled device which have reactance X and X_T .

5.3.1 EQUIVALENT CIRCUIT OF STATCOM

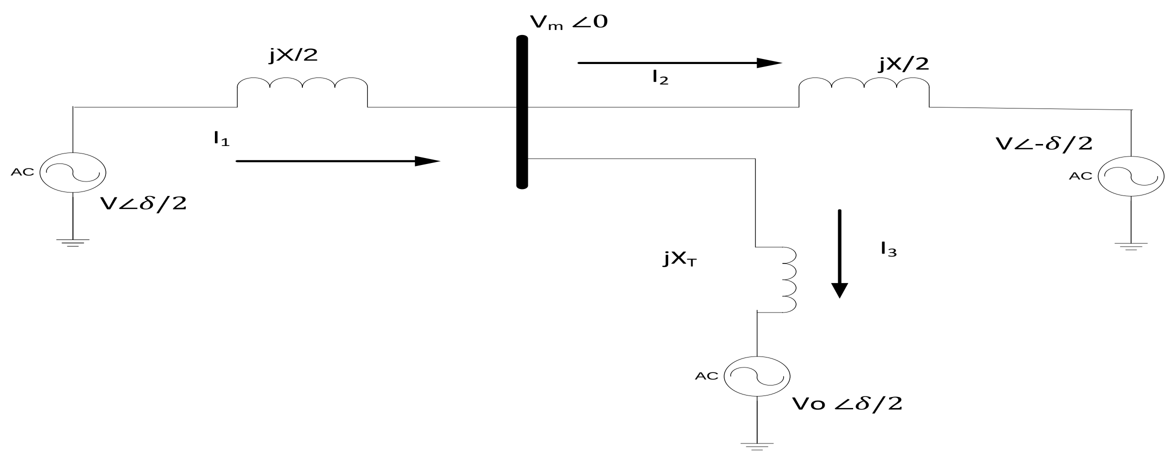

Fig. 5.5 Equivalent circuit STATCOM at midpoint of transmission

Therefore, mathematical expression as below

$$I_1 = I_2 - I_3 \qquad \ldots\ldots\ldots\ldots (5.6)$$

$$[\ I_1 = \frac{V\angle\delta/2 - V_m\angle 0}{jX/2}\ ], \quad [\ I_2 = \frac{V_m\angle 0 - V0\angle 0}{jX_T}\ ] \ \&\ [I_3 = \frac{V_m\angle 0 - V\angle -\delta/2}{jX/2}\ ]$$

Thus, from above relations

$$\frac{V\angle\delta/2 - V_m\angle 0}{jX/2} = \frac{V_m\angle 0 - V_o\angle 0}{jX_T} + \frac{V_m\angle 0 - V\angle -\delta/2}{jX/2} \qquad \ldots\ldots\ldots (5.7)$$

$$V_m[\frac{4}{X} + \frac{1}{X_T}] = \frac{2V}{X}[\cos\delta/2 + j\sin\delta/2] + \frac{2V}{X}[\cos\delta/2 - j\sin\delta/2] + \frac{V_o}{X_T}$$

$$V_m[\frac{4}{X} + \frac{1}{X_T}] = \frac{4V}{X}[\cos\delta/2] + \frac{V_o}{X_T}$$

$$V_m = \frac{4VX_T}{X + 4X_T}[\cos\delta/2] + \frac{V_oX}{X + 4X_T} \qquad \ldots\ldots\ldots (5.8)$$

$$P_{max} = \frac{2VV_m}{X}[\sin\delta/2] \qquad \ldots\ldots\ldots (5.9)$$

$$P_{max} = \frac{2V}{X}\{\frac{4VX_T}{X + 4X_T}[\cos\delta/2] + \frac{V_oX}{X + 4X_T}\}[\sin\delta/2]$$

$$P_{max} = \frac{4V^2X_T}{X(X + 4X_T)}\sin\delta + \frac{2VV_oX}{X + 4X_T}\sin{}^{\delta}/_{2} \qquad \ldots\ldots\ldots (5.10)$$

5.4 Conclusion

In this chapter discussed about the power electronics devices such as used to controlling voltage profile to reactive power control. Basically mainly here focused on STATCOM (VSC) with dc link power storage capacitor. V-I characteristics represents the operating modes of STATCOM in capacitive and inductive mode as voltage profile limit (1.0 p.u.) and current 0.2 p.u for maximum output voltage V_m .

CHAPTER 6

DISCUSSION AND RESULTS

CASE STUDY

6.1 Test Case:- IEEE-14 Bus Test System

IEEE-14 bus power system network consists of 5 generators, 14 buses, 16 lines, 4 transformers, 11 loads as shown figure. The system has generators located at buses 1, 2, 3, 6, 8 and 4 transformers with off nominal tap ratio in line 5-6, 4-7, 7-8, 7-9 where bus 1 assuming as Slack bus as shown figure. The system connectivity and transmission data, generator data and load data are given in tables. FACTS device (STATCOM) installed at identified weakest buses of IEEE-14 system by calculating voltage profile lower limit which are maintain 0.98 (p.u) lower limits and 1.0 (p.u) upper limit. Solved by using Newton Raphson Power flow method with MATLAB programming. The power flow results superimposed on the one line diagram of the system the voltage magnitudes and phase angles are given in tabulated form in result section.

Bus Data

	Generation Power		Load demand Power		Compensated power limit	
Bus No.	Real (MW)	Reactive (MVAr)	Real (MW)	Reactive (MVAr)	Real (MW)	Reactive (MVAr)
1	232.4	-16.9	0	0	0	0
2	40	42.4	21.7	12.7	-40	50
3	0	23.4	94.2	19	0	40
4	0	0	47.8	3.9	0	0
5	0	0	7.6	1.6	0	0
6	0	12.2	11.2	7.5	-6	24
7	0	0	0	0	0	0
8	0	17.4	0	0	-6	24
9	0	0	29.5	16.6	0	0
10	0	0	9	5.8	0	0
11	0	0	3.5	1.8	0	0
12	0	0	6.1	1.6	0	0
13	0	0	13.5	5.8	0	0
14	0	0	14.9	5	0	0

Table no. 6.1

Line data

Interconnected Buses	Resistance (p.u)	Reactance (p.u)	Susptance (p.u)	X'mer Tapsetting
1 - 2	0.0194	0.0592	0.0264	1
2 - 3	0.0472	0.198	0.0219	1
2 - 4	0.0581	0.1763	0.0187	1
1 - 5	0.054	0.2231	0.0246	1
2 - 5	0.057	0.1741	0.017	1
3 - 4	0.067	0.171	0.0173	1
4 - 5	0.0134	0.0421	0.0064	1
5 - 6	0	0.252	0	0.932
4 - 7	0	0.2091	0	0.978
7 - 8	0	0.1762	0	0.968
4 - 9	0	0.05562	0	0.969
7 - 9	0	0.11	0	1
9 - 10	0.0318	0.0845	0	1
6 - 11	0.095	0.1989	0	1
6 - 12	0.1229	0.2558	0	1
6 - 13	0.0663	0.1303	0	1
9 - 14	0.01271	0.2704	0	1
10 - 11	0.0821	0.1921	0	1
12 - 13	0.2209	0.1999	0	1
13 - 14	0.0171	0.348	0	1

Table no. 6.2

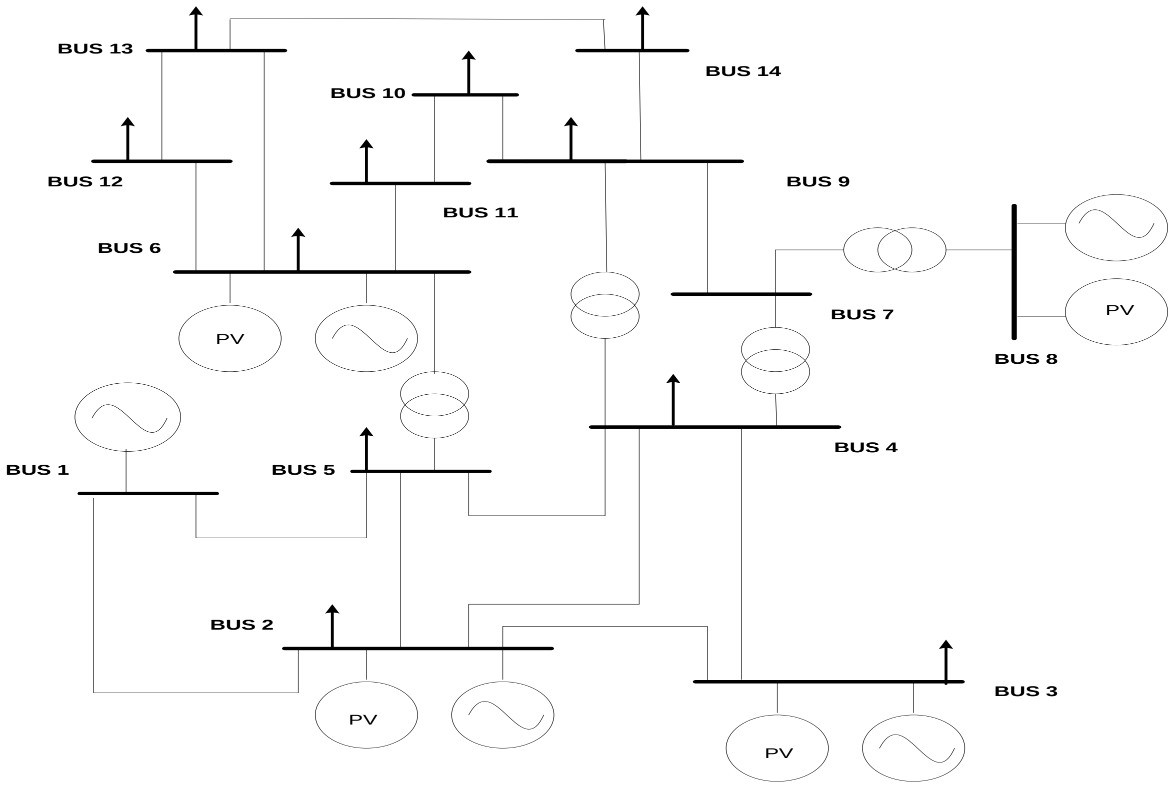

Fig. 6.1 Without STATCOM

6.2 Results Of IEEE - 14 Bus System With And With Out STATCOM Under Variation Load.

After increasing the load values 0 to 50 percent in 5 percent interval. I have performed power flow solution and have tabulated results as shown below. Here, I have focused on voltage profile of the system with and without STATCOM. On comparing by plotted graph of the power flow results, it is seen that when the STATCOM is connected in power system the voltage magnitudes are maintained voltage lower limit 0.98 and voltage upper limit 1.0 p.u. (approx).

At each weakest bus of the power system. Also maintain phase angle of uncontrolled power system mode of operation.

There are various tables represents comparison of results with and without STATCOM after increasing load.

Shown In table no. 6.3 , 6.4, 6.5 not identified weakest buses as minimum voltage profile limit 0.98 p.u. in IEEE 14 bus system during no change, 5% and 10% increase the load , it is also clear from plotted graph between voltage profile and phase angle with and without STATCOM which is shown figure 6.1 to figure 6.6.

Table no. 6.6 shows the result of 15% increasing load bus no 3 and 14 voltage goes down as voltage profile limit. Then identified weakest bus, of IEEE-14 bus power system there is 0.66% to 2.51% voltage regulation which is negligible. And compensated by STATCOM also represented table no 6.7 shows result of 20% increasing load. Voltage profile goes down from maintained voltage profile limit. Bus no. 3, 4, 14 are indentified weakest bus of IEEE-14 bus system also compensate by STATCOM to maintained voltage profile (0.98 P.u. or 1.0 P.u.) to control reactive power. There is 4.5% voltage regulation.

There are load increasing 25% to 40% of main load. Then bus no.3, 4, 9, 10 and 14 are identified weakest bus and voltage regulation goes to 3.5% to 7.5% which are maintain the (0.98 p.u or 1.0 p.u) by STATCOM. Table no. 6.13 & 6.14 shows the results of 45% & 50% increasing in load. Voltage goes down (i.e voltage sag) of voltage profile limit (0.98 p.u or 1.0 p.u) which have voltage regulation 4% to 9.5% thus the identified weakest bus 3,4,5,7,9,10,12,13,14, which are compensated or maintained voltage profile limit (.98 p.u or1.0 p.u) or control reactive power by STATCOM of IEEE-14 bus system.

Results shows of all over 0 to 50% increasing load, voltage goes down of voltage profile limit (0.98 p.u or 1.0 p.u) there are 3, 4, 5, 7, 9, 10, 12, 13, and 14 are indentified weakest buses as voltage profile limit which are compensated by STATCOM

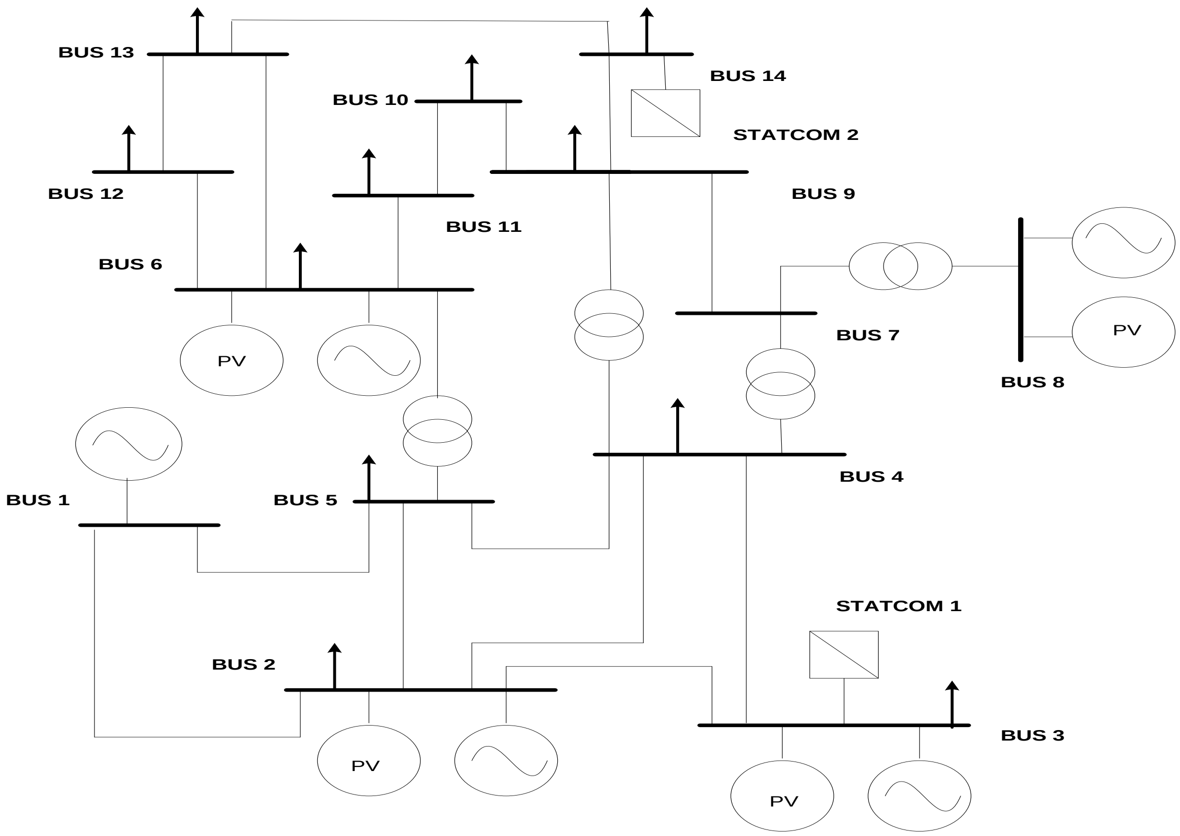

Fig. 6.2 With STATCOM

No change in load				
	Without STATCOM		With STATCOM	
Bus No.	V (p.u)	Angle (Deg)	V (p.u)	Angle (Deg)
1	1.06	0	1.06	0
2	1.035	-4.856	1.035	-5.204
3	0.9957	-12.736	1.01	-13.6695
4	1.0017	-10.2037	1.0031	-10.8317
5	1.0017	-8.7527	1.01	-9.2822
6	1.01	-14.4879	1.0423	-15.3102
7	1.0422	-13.3545	1.0283	-14.1379
8	1.0281	-13.3545	1.06	-14.1379
9	1.0115	-15.0322	1.0111	-15.9015
10	1.0086	-15.2222	1.0081	-16.1033
11	1.02	-14.9435	1.01	-15.8158
12	1.0259	-15.373	1.0257	-16.2509
13	1.02	-15.4169	1.01	-16.3213
14	1.0003	-16.471	1	-17.4295

Table no. 6.3 Results of No Change in load

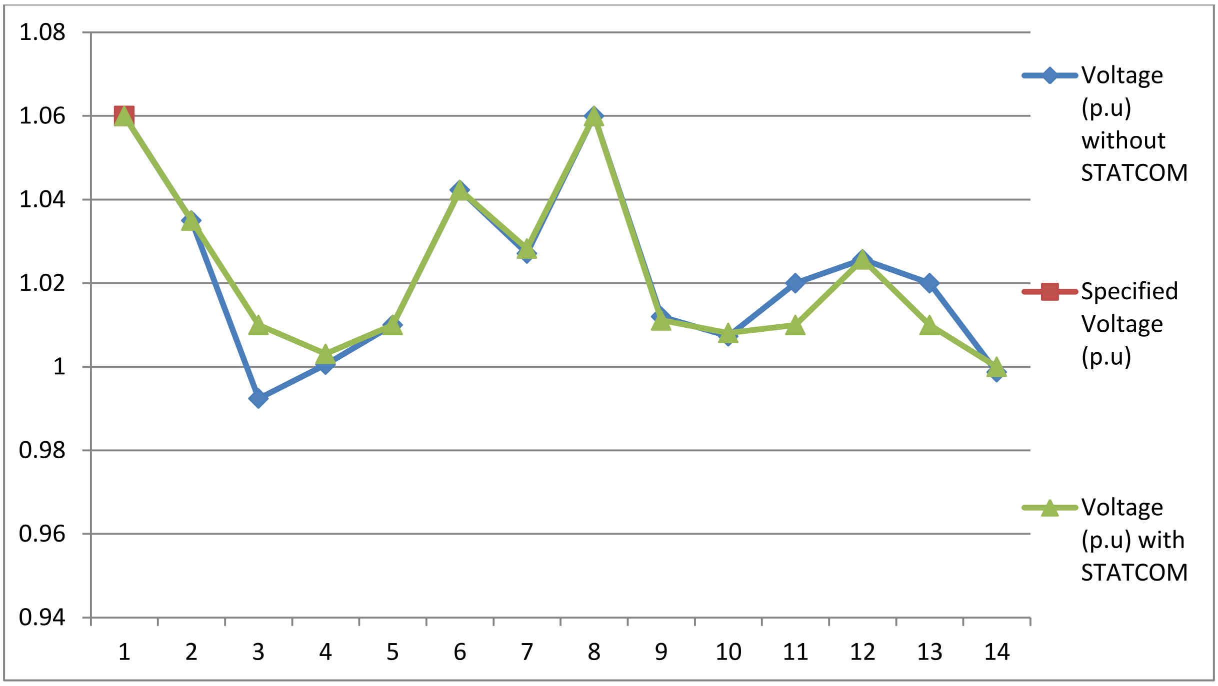

Figure no. 6. 3 Voltage (p.u) No Change in load

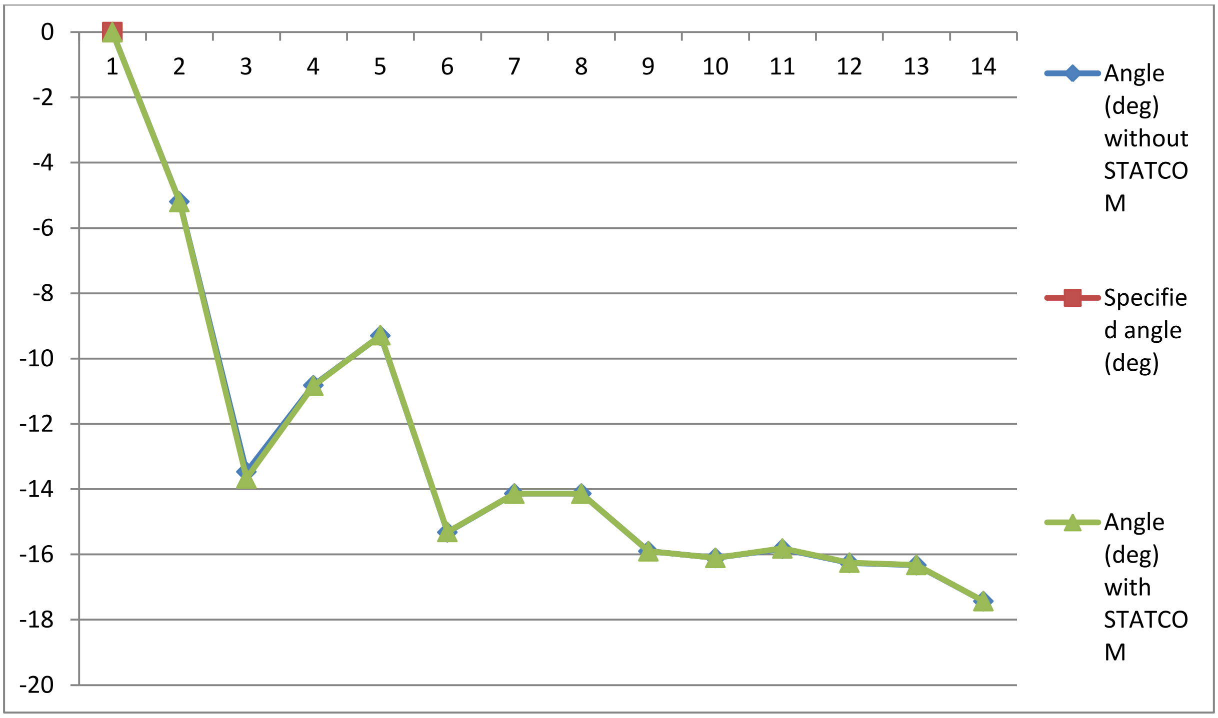

Figure no. 6.4 Angle (Deg) with No Change in load

5 percent change in load				
	Without STATCOM		With STATCOM	
Bus No.	V (p.u)	Angle (Deg)	V (p.u)	Angle (Deg)
1	1.06	0	1.06	0
2	1.035	-5.1925	1.035	-5.204
3	0.9924	-13.4676	1.01	-13.6695
4	1.0005	-10.818	1.0031	-10.8317
5	1.01	-9.298	1.01	-9.2822
6	1.0423	-15.3219	1.0423	-15.3102
7	1.0271	-14.1348	1.0283	-14.1379
8	1.06	-14.1348	1.06	-14.1379
9	1.012	-15.9014	1.0111	-15.9015
10	1.0073	-16.1077	1.0081	-16.1033
11	1.02	-15.831	1.01	-15.8158
12	1.0257	-16.2607	1.0257	-16.2509
13	1.02	-16.329	1.01	-16.3213
14	0.9987	-17.4327	1	-17.4295

Table no. 6.4 Results of 5 % increase in load

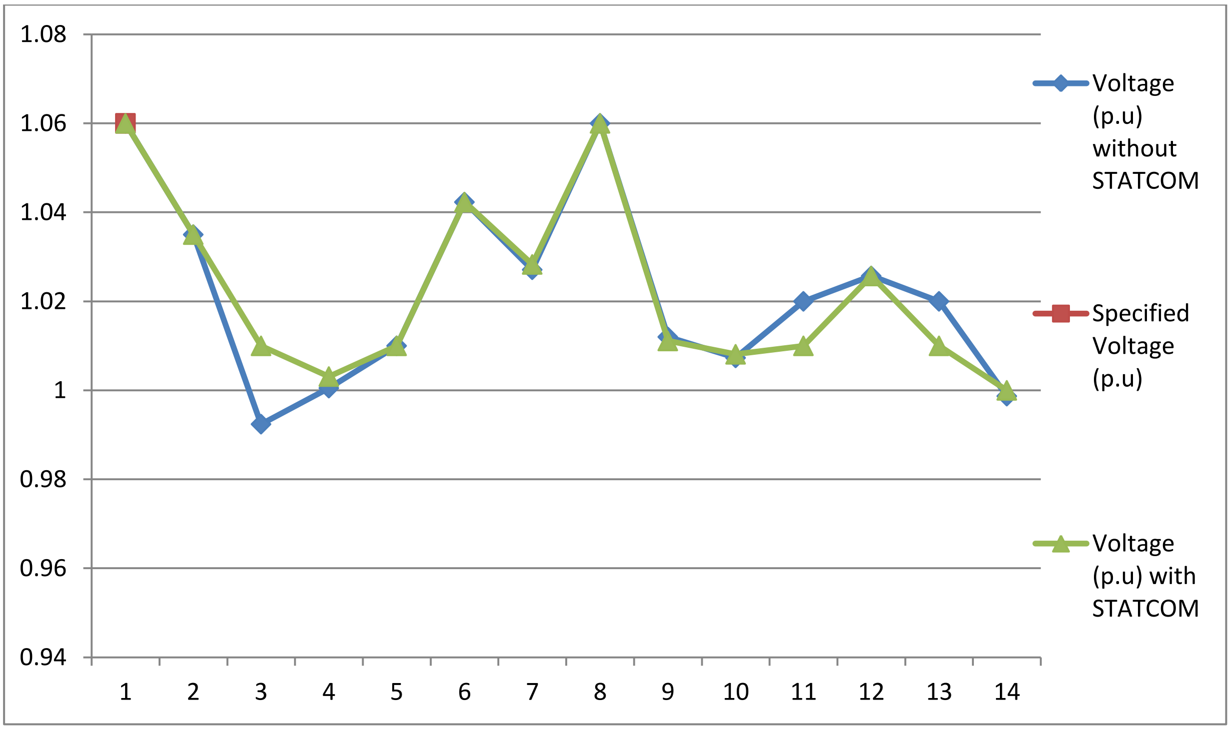

Figure no. 6.5 Voltage (p.u) with 5% increase in load

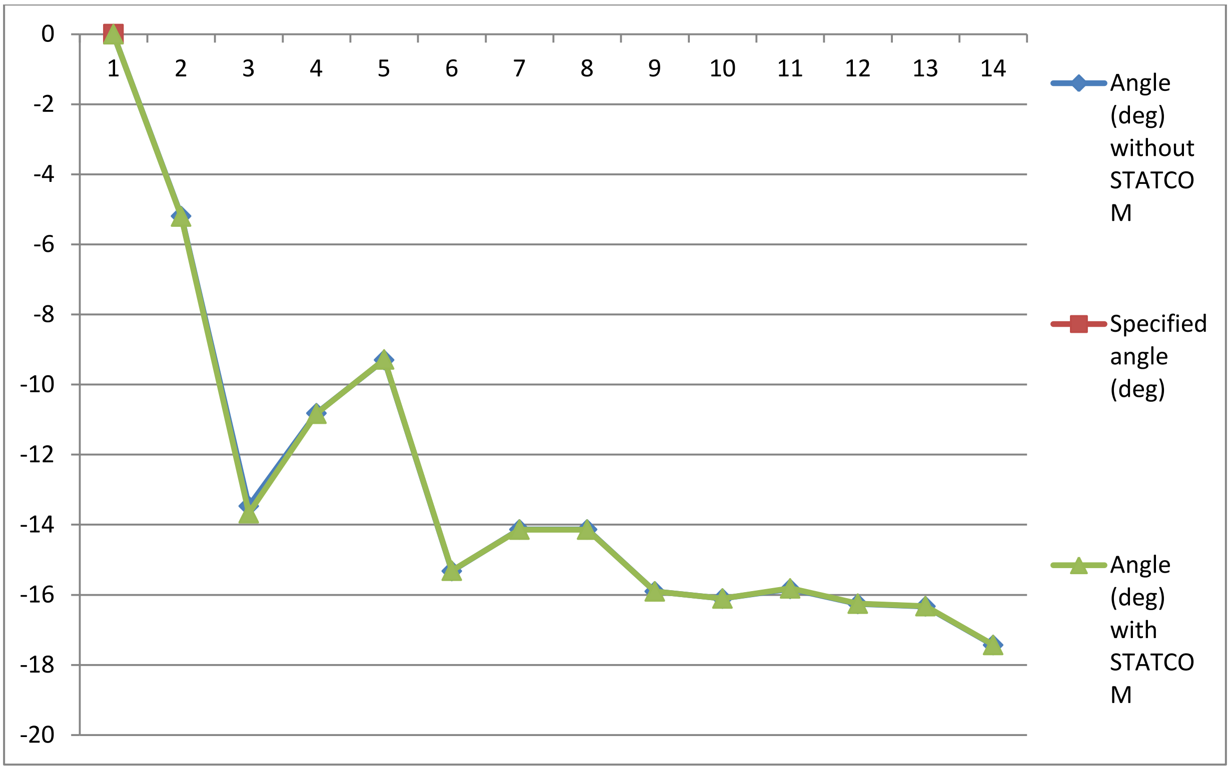

Figure no. 6.6 Angle (Deg) with 5% increase in load

10 percent change in load				
	Without STATCOM		With STATCOM	
Bus No.	V (p.u)	Angle (Deg)	V (p.u)	Angle (Deg)
1	1.06	0	1.06	0
2	1.035	-5.5311	1.035	-5.5444
3	0.989	-14.2043	1.01	-14.4377
4	0.9994	-11.4357	1.0025	-11.45
5	1.01	-9.8465	1	-9.8253
6	1.0423	-16.1601	1.0423	-16.1427
7	1.026	-14.9191	1.0276	-14.9185
8	1.06	-14.9191	1.06	-14.9185
9	1.0084	-16.7752	1.0102	-16.7692
10	1.0059	-16.998	1.0072	-16.9857
11	1.02	-16.7232	1.01	-16.696
12	1.0255	-17.1529	1.0255	-17.139
13	1.02	-17.2457	1.01	-17.2356
14	0.997	-18.3996	1	-18.4057

Table no. 6.5 Results of 10% increase in load

Figure no. 6.7 Voltage (p.u) 10% increase in load

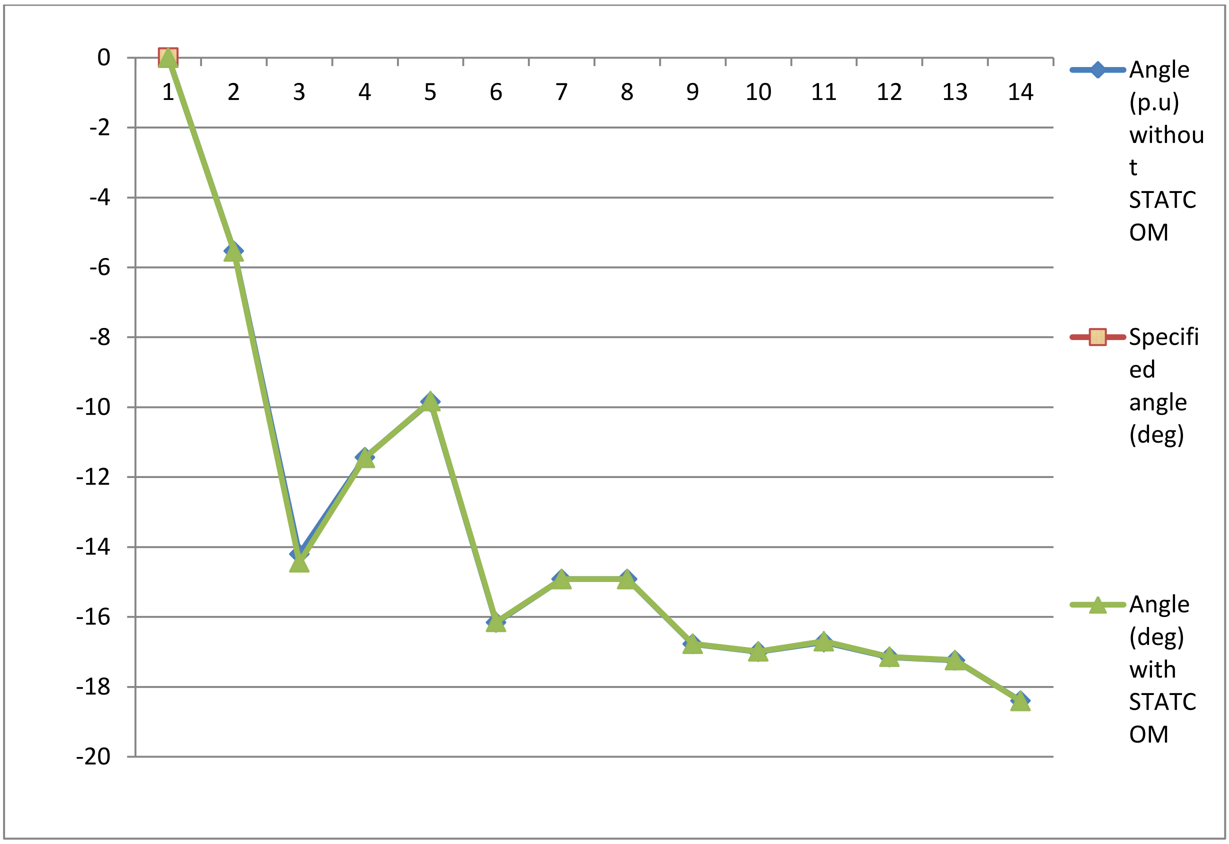

Figure no. 6.8 Angle (Deg) with 10% increase in load

15 percent change in load				
	Without STATCOM		With STATCOM	
Bus No.	V (p.u)	Angle (Deg)	V (p.u)	Angle (Deg)
1	1.06	0	1.06	0
2	1.035	-5.8718	1.045	-5.0785
3	0.9852	-14.9747	1.01	-12.9813
4	0.9975	-14.0459	1.0051	-10.2971
5	1.01	-12.4009	1	-8.7904
6	1.0424	-17.0255	1.0423	-14.5864
7	1.0206	-15.7007	1.0294	-13.4674
8	1.05	-15.7007	1.06	-13.4674
9	1.0043	-17.6524	1.0123	-15.16
10	1.0028	-17.9032	1.0097	-16.9857
11	1.02	-17.6582	1.01	-15.347
12	1.0253	-18.0733	1.0258	-15.4827
13	1.02	-18.1916	1.01	-15.5321
14	0.9937	-19.401	1	-16.5898

Table no. 6.6 Results of 15 % increase in load

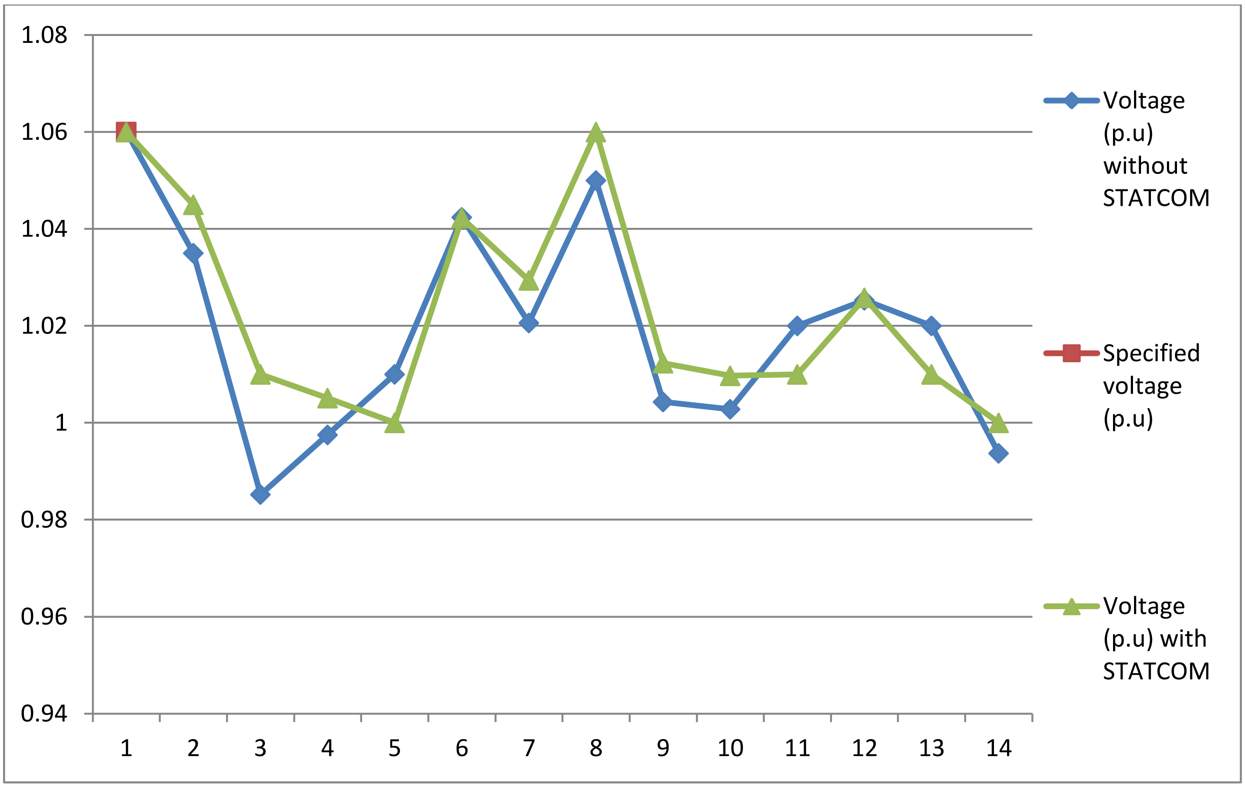

Figure no. 6.9 Voltage (p.u) with 15% increase in load

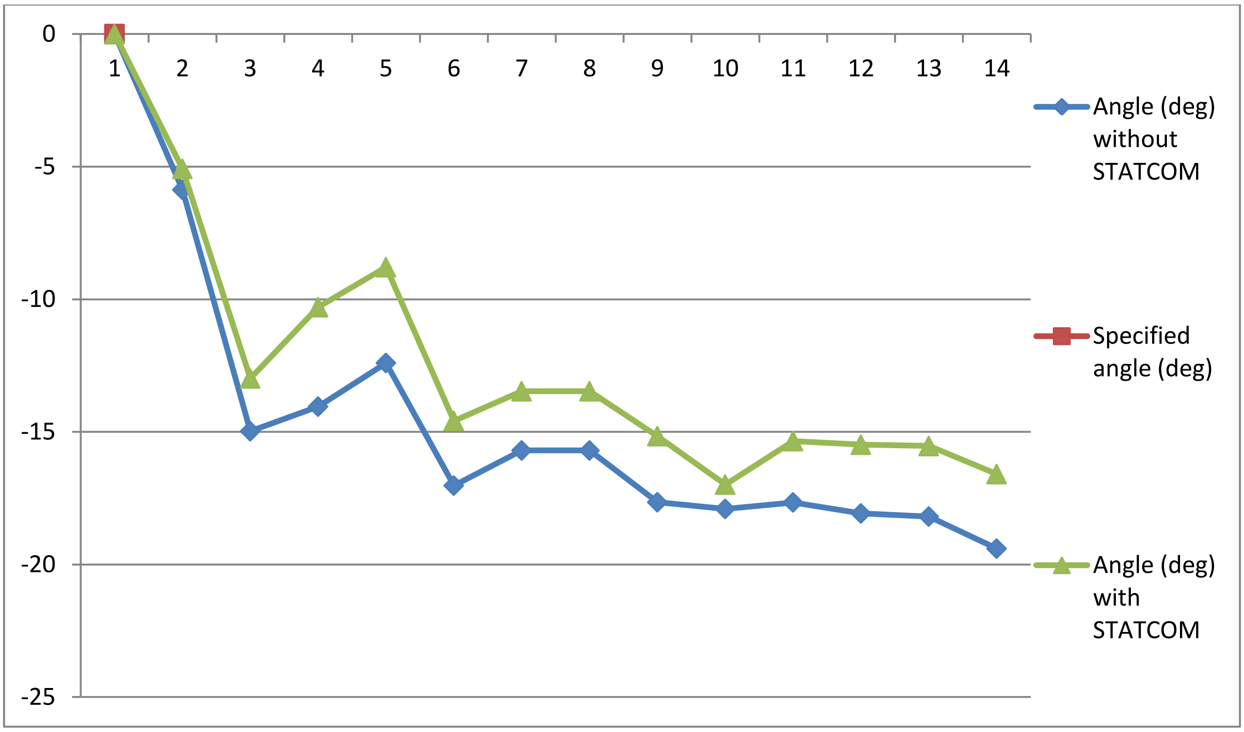

Figure no. 6.10 Angle (Deg) with 15% increase in load

20 percent change in load				
	Without STATCOM		With STATCOM	
Bus No.	V (p.u)	Angle (Deg)	V (p.u)	Angle (Deg)
1	1.06	0	1.06	0
2	1.025	-6.1266	1.035	-6.2315
3	0.9679	-15.985	1.01	-15.8255
4	0.9805	-12.6955	1.012	-12.6865
5	0.99	-10.9203	1	-10.8433
6	1.0379	-17.947	1.0423	-17.819
7	1.0129	-16.592	1.0262	-16.4904
8	1.05	-16.592	1.06	-16.4904
9	0.997	-18.6567	1.0083	-18.5163
10	0.9974	-18.9549	1.0053	-18.7625
11	1.02	-18.7842	1.01	-18.4685
12	1.023	-19.0977	1.0251	-18.9266
13	1.02	-19.3378	1.01	-19.0765
14	0.9889	-20.5885	1	-20.3711

Table no. 6.7 Results of 20 % increase in load

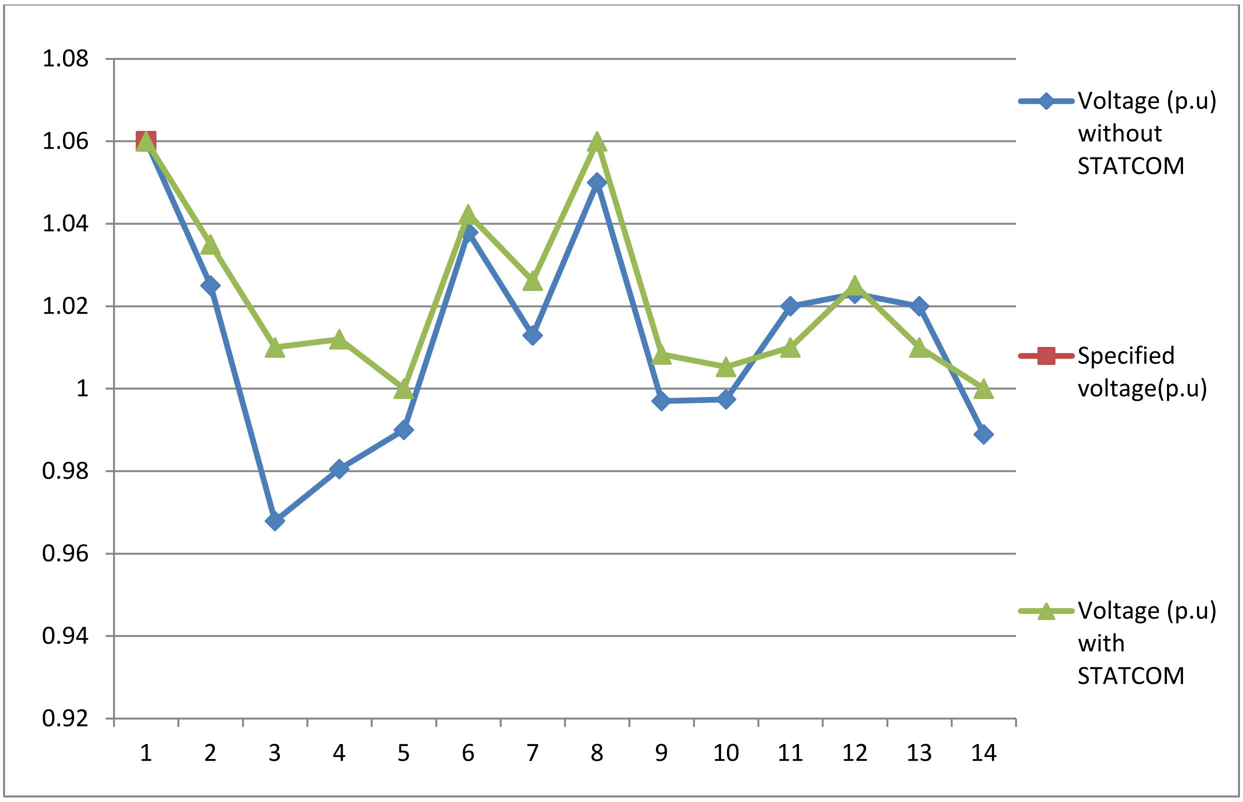

Figure no. 6.11 Voltage (p.u) with 20% increase in load

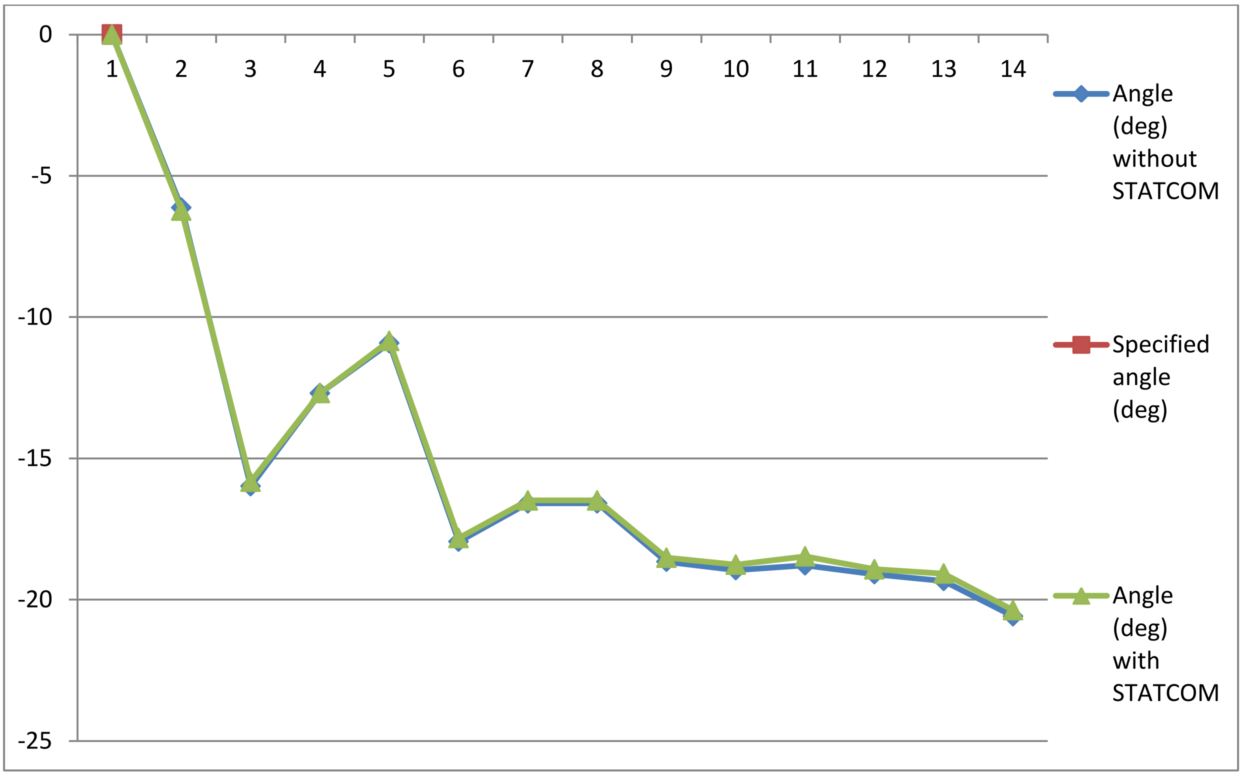

Figure no. 6.12 Angle (Deg) with 20% increase in load

25 percent change in load				
	Without STATCOM		With STATCOM	
Bus No.	V (p.u)	Angle (Deg)	V (p.u)	Angle (Deg)
1	1.06	0	1.06	0
2	1.025	-6.4769	1.035	-6.5783
3	0.9633	-16.5981	1.01	-16.7645
4	0.9775	-13.3079	1.005	-13.323
5	0.99	-11.4126	1	-11.4725
6	1.0222	-18.795	1.0423	-18.6629
7	1.0028	-17.4528	1.0255	-17.2819
8	1.04	-17.4528	1.06	-17.2819
9	0.9835	-19.6675	1.0073	-19.3958
10	0.9815	-19.951	1.0043	-19.6571
11	1	-19.6698	1.01	-19.361
12	1.046	-20.1033	1.0244	-19.8265
13	1	-20.2926	1.01	-20.0033
14	0.9714	-21.6537	1	-21.3605

Table no. 6.8 Results of 25 % increase in load

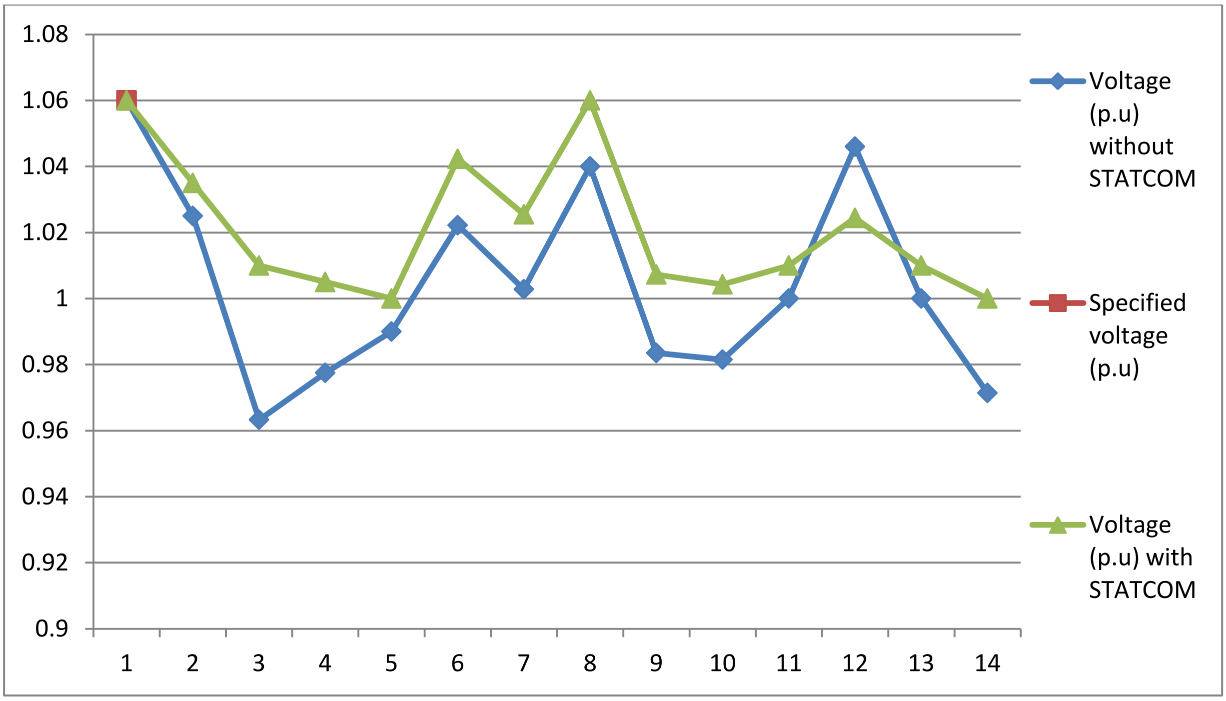

Figure no. 6.13 Voltage (p.u) with 25% increase in load

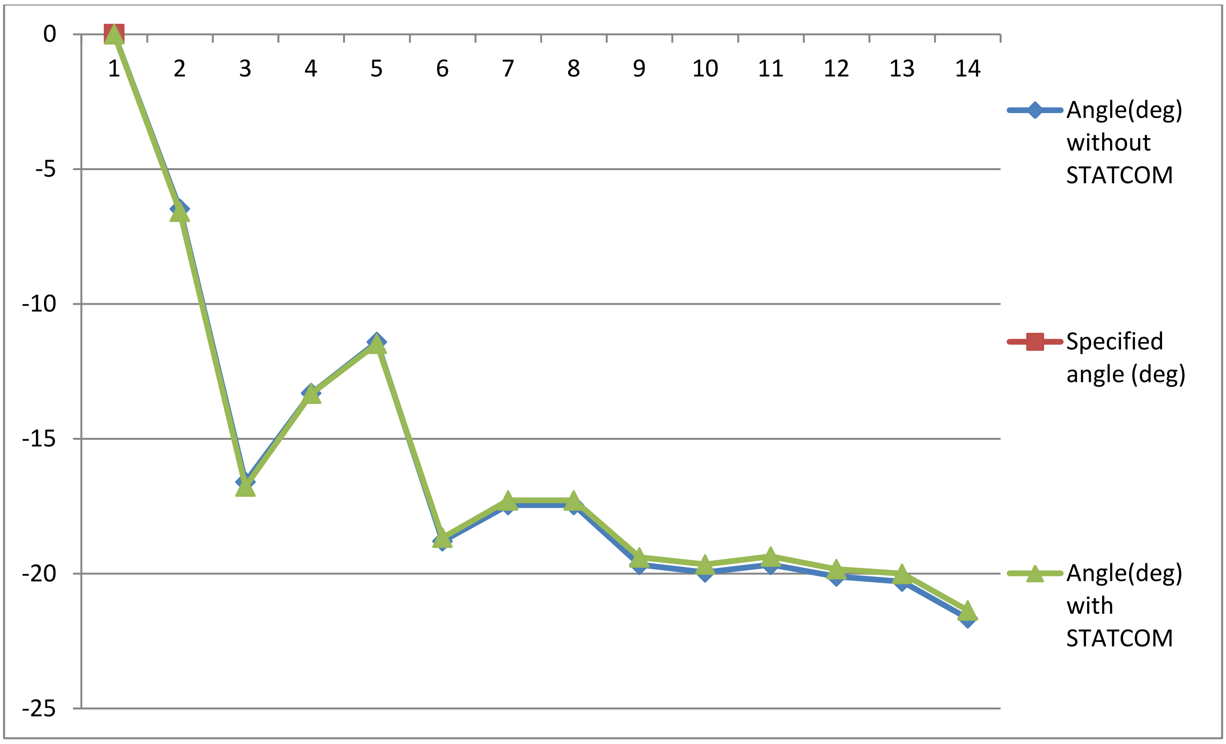

Figure no. 6.14 Angle (Deg) with 25% increase in load

30 percent change in load				
	Without STATCOM		With STATCOM	
Bus No.	V (p.u)	Angle (Deg)	V (p.u)	Angle (Deg)
1	1.06	0	1.06	0
2	1.015	-6.6949	1.035	-6.9921
3	0.9531	-17.4346	1.01	-17.7447
4	0.9737	-14.0303	0.9871	-13.9239
5	0.99	-12.0878	1	-11.837
6	1.0222	-19.8808	1.0379	-19.5392
7	1.0006	-18.3661	1.016	-18.1183
8	1.04	-18.3661	1.05	-18.1183
9	0.9809	-20.6797	1.004	-20.343
10	0.9794	-20.9857	0.9992	-20.6524
11	1	-20.7183	1.01	-20.4326
12	1.044	-21.1461	1.0226	-20.814
13	1	-21.3622	1.01	-21.1213
14	0.9697	-22.7784	1	-22.5673

Table no. 6.9 Results of 30 % increase in load

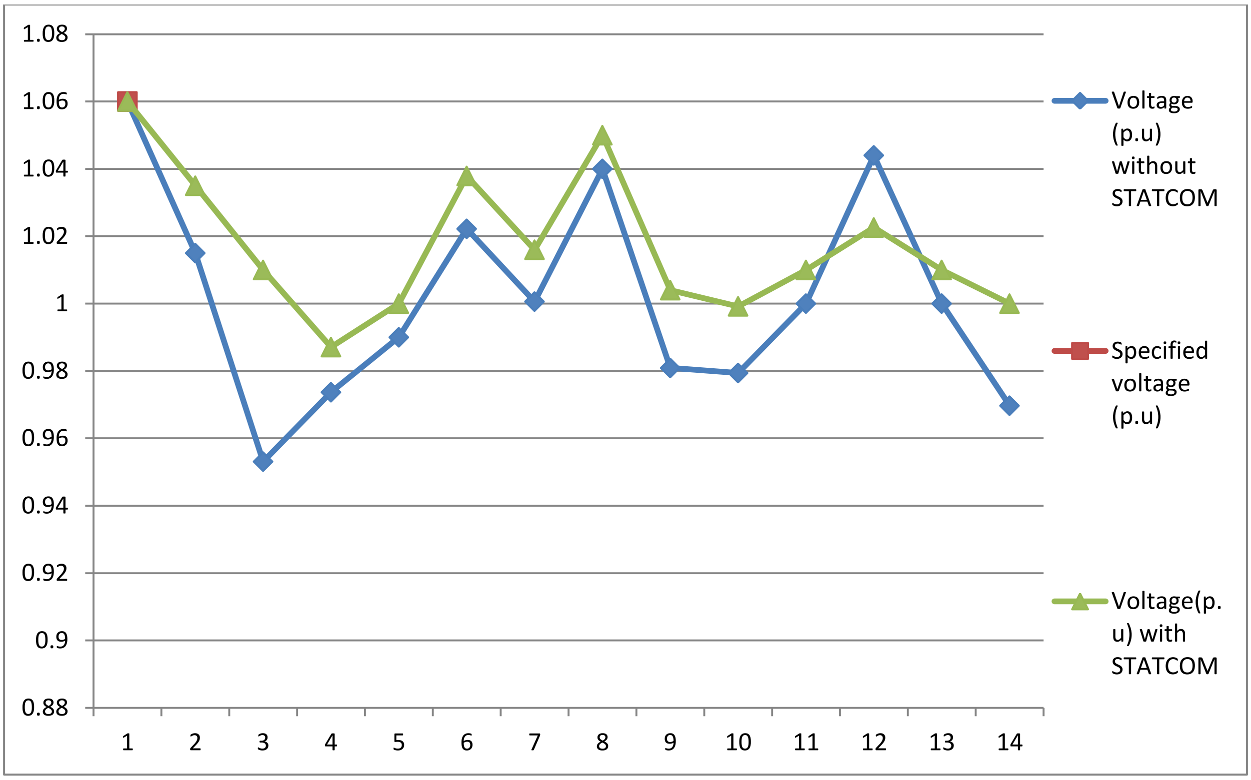

Figure no. 6.15 Voltage (p.u) with 30% increase in load

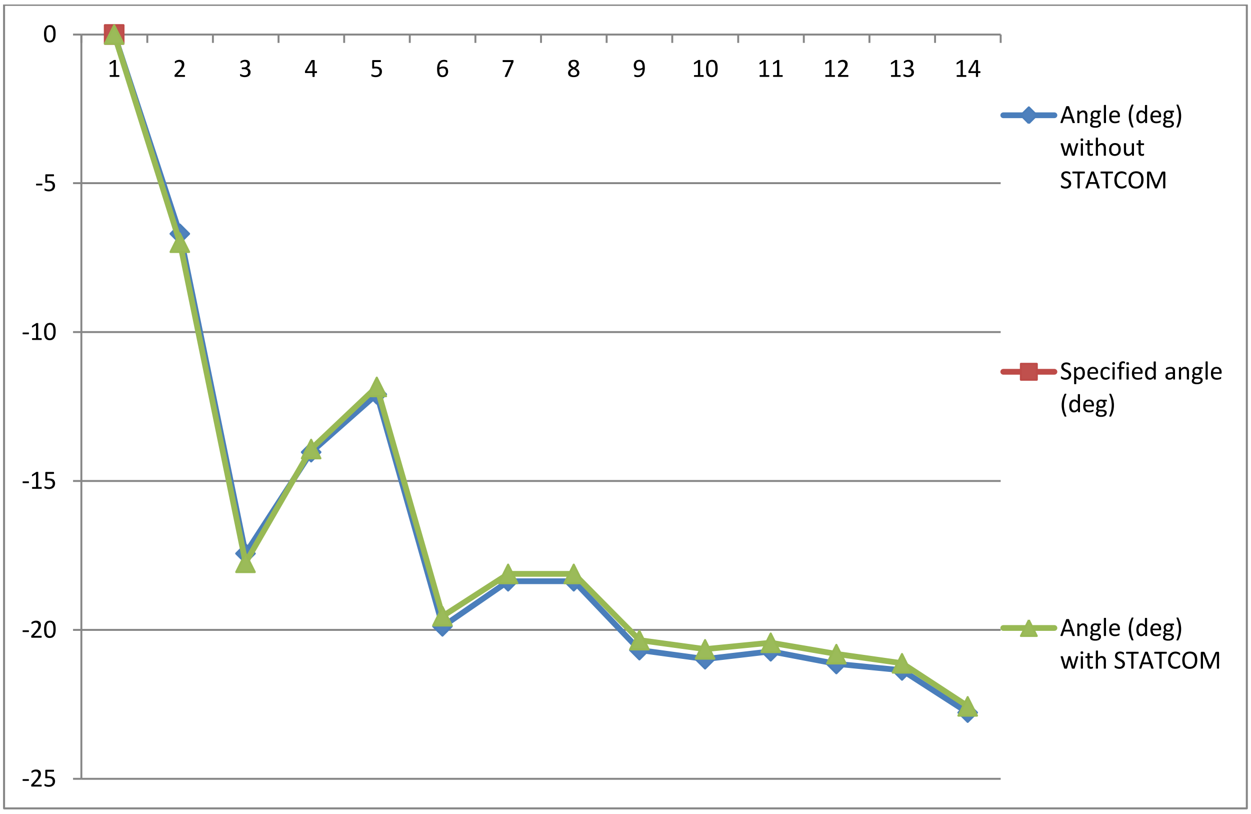

Figure no. 6.16 Angle (Deg) with 30% increase in load

35 percent change in load				
	Without STATCOM		With STATCOM	
Bus No.	V (p.u)	Angle (Deg)	V (p.u)	Angle (Deg)
1	1.06	0	1.06	0
2	1.015	-7.0513	1.035	-7.3489
3	0.9493	-18.2257	1.01	-18.5499
4	0.9724	-14.6854	0.9858	-14.5665
5	0.99	-12.67	1	-12.4022
6	1.0222	-20.7711	1.0222	-20.4742
7	0.9994	-19.1998	1.0125	-18.9809
8	1.04	-19.1998	1.05	-18.9809
9	0.9792	-21.6095	0.994	-21.3342
10	0.9779	-21.9333	0.9883	-21.61
11	1	-21.6682	1.01	-21.2306
12	1.042	-22.936	1.043	-21.8259
13	1	-21.3367	1.01	-22.101
14	0.9672	-23.8085	1	-23.7676

Table no. 6.10 Results of 35 % increase in load

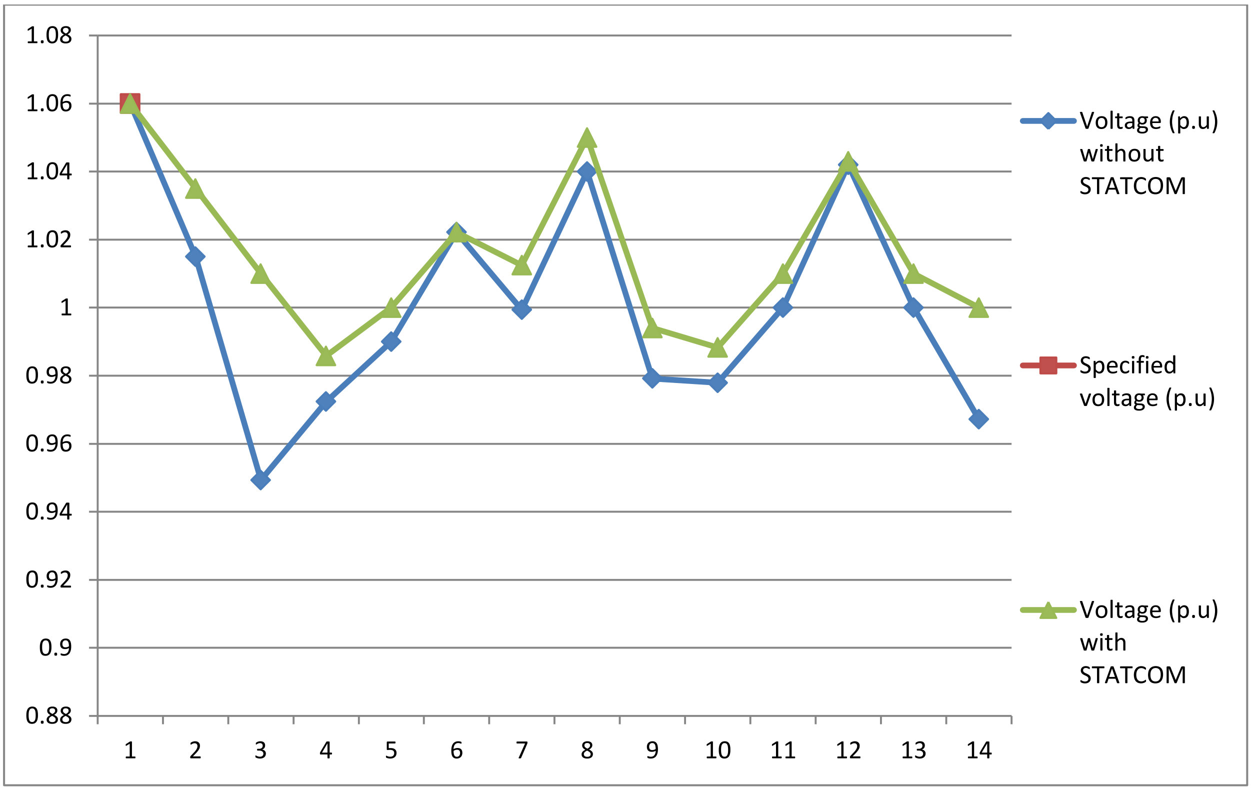

Figure no. 6.17 Voltage (p.u) with 35% increase in load

s

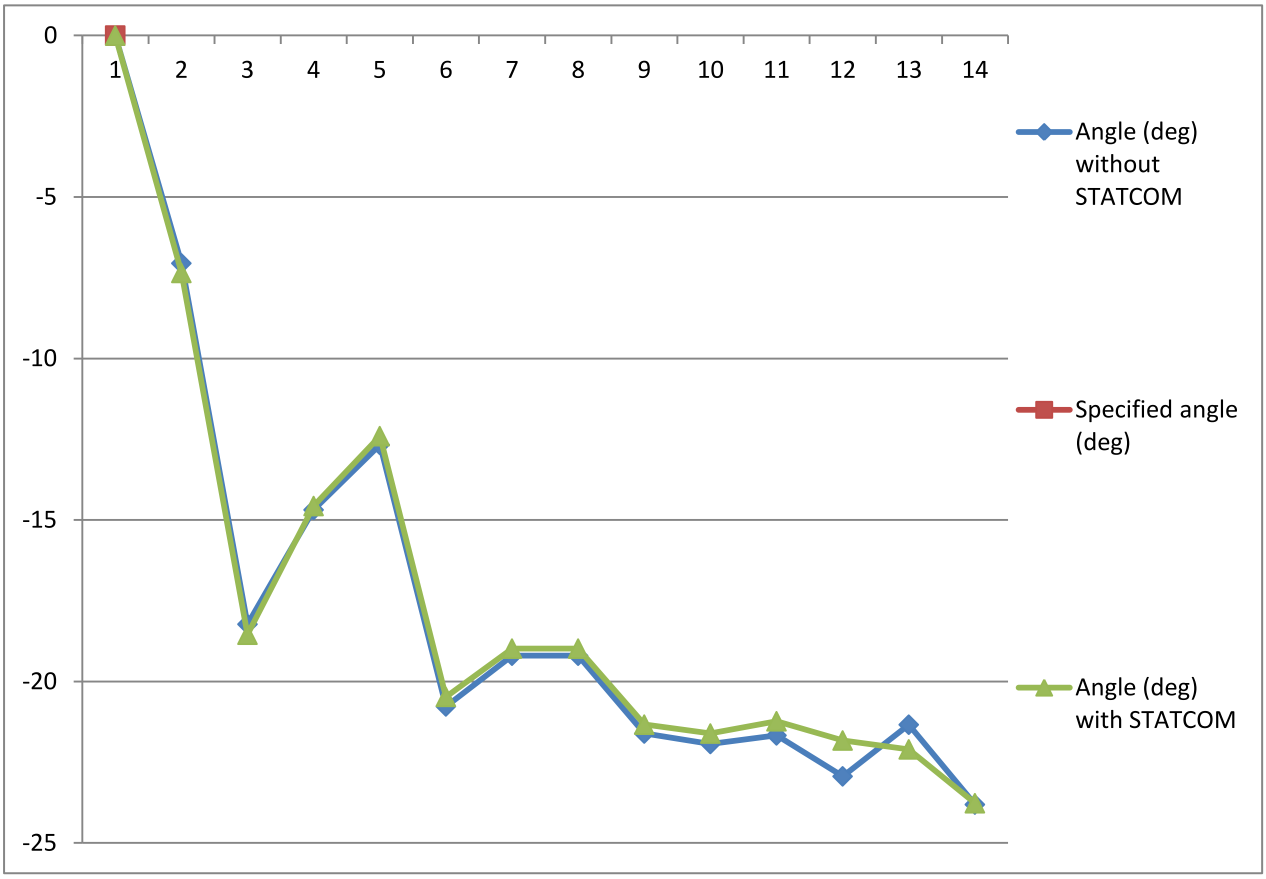

Figure no. 6.18 Angle (Deg) with 35% increase in load

40 percent change in load				
	Without STATCOM		With STATCOM	
Bus No.	V (p.u)	Angle (Deg)	V (p.u)	Angle (Deg)
1	1.06	0	1.06	0
2	1.015	-7.4721	1.035	-7.3489
3	0.9377	-19.1653	1.01	-18.5499
4	0.9576	-15.0389	0.9858	-14.5665
5	0.97	-13.0839	1	-12.4022
6	1.0177	-21.7211	1.0222	-20.4742
7	0.9925	-20.1242	1.0125	-18.9809
8	1.04	-20.1242	1.05	-18.9809
9	0.9725	-22.6566	0.994	-21.3342
10	0.973	-23.0267	0.9883	-21.61
11	1	-22.8286	1.01	-21.2306
12	1.0018	-23.1527	1.0043	-21.8259
13	1	-23.5229	1.01	-22.101
14	0.9626	-25.0406	1	-23.7676

Table no. 11 Results of 40 % increase in load

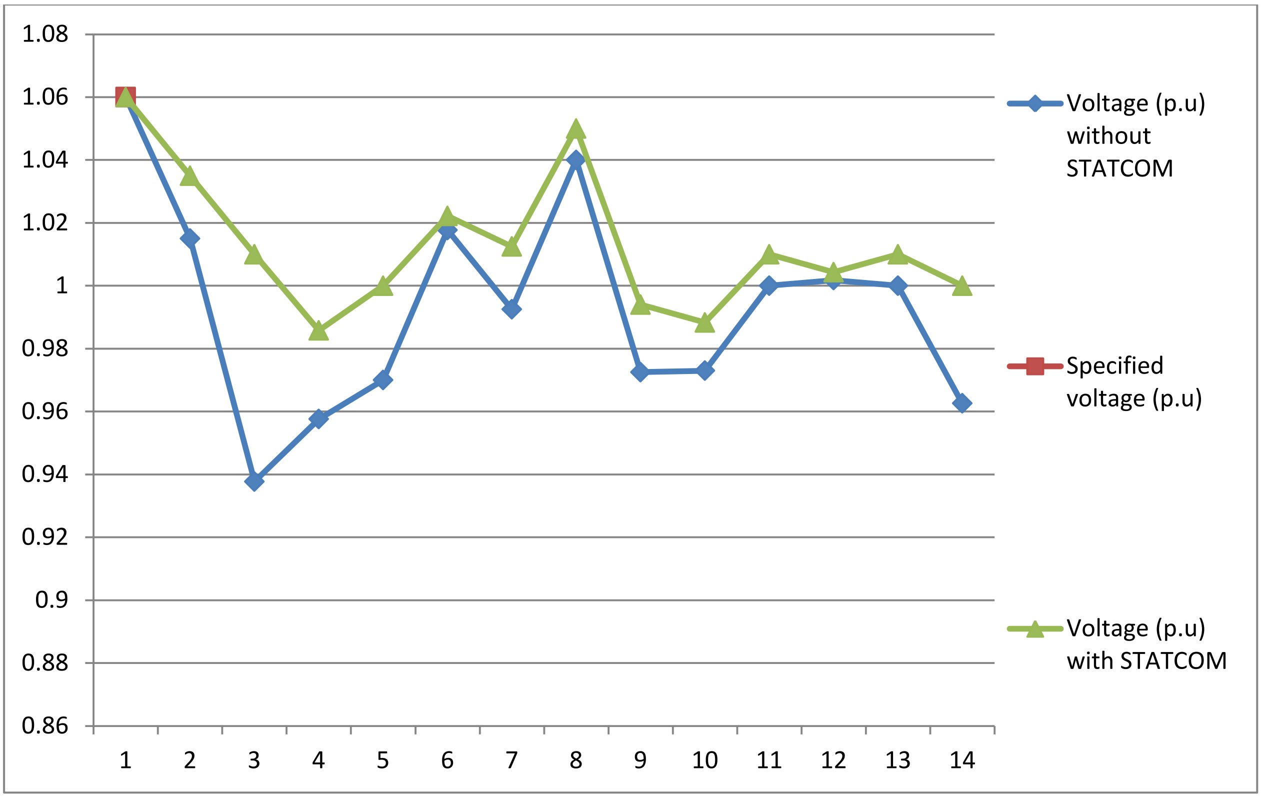

Figure no. 6.19 Voltage (p.u) with 40% increase in load

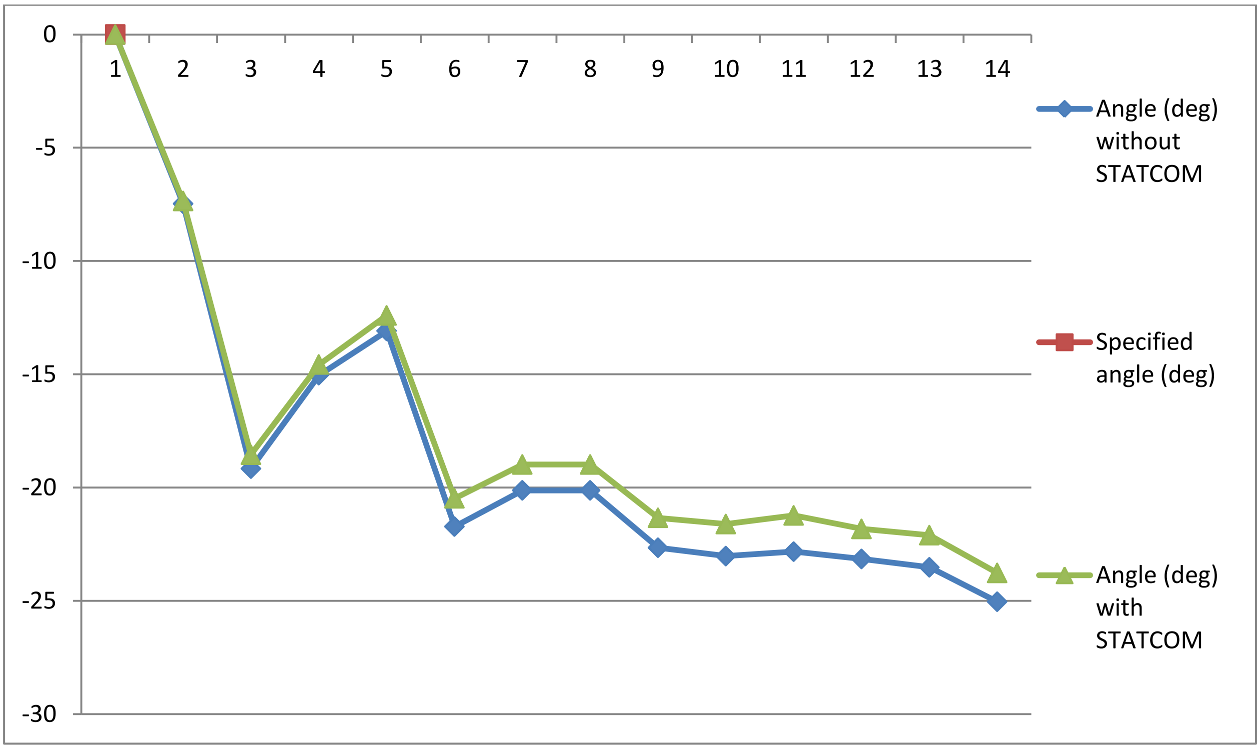

Figure no. 6.20 Angle (Deg) with 40% increase in load

45 percent change in load				
	Without STATCOM		With STATCOM	
Bus No.	V (p.u)	Angle (Deg)	V (p.u)	Angle (Deg)
1	1.06	0	1.06	0
2	1.005	-7.7129	1.025	-7.9439
3	0.9265	-20.0824	1.01	-20.2996
4	0.9527	-16.1044	0.9822	-15.9424
5	0.97	-13.8048	0.98	-13.6462
6	1.0073	-22.8297	1.0233	-22.3587
7	0.9844	-21.1472	1.0064	-20.715
8	1.03	-21.1472	1.04	-20.715
9	0.9645	-23.8241	0.9899	-23.2619
10	0.967	-24.2833	0.9844	-23.5826
11	1	-24.2458	1.01	-23.2317
12	0.986	-24.2742	1.0039	-23.8318
13	0.98	-24.4855	1.01	-24.1691
14	0.9482	-26.1633	1	-25.9857

Table no. 6.12 Results of 45 % increase in load

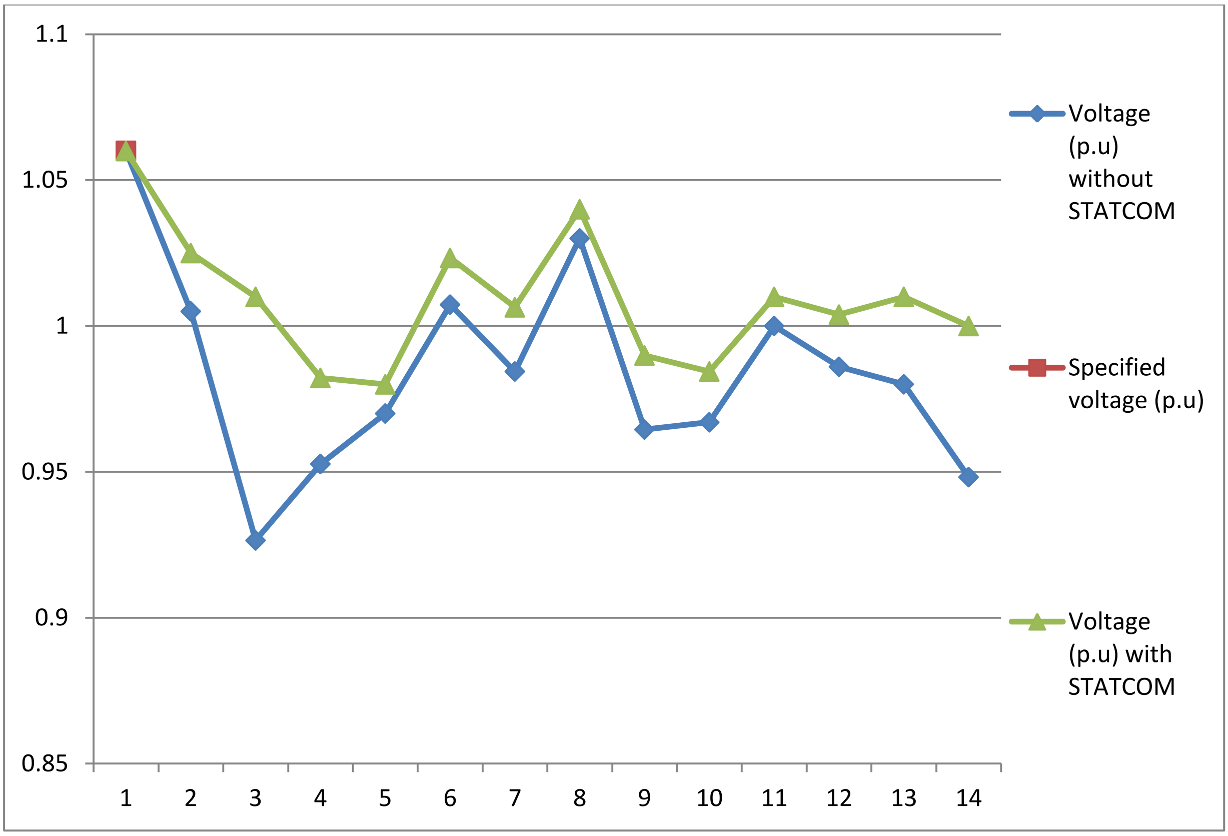

Figure no. 6.21 Voltage (p.u) with 45% increase in load

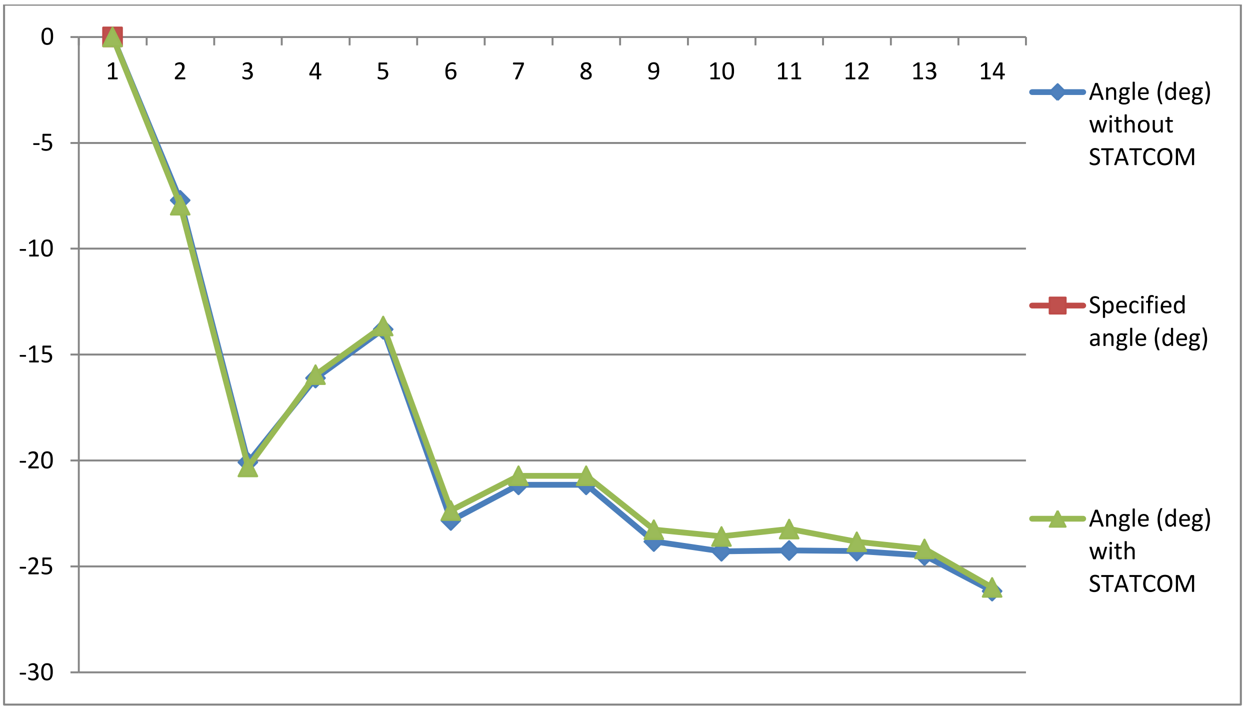

Figure no. 6.22 Angle (Deg) with 45% increase in load

50 percent change in load				
	Without STATCOM		With STATCOM	
Bus No.	V (p.u)	Angle (Deg)	V (p.u)	Angle (Deg)
1	1.06	0	1.06	0
2	1.005	-8.0795	1.025	-7.9439
3	0.9219	-20.913	1.01	-20.2996
4	0.9505	-16.7726	0.9822	-15.9424
5	0.97	-14.4079	0.98	-13.6462
6	1.002	-23.7952	1.0233	-22.3587
7	0.9798	-22.271	1.0064	-20.715
8	1.03	-22.0271	1.04	-20.715
9	0.956	-24.8345	0.9899	-23.2619
10	0.9546	-25.2169	0.9844	-23.5826
11	0.98	-24.9206	1.01	-23.2317
12	0.9832	-25.3575	1.0039	-23.8318
13	0.98	-25.7119	1.01	-24.1691
14	0.9423	-27.4156	1	-25.9857

Table no. 6.13 Results of 50 % increase in load

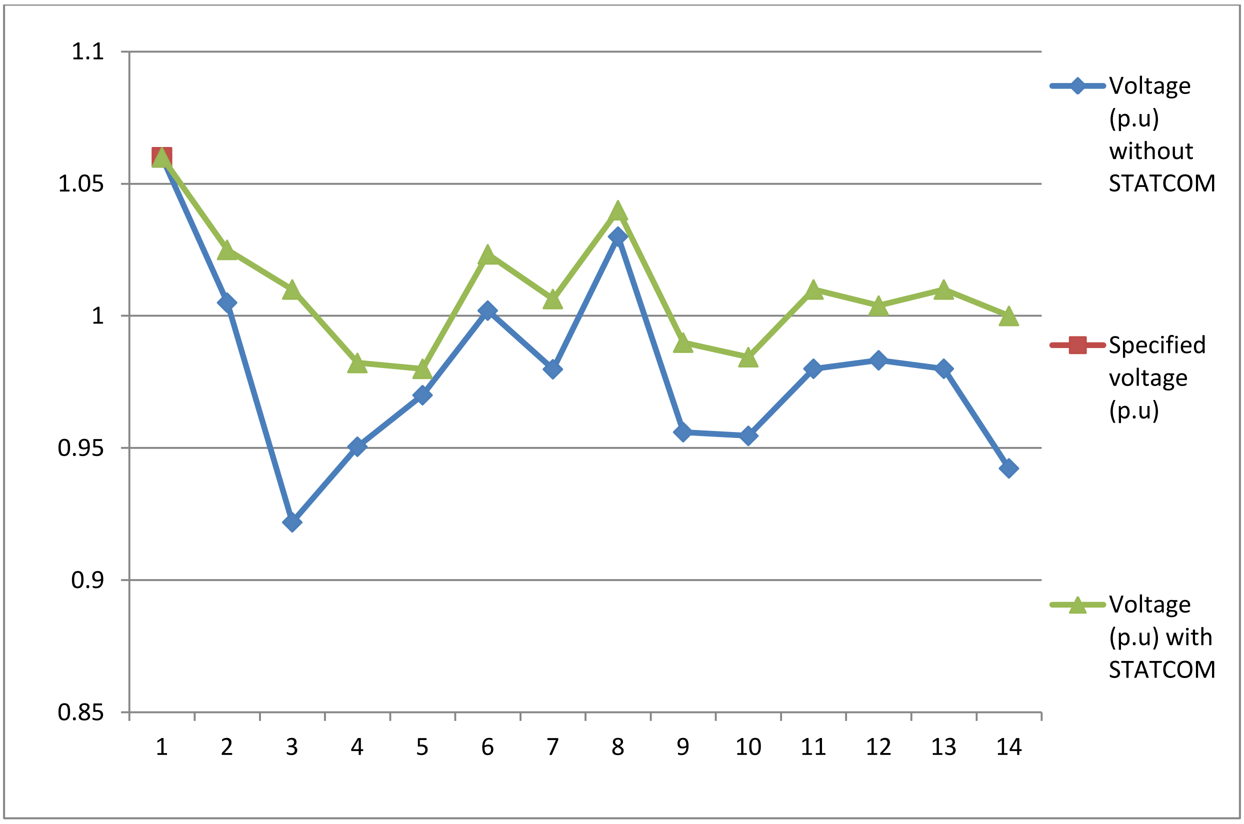

Figure no. 6.23 Voltage (p.u) with 50% increase in load

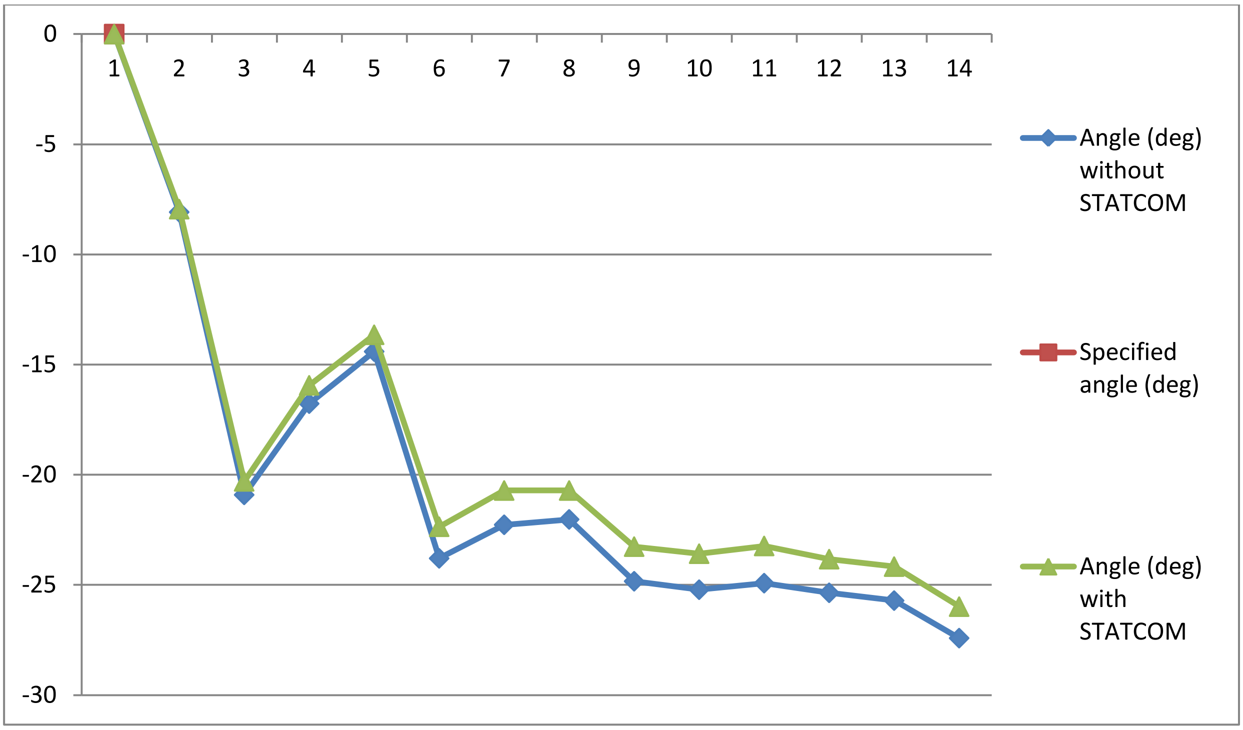

Figure no. 6.24 Angle (Deg) with 50% increase in load

6.3 Conclusion:-

The above tabulated results are shows the result of increasing load 0 to 25% with 5% interval. The 3,4,10, buses are identified weakest buses whenever increasing load 30% to 50% in terms of 5% interval voltage profile goes down and voltage regulation on will 3.5% to 9.5% and indentified weakest buses 3, 4, 5, 7, 9,10, 12, 13, and 14 buses. Which are maintain with in voltage limit (0.98.p.u or 1.0 p.u) by FACTS controller STATCOM.

CHAPTER 7

CONCLUSION AND FUTURE WORK

CONCLUSION

This project, proposed was tested load flow analysis Newton Raphson method for identification of weakest buses in IEEE-14 bus system by using MATLAB programming and optimal location for FACTS device STATCOM found out as voltage profile limit. The mathematical that describes its operation during steady state is non linear. For most practical situations the power network is a very large scale system, which **must be** reached by iteration required robust and efficient numerical technique. For several decades Newton-Raphson method with its quadratic convergence characteristics, has proved invaluable in solving the power flow. From the optimal location, injected power rating STATCOM by MATLAB programming, depend upon the voltage magnitude and phase angle as increasing load. A method to identify weakest buses, location and size of the device based on load demand or voltage profile limits. For continuation power flow given and results obtained have clear shown the effectiveness of FACTS device STATCOM in improving the transmission efficiency and capabilities of the system. It is clear from the analysis of the results that the shunt devices like STATCOM and SVC gives the best performance for improving voltage profile.

FUTURE WORK

The FACTS controller STATCOM uses for improving voltage profile and phase angle or reactive power in IEEE-14 bus system which is consist voltage source converter (VSC). It has been emphasised that all of the power electronics elements (i.e GTO or IGBT) produce harmonic distortion, which is an undesirable side effects as part of their operation. The various means of harmonic cancellation, such as switching control, multilevel configuration, three phase connection and filtering equipments. This harmonic distortion cancellation and improve voltage profile of large bus power system is a topic for future work.

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