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N-1 Contingency analysis in a Congested power system and enhance the voltage stability using FACTS Devices

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ABSTRACT

In a deregulated power systems environment, congestion management is one of the technical problem needs to maintain a system as stable condition. One of the objective functions in congestion management is N-1 contingency analysis. Using N-1 contingency analysis find out the worst line outage and analysis that line, maintain the whole system as stable after the line outage. Two types of Methodologies used in congestion Management are non-cost allowed methods and cost allowed methods. In this research work congestion is released by using cost allowed methods considering Flexible AC Transmission System (FACTS) Device such that TCSC (Thyristor controlled series Compensator) and UPFC (Unified Power Flow Controller) devices. The best location of FACTS device like TCSC and UPFC are found by using sensitivity based Eigen value analysis and the performance analysis has been worked out for IEEE14 test bus systems using Matrix laboratory (MATLAB)-Power System analysis toolbox (PSAT). The result shows that the proposed approach has a capability to enhance the Voltage stability, small signal stability and minimize the real power loss in the power systems network.

Keywords: Congestion Management, TCSC, UPFC, PSAT, Small Signal Stability, Voltage Stability, N-1 Contingency analysis

1. INTRODUCTION

In a regulated power system environment Generation, transmission, Distribution are controlled in a single company, but in a deregulated power system environment has entities like GENCOs (Power Generation Companies), TRANSCOs (Power Transmission Companies), DISCOs (Power Distribution Companies), ISO (Independent system operator), RESCO (Retailer). The ISO has the responsibility of ensuring the security and reliability of entire power system. The power transaction between the companies will create congestion in a transmission lines which may get overloaded. In Modern days power system had complicated networks. It has hundreds of generating power stations and substations. The electric power transfer in multi machine systems is constrained by line outage, generator outage, change in energy demands and uncoordinated transactions. In those objectives, N-1 contingency analysis is used to identify that mostly severed transmission lines and that lines are consider for analysis. That constraint limits a full utilization of a transmission lines. FACTS (Flexible Alternate Current Transmissions System) is the technology that offers the needed stability in the transmission systems. From the Literature survey contingency analysis done in various papers. After N-1 contingency analysis the system voltage is maintained stable [1]. Contingency ranking is worked out and find the worst line using PSAT [2]. Contingency analysis in a restructured power system is analyzed [3]. The ieee30 bus system is considered for contingency analysis using PSAT [4]. Continuous power flow method is used and voltage level is maintained stable [6]. IEEE 14 bus system is considered and contingency analysis is done with TCSC[10]. N-1 contingency is done using optimal transmission switching and voltage level maintained secured

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[11]. PSAT software and past synaptic scheme is analyzed [14]. N-1 contingency analysis in IEEE14 test bus system is done by using PSAT software and find out the worst line outage using that analysis. In the worst line outage case the system is unstable, by using sensitivity based Eigen value analysis find out the best location of the FACTS devices. Locate that FACTS Devices and maintained the system as stable.Recently some of the FACTS device has been applied in the power system for Voltage stability, small signal stabilities and transient stabilities. TCSC, UPFC devices are used to regulate the voltage. FACTs devices used to enhance the small signal stabilities, transient stability in the power systems. By using state matrix and Jacobian matrix the Eigen value can be calculated. The optimal location of TCSC, UPFC using sensitivity based Eigen value analysis plays a role to improve that stability. This paper presents the analysis of best location of TCSC, UPFC used to enhance the small signal stabilities, Voltage stability.

2. CONTINGENCY ANALYSIS IN POWER SYSTEM

Contingency analysis (CA) is also named as security analysis in the power system. Contingency analysis is to evaluate the power systems and find the overloads and problems that can happen in electrical network. Contingency analysis in power system is in abnormal condition. Due to contingency condition an entire system or some part of the systems coming under congestion. Contingency happens for unexpected opening of the power transmission lines. Generators tripping condition, Sudden changes in power generation, unexpected changes in loads. CA offers tools for analyzing, creating, managing, and reporting lists of contingencies and violations.

2.1. Types of Violations

Transmission Line contingencies and power generators contingencies are generally most common type of contingency. These contingency are mainly causes two major type of violations.

2.1.1. Low Voltage Violation

Low voltage violations occur at the buses. This indicates the voltage in the bus is below the limit. The specified values of the voltage in the buses are normally 0.8-1.1 p.u. If the voltages at the buses are falls below 0.8 p.u then the bus is named as low voltage bus. If the voltage is above 1.1 p.u the bus had a high voltage problem.

2.1.2. Line MVA Limits Violation

Contingencies occur in the power systems when the MVA rating of the transmission line exceeds specified rating. In the transmission line amplitude of current flow increases then these types of violations may happen. The power transmission lines able to withstand 125% of their MVA limit. If the current crosses the 80-90 % of the limit, it is declared as an alarm situation. Different types of corrective actions to solve this type of problems.

3. N-1 Contingency Analysis

Congestion may be occurs in the power systems due to line outage, generator outage, change in energy demands and uncoordinated transaction. In those objectives, N-1 contingency analyze is to identify that mostly severed transmission lines and that lines are consider for analysis.In the loss of any power system portion that has only one of the transmission apparatus or power plant tripped but not includes the bus bar and radial line. As per NERC standards the category is N-1 then the system is constant and there is no loss of demand and no cascading outages. This is the primary contingency. It is the planned or unexpected event. The primary contingency analysis (N-1) the term N is total no.of buses in power systems.

4. PROPOSED METHODOLOGY FOR STABILITY

The simulation is worked by using PSAT software to compute and plot the Eigen values with the participation factor of the power system. PSAT is the Matlab tool for power systems control and analysis.

PSAT used for

- Power Flow Analysis
- Continuous Power Flow Analysis
- N – 1 Contingency Analysis
- Optimization of power flow
  - ✓ Maximization of Social Welfare
  - ✓ Maximum Loading condition
  - ✓ Voltage Stability
  - ✓ Multi Objective Optimization
- Eigen Value Analysis
  - ✓ Small Signal Stability Analysis
  - ✓ Power Flow Sensitivity Analysis
- Time Domain Simulation (Transient Stability Analysis)

All these actions done by GUIs (Graphical user interfaces) and Simulink-based library offers a user friendly tool for power system design. Fig.1. shows the synoptic scheme of PSAT toolbox[14]. Once the

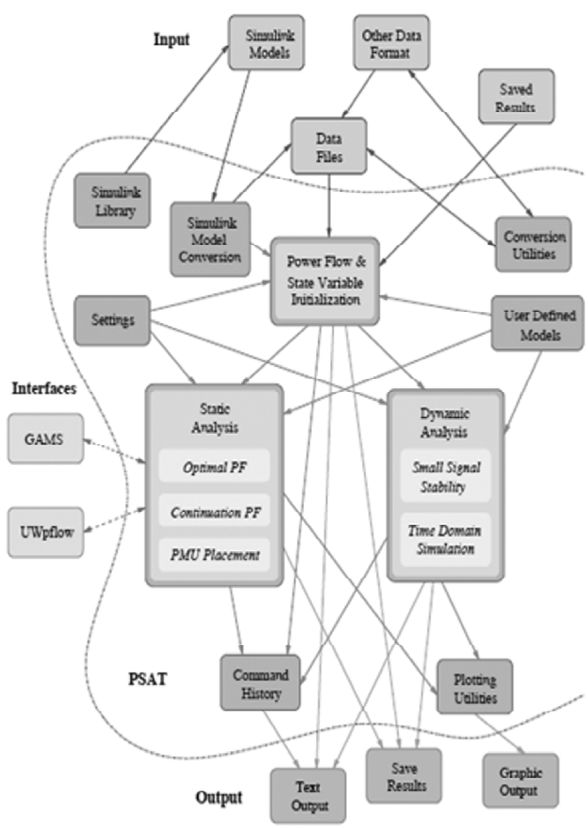

Figure 1: PSAT Synoptic Scheme

power flow in electric network has been solved, the procedures are used to find the best location of TCSC, UPFC for small signal stability analysis based on sensitivity based Eigen value analysis. The proposed methodology used to shift the Eigen values from positive real axis to negative real axis. It provides more damping to reduce oscillations and high precision results in determining the stability of the system.

5. OBJECTIVE FUNCTIONS

Below objective functions considered in congestion management problem

5.1. Small Signal Stability analysis

Small signal stability defines due to small disturbances the power system is to maintain synchronism. A DAE (Differential Algebraic Equation) set is used for the small signal stability in PSAT in the form:

$$x = f(x, y) \tag{1}$$

$$0 = g(x, y) \tag{2}$$

Here, x = state variable vector, y = algebraic variable vector.

5.2. Voltage Stability analysis

The voltage level is to maintain as stable and within the limit. Voltage range is in between 0.8 and 1.1 p.u, the value of objective functions is equal to 1. If the voltage level is outside the range means the value decreases exponentially with the voltage deviation.

$$VS = \begin{cases} 1 & , \quad if \;\; 0.8 < Vb < 1.1 \\ \exp\left(\mu\left|1 - Vb\right|\right), & otherwise \end{cases} \tag{3}$$

5.3. Minimization of real power loss

The objective function considering minimization of real power loss as it can be represented as given inequation.

$$P_{loss} = \sum_{i=1}^{N_L} gi, j\left(V_{i^2} + V_{j^2} - 2\ V\ _iV_j\ \ Vj\right)\cos\left(\delta_i - \delta_j\right) \tag{4}$$

where

V_i is the voltage magnitude at bus

gi, j is the conductance of line i-j

δ_i is the voltage angle at bus i

NL is the total number of transmission lines

6. CONCEPTS OF EIGEN VALUE ANALYSIS

The power system stability is determined using Eigen-values. Non-oscillatory modes are related with real Eigen values and oscillatory modes are related with complex Eigen values. The stability of the power system represented with Negative Eigen values. The Instability of the power system represented with Positive Eigen values.The real part of the Eigen values represented with damping. The imaginary part of the Eigen values represented with frequency of oscillations.

The Eigen values complex pair:

$$\lambda = \sigma + j\omega \tag{5}$$

The frequency of the oscillation is signified by:

$$f = \omega/2\pi \tag{6}$$

The damping ratio is denoted by

$$\Leftrightarrow = -\sigma/\sqrt{\sigma^2 + \omega^2} \tag{7}$$

The rate of the decay is concluded through the damping ratio.

The damping in the power system is calculated by using the parameters σ and ω. The main factors used to calculate damping are frequency of oscillation and damping ratio. Damping ratio is more means the system will give more damping to oscillate.

7. PROCEDURES IN STABILITY OF THE POWER SYSTEM

Steps

1: PSAT simulation model needs to prepare.

2: NR(Newton Raphson) power flow is to run.

3: Time domain simulation is to run.

4: Eigen value analysis is to run.

5: Positive Eigen values needs to check.

6: Weakest bus of the power system found based on positive Eigen values.

7: In the weakest bus the FACTS devices are applied and parameters of FACTS devices needs to tune

8: Again NR power flow and time domain simulation needs to run.

9: Positive Eigen values of the power system needs to check.

10: If the positive Eigen values available means continue the Process from 7-9.

11: The positive Eigen values are not available means the system is maintained as stable.

12: The process needs to end

8. POWER SYSTEM STUDY IN IEEE14 BUS TEST SYSTEM

The IEEE14 bus test system modeled in the PSAT toolbox is in the fig 2. IEEE 14 bus test system consists of 5 generator units, 14 numbers of transmission lines, 11 numbers of static load and 4 numbers of transformer. Base MVA is considering as 100 and base voltage in the system is 69KV.

9. CONGESTION MANAGEMENT IN THE POWER SYSTEM AND RESULTS DISCUSSION

Under normal loading condition the system is in stable condition. If the demand is increased the loads also increased, In that overloading condition the system gets congested. In this case IEEE 14 bus system gets overloaded by connecting excess loads on the buses 9, 10, 11, 14 the system is get congested, In this Congested overloaded power system N-1 Contingency analysis is done and the results are tabulated below in Table 1.

While running the N-1 Contingency analysis for the line outage 6-11and 8-7 will give a feasible output as given in the table 1. When the line outage happens in the remaining line there will be an impact in line 6-11 and 8-7 abruptly which given an unfeasible result. From this report the Transmission line 6-11 selected as a worst case line and that line considered for N-1 contingency analysis.

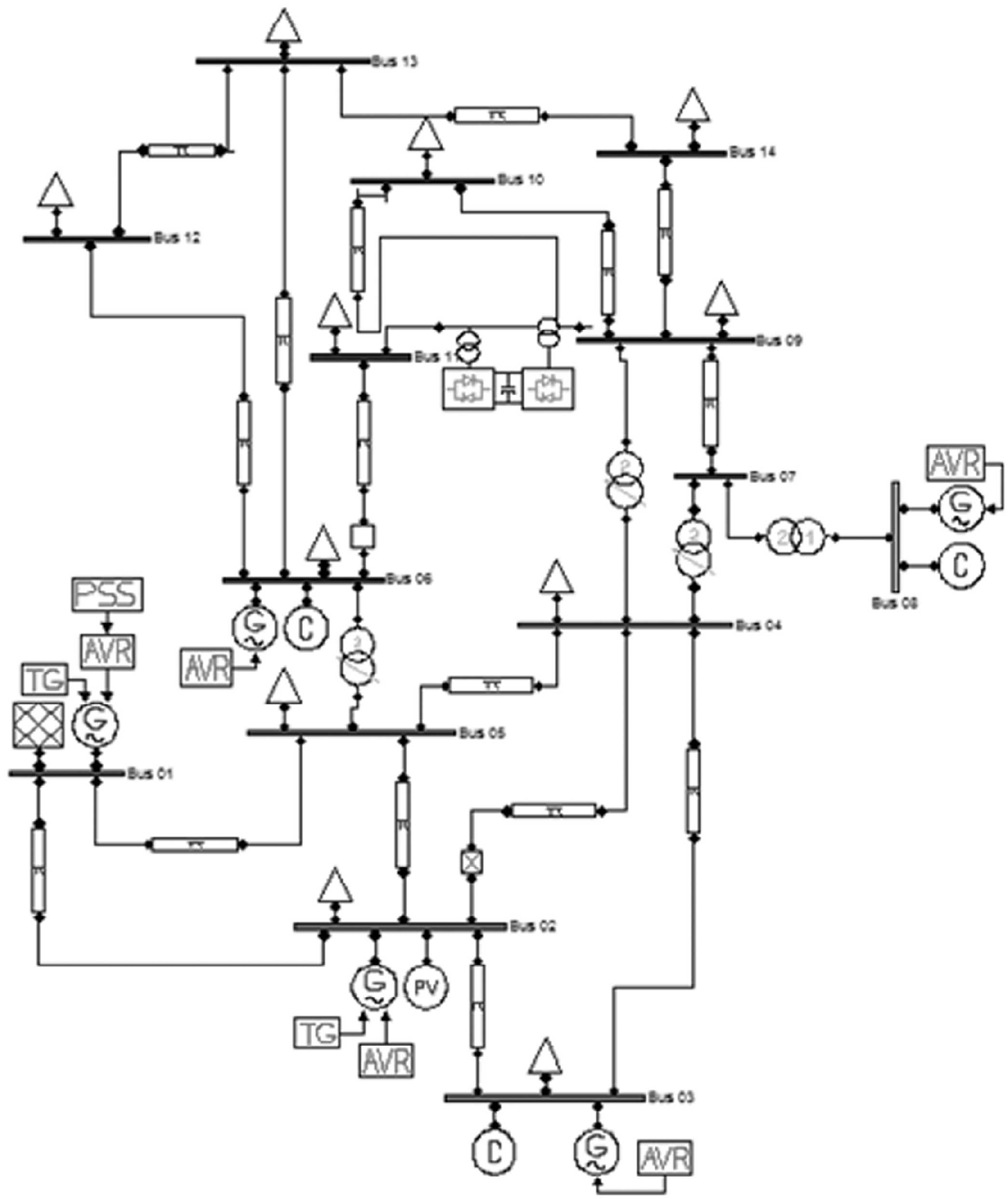

Figure 2: PSAT model of IEEE 14 bus test system

Table 1
N-1 Contingency analysis report

Line	*Outage of this line*	*Worst case line outage*	*Pij base [p.u.]*	*Pij max [p.u]*	*Sij base [p.u]*	*Sij max [p.u]*
2-5	Unfeasible	6-11	0.932	0.787	0.965	0.802
6-12	Unfeasible	6-11	0.222	0.251	0.241	0.266
12-13	Unfeasible	8-7	0.130	0.144	0.143	0.163
6-13	Unfeasible	8-7	0.640	0.717	0.754	0.814
6-11	Feasible	8-7	0.298	0.403	0.434	0.620
11-10	Unfeasible	6-11	0.233	0.052	0.348	0.059
9-10	Unfeasible	8-7	0.083	0.040	0.091	0.145
9-14	Unfeasible	6-11	0.263	0.136	0.266	0.138

(*contd...*)

(*Table 1 contd...*)

Line	*Outage of this line*	*Worst case line outage*	*Pij base [p.u.]*	*Pij max [p.u]*	*Sij base [p.u]*	*Sij max [p.u]*
14-13	Unfeasible	8-7	0.274	0.326	0.335	0.400
7-9	Unfeasible	8-7	0.882	0.816	1.044	0.840
1-2	Unfeasible	6-11	3.491	2.718	3.533	2.845
3-2	Unfeasible	6-11	1.274	1.065	1.274	1.079
3-4	Unfeasible	8-7	0.125	0.022	0.400	0.377
1-5	Unfeasible	6-11	1.622	1.287	1.653	1.289
5-4	Unfeasible	8-7	0.950	0.781	0.956	0.802
2-4	Unfeasible	6-11	1.166	0.995	1.192	1.003
4-9	Unfeasible	8-7	0.351	0.361	0.383	0.395
5-6	Unfeasible	6-11	1.317	0.994	1.368	0.995
4-7	Unfeasible	8-7	0.882	0.816	0.886	0.838
8-7	Feasible	6-11	0.000	0.195	0.722	0.823

9.1. Outage of Line 6-11

At the time of Line outage 6-11 the system is get unstable condition. The low voltage limitation at bus 11 and 4nos of Line MVA Limits Violations at bus 2,3,6 and 8.By improving the system FACTS devices used to maintain a system as stable. The location of FACTS devices found from sensitivity based eigen value analysis.

9.1.1. Small signal stability analysis

The Eigen values analyses are taken after the time domain simulations for over loading condition. The results are shown below table 2.It shows that positive Eigen value in the system is two and the system is now in unstable condition due to line 6-11 outages. To maintain a small signal stability to apply FACTS devices in the suitable place between buses 10-11 from the sensitivity based eigen value analysis. The Results for applying TCSC and UPFC device are tabulated, from the results the positive eigens are reduced from 2 to 0 and negative eigens are increased. So the system is maintained stable by using FACTS devices.

9.1.2. Voltage stability analysis

From the below fig 3, the voltage level in the buses 9, 11 and 10 are low as compare with remaining buses. Due to over loading condition the voltage level of the bus 11 affected, voltage level reaches 0.78 p.u at line Outage 6-11. Figure 3 and 4 shows the voltage profile line outage without FACTS devices.

Table 2
EIGEN VALUE ANALYSIS OF THE SYSTEM Line outage case and With FACTS Devices

	Line Outage 6-11	*With TCSC*	*With UPFC*
Dynamic Order	58	60	61
Buses	14	14	14
Positive Eigens	2	0	0
Negative Eigens	55	59	61
Complex Pairs	12	13	12
Zero Eigens	1	1	0

By locating the TCSC device between bus10-11 the voltage is maintained stable and which is in the limit 0.8p.u to 1.1p.u. Fig 5 and 6 shows the stabled voltage by using TCSC device.

By locating the UPFC device between bus10-11 the voltage at bus 11 is maintained stable and which is in the limit 0.8p.u to 1.1p.u. Fig 7 and 8 shows the stabled voltage by using UPFC device. Table 3 shows the compared voltage level Line outage case and with FACTS devices. From the table UPFC provides a best result compared TCSC device.The voltage is maintained stable.

9.1.3. Minimization of real power loss

By using FACTS devices the real power and reactive power losses are minimized the results are shown in the table 4. The summary report includes total load and generation with losses. From the results UPFC device had a good result compared with TCSC device.

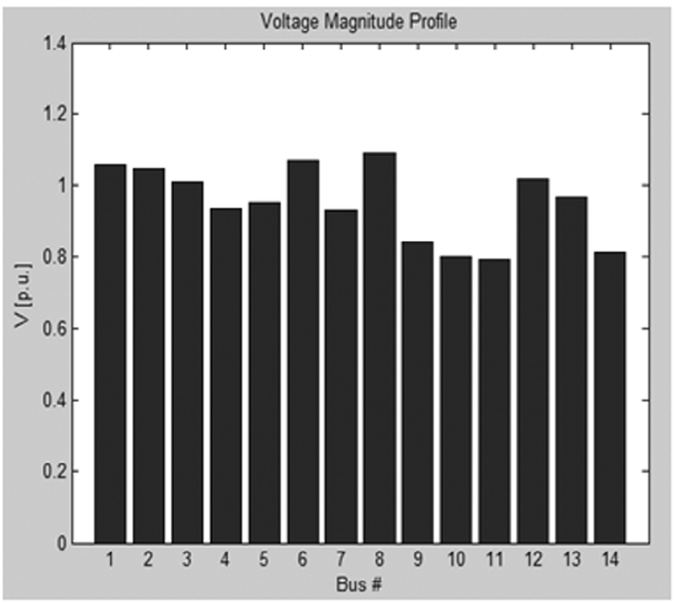

Figure 3: Voltage Profile at line Outage 6-11

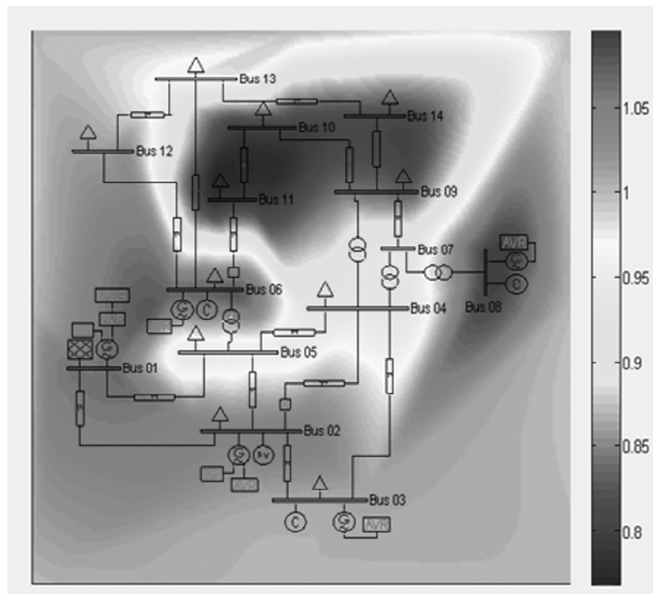

Figure 4: 2D View of Voltage Profile at line Outage 6-11

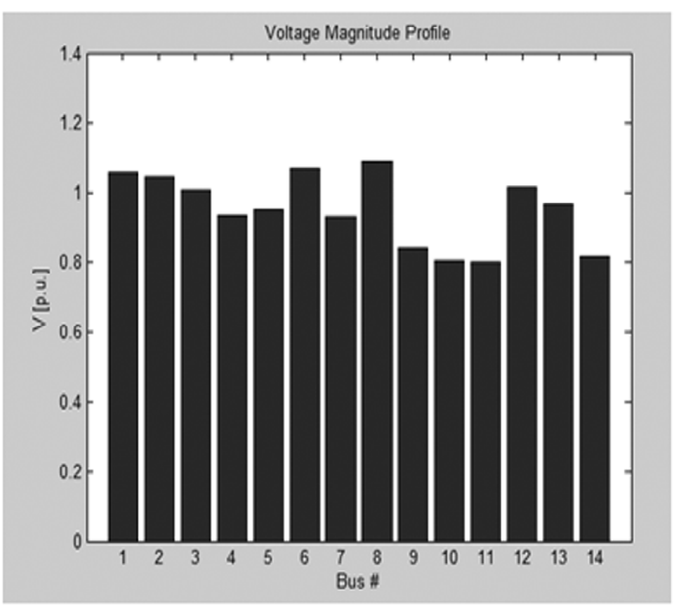

Figure 5: Voltage Profile with TCSC device

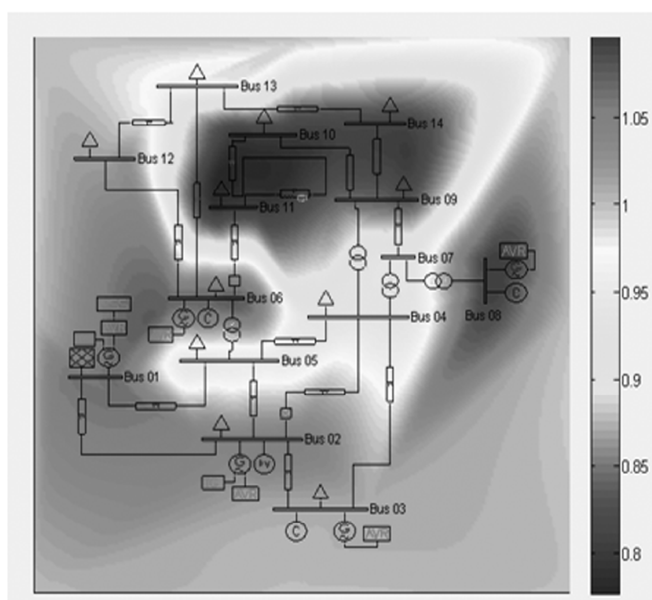

Figure 6: 2D View of Voltage Profile with TCSC device

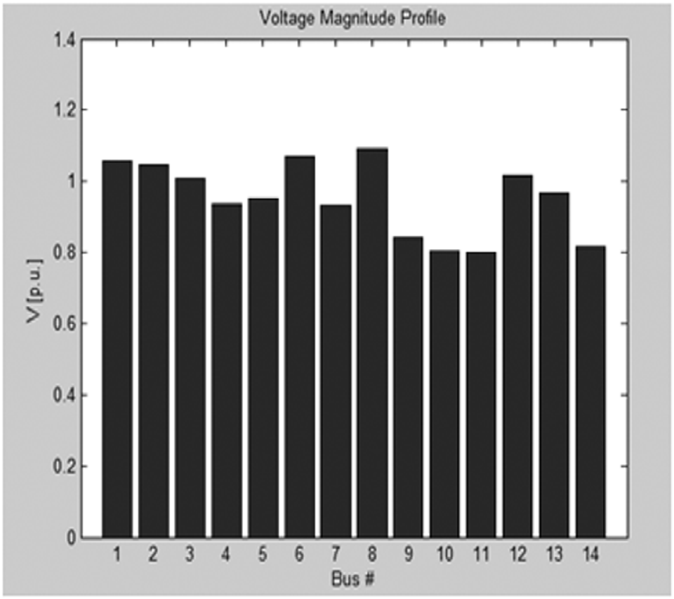

Figure 7: Voltage Profile with UPFC device

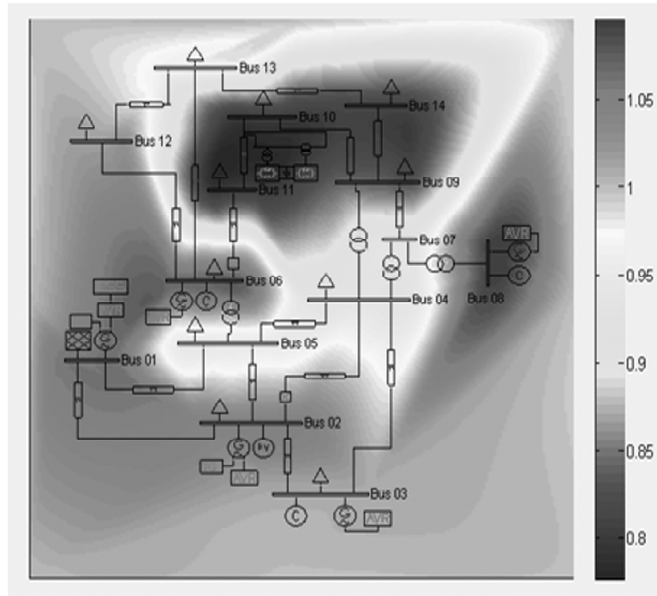

Figure 8: 2D View of Voltage Profile with UPFC device

Table 3
Voltage level comparison WITHOUT AND with FACTS

Bus Number	*Line Outage 6-11 [p.u.]*	*Voltage at each bus with TCSC [p.u.]*	*Voltage at each bus with UPFC [p.u.]*
1	1.06	1.06	1.06
2	1.045	1.045	1.045
3	1.01	1.01	1.01
4	0.9367	0.936	0.9368
5	0.953	0.953	0.9531
6	1.07	1.07	1.07
7	0.9328	0.933	0.933
8	1.09	1.09	1.09
9	0.8401	0.8403	0.8404
10	0.8020	0.8024	0.8024
11	0.7807	0.8014	0.8021
12	1.016	1.0163	1.016
13	0.9682	0.9683	0.9683
14	0.8146	0.8147	0.8148

Table 4
Summary report with and without FACTS

Summary Report	*Line Outage 6-11*	*With TCSC*	*WithUPFC*
Total Power Generation			
Real Power [p.u.]	5.5112	5.4809	5.4752
Reactive Power [p.u.]	4.4735	4.4139	4.3826
Total Loads			
Real Power [p.u.]	4.846	4.846	4.846
Reactive Power [p.u.]	1.7372	1.7372	1.7372
Total Power Losses			
Real Power [p.u.]	0.6652	0.6348	0.6291
Reactive Power [p.u.]	2.7363	2.6767	2.6454

From results in the congested power system the N-1 contingency analysis are done and the worst line outage is found that is line 6-11.That line 6-11 considered for N-1 contingency analysis and using FACTS devices that worst line case also maintained as stable condition.

10. CONCLUSION AND FUTURE WORK

IEEE14 bus test system taken here and N-1 contingency analysis will be done and worst case line found out from that test bus system. That worst line considered here for N-1 contingency analysis. Line outage case the system is in unstable by using FACTS Devices like TCSC and UPFC the worst case system is maintained as stable. The location of FACTS devices found sensitivity based eigen value analysis. The small signal stability is maintained in the power system by changing the positive eigen value two to zero using TCSC and UPFC devices. From the graphs the voltage level of the power system maintained as stable, voltage levels are within the limit when TCSC and UPFC is used. The Eigen value analysis has been carried out for overloading condition and maintainsthe small signal stability, Voltage stabilityand Power losses are minimized using PSAT (Power System Analysis Tool) software. The future work can be carried out using computational algorithms like PSO, Neural network, Firefly algorithm, ACO etc.

REFERENCES

[1] Haoyu Yuan, Fangxing Li “Hybrid voltage stability assessment (VSA) for N 1 contingency” ELSEVIER Electric Power Systems Research 122 (2015) 65-75.

[2] N.K. Sharma, Sudhir P. Phulambrikar, “Contingency Ranking and Analysis using PSAT” Innovative Systems Design and Engineering Vol. 4, No. 6, 2013.

[3] Ch. Krishna Chaitanya, J. Krishna Kishore “Contingency Analysis In Restructured Power System” International Journal of Innovative Research and Development, Volume 2, Issue11, 2013.

[4] Sushil Kumar 1, Harmeet Singh 2 “Contingency Analysis of 30 Bus Power SystemUsing PSAT” IJRASET journal, Volume 3 Issue V, May 2015.

[5] M. K. Maharana, Samrat Malakar “Sensitivity Based Network Contingency Ranking Using Newton RaphsonPower Flow Method” IJSET journal (ISSN: 2277-1581)Volume No. 4 Issue No. 2, pp. 45-49 01 Feb. 2015.

[6] M. Alinezhad and M.A. Kamarposhti “Static Voltage Stability Assessment Consideringthe Power System Contingencies using Continuation Power Flow Method”, International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering Vol. 3, No. 2, 2009.

[7] S.A. Hosseini, N. Amjady, M. Shafie-khah “A new multi-objective solution approach to solve transmissioncongestion management problem of energy markets” ELSEVIER Applied Energy 165 (2016) 462-471.

[8] Akanksha Mishra, Venkata Nagesh Kumar Gundavarapu “Line utilisation factor-based optimalallocation of IPFC and sizing using fire fly algorithm for congestion management” IET Generation, Transmission & Distribution Accepted on 16th September 2015.

[9] M. Esmaili, H.A. Shayanfar, Ramin Moslemi “Locating series FACTS devices for multi-objective congestionmanagement improving voltage and transient stability” ELSEVIER 236 (2014) 763-773.

[10] Y. Venkatrao, J. Srinivasarao “CONTINGENCY ANALYSIS IN 14-BUS POWER SYSTEM WITH TCSC” IJAREEIE journal Vol. 4, Issue 11, November 2015.

[11] M. Khanabadi, H. Ghasemi, and M. Doostizadeh “Optimal Transmission Switching Considering Voltage Security and N-1 Contingency Analysis” IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 28, NO. 1, FEBRUARY 2013.

[12] Bharadwaj R. Sathyanarayana, and G.T. Heydt, “Sensitivity-Based Pricing and Optimal Storage Utilization in Distribution Systems” IEEE TRANSACTIONS ON POWER DELIVERY, VOL. 28, NO. 2, APRIL 2013.

[13] K. Singh, N.P. Padhy, and J. Sharma “Influence of Price Responsive Demand Shifting Bidding on Congestion and LMP in Pool-Based Day-Ahead Electricity Markets” IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 26, NO. 2, MAY 2011.

[14] Federico Milano, L.Vanfretti, and J.C. Morataya “An Open Source Power System Virtual Laboratory: The PSAT Case and Experience.” IEEE Transactions, Vol. 51, No. 1, February 2008.

[15] S. Hajforoosh1 S.M.H. Nabavi “Coordinated aggregated-based particle swarm optimisation algorithm for congestion management in restructured power market by placement and sizing of unified power flow controller” IET Sci. Meas. Technol., 2012, Vol. 6, Iss. 4, pp. 267-278 267.

[16] P.K. Tiwari Y.R. Sood "Efficient and optimal approach for location and parameter setting of multiple unified power flow controllers for a deregulated power sector" IET Gener. Transm. Distrib., 2012, Vol. 6, Iss. 10, pp. 958-967.

[17] A. Kumar, Charan Sekhar "Comparison of Sen Transformer and UPFC for congestion management in hybrid electricity markets" ELSEVIER, Electrical Power and Energy Systems 47 (2013) 295-304.

[18] Nima Amjady, Mahmood Hakimi "Dynamic voltage stability constrained congestion management framework for deregulated electricity markets" ELSEVIER, Energy Conversion and Management 58 (2012) 66-75.

[19] A.Yousefi, T.T. Nguyen, H. Zareipour, O.P. Malik "Congestion management using demand response and FACTS devices" ELSEVIER, Electrical Power and Energy Systems 37 (2012) 78-85.

[20] S.M.H. Nabavia, A. Kazemia, M.A.S. Masoumb "Social welfare maximization with fuzzy based genetic algorithm by TCSC and SSSC in double-sided auction market" ELSEVIER, Scientia Iranica D (2012) 19 (3), 745-758.

[21] M. Esmaili, N. Amjady, H.A. Shayanfar "Multi-objective congestion management by modified augmented e-constraint method" ELSEVIER, Applied Energy 88 (2011) 755-766.

[22] Seyed Abbas Taher, Muhammad Karim Amooshahi "Optimal placement of UPFC in power systems using immune algorithm" ELSEVIER, Simulation Modelling Practice and Theory 19 (2011) 1399-1412.

[23] S. Visalakshi, S. Baskar "Decentralized Congestion Management Using Modified NSGA-II" Springer Link, Arabian Journal for Science and Engineering August 2011, Volume 36, Issue 5, pp. 827-840.

[24] MohsenGitizadeh, M. Kalantar "Genetic algorithm-based fuzzy multi-objective approach to congestion management using FACTS devices" Springer Link, Electrical Engineering February 2009, Volume 90, Issue 8, pp. 539-549.

[25] Prabha kundur "Power system stability and control". Tata McGraw Hill ISBN-13;978-0-07-063515-9

[26] Narain G. Hingorani, Laszlo Gyugyi "Understanding FACTS". ISBN 81-86308-79-2

[27] K. Vijayakumar "Multi objective Optimization Methods for Congestion Management in Deregulated Power Systems" Journal of Electrical and Computer Engineering Volume 2012, Article ID 962402, 8 pages doi:10.1155/2012/962402