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Contingency Analysis in Deregulated Power System Using Facts Device (TCSC)

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Abstract:- Contingency Analysis is one of the basic power system studies. It is the protection of the system operation under the loss of one or more of the major system components. To calculate the violations Contingency Analysis is the most preferable choice. Power system engineers use contingency analysis to foretell the result of any component failure. Contingency analysis is a computer application that uses a simulated model of the power system to judge the results and to calculate any overloads and to take necessary actions to keep the power system secure and reliable. To reduce the power flows in heavily loaded lines Flexible AC Transmission System devices are the most alternativeequipment. It results the low system loss, increasing the stability of the network and increased load ability. This paper shows a 24-Bus power system which gives the information about the contingencies and violations.

Keywords:- Contingency Analysis, LODFs, PTDFs, FACTS devices, Single Contingency, Multiple Contingency.

I. INTRODUCTION

In Deregulated power system security is the most difficult work because of the great rivalry in power market and open approach network. The security estimation is the most challenging task as it gives the knowledge about the system state in the event of contingency. In the stage of designing and operation of a power system the main thing in all controlling areas is to provide the protection. It occurs due to any outage of any equipment leads to transient instability of the system and can be checked without waiting by the usage of protective devices put in place.

Outage of second line can cause the small change in the power flow on the line which is used by LODF.

LODFs are only used to decide the change in the MW flow consider similarities to the pre-contingency flow.

LODFs are approximately not influence the flows but they depend on the accepted network topology[6]. Power Transfer Distribution Factors show the linearized influence on transfer of power.

Flexible Alternative Current Transmission System (FACTS) devices are used to something in an effective way as one of such technology which can make something smaller the transmission congestion and control to more suitable use of the existing grid infrastructure. Many different issues connected with the usage of FACTS devices are their modeling, approximate size, optimal location, settings and cost.

Thyristor Controlled Switching Compensator (TCSC) is connected in series with transmission lines and which provide not interrupted and changeable control of line impedance with much faster response compared to conventional control devices. To determine the suitable location for FACTS devices a loss sensitivity method is used [5].

II. CONTINGENCY ANALYSIS

Contingency Analysis can results the classification of the power system into two states those are secure and insecure states.When number of contingencies is more contingency analysis took more time consuming process. Contingencies are known as possible causing harmful disturbances that exist in the control state of a power system.Contingencies referring to interrupts like generator, transformer and transmission lines outages will cause quick and big changes in both the outline and the state of the system [3] [12]. The contingency list is choosing by the help of contingency ranking.Contingencies may result in extreme violations of the operating compulsions.

The main objective of contingency analysis is to find out the line overloads or voltage violations under such contingencies and to start complete measures thatare make necessary to mitigate these violations.Voltage violations are caused by single or multiple contingencies andthose are called as voltage contingencies.AC Load flow method is more accurate compared to DC Load flow method [1]. In contingency analysis coming to the outages single outage case is studied in 60 seconds and for thousand outages it would took 16 minutes. Contingency Analysis is studied in two types of tools those are off-line analysis and on-line analysis [12]. In contingency analysis two types of contingencies are there those are Generator contingency and Line contingency. These are occurs due to two types of violations.

- Low Voltage Violations.
- Line MVA Limit Violations [2].

Low voltage violations are occurs due to the insufficient reactive power. These are occurs at the buses. Low voltage means voltage falls below 0.95 p.u at the bus. High voltage means voltage rises above 1.05 p.u at the bus. In case of Line MVA limit violations occurs in the system when the line MVA rating go beyond its actual rating. In general the lines are designed for able to withstand 125% of its MVA limit.

III. PRIMARY CONTINGENCY (N-1) ANALYSIS

A single contingency condition is or N-1 is the loss of any power system part that has only one of the transmission equipment or powerplant tripped but notincludes the bus bar and radial line. In general the state of the system is determined on the basisof ability to meet the expected demand under all levels of contingencies.In power system loss of one or more system parts that happen first that is called as primary contingency. It may be a planned event or unplanned event [4]. In primary contingency analysis (N-1) the term N is given as the totalnumber of components in the power system. In this state the system is in secure state.

IV. MULTIPLE CONTINGENCY (N-1-1) ANALYSIS

After primary contingency the secondary contingency will occur and it is unplanned event.A ordered series of events consisting of the initial loss of a transmission component or single generator (primary contingency), followed by the system changes, followed by another loss of a transmission component or single generator (secondary contingency) [4].

As per NERC Transmission Planning Standards the electric system performance needs the some contingency states those are, caused by the event in the loss of single element, caused by event in the loss of two or more elements, great incidents resulting in two or more elements take away from service [10].N-1-1means that two components have failed, it is normally comparative bad than having only one fail.

- To explain a secure base case condition need to stop and changes are necessary.
- To make clear of a secure primary contingency base case need to examine and modifications are required.
- Automatically explain the couple of secondary (N-1-1) contingencies.
- Inclusive power systems changes of N-1-1 contingencies are automatically analyze and summary reports are created for documentation.

Overview of N-1-1 Analysis process:

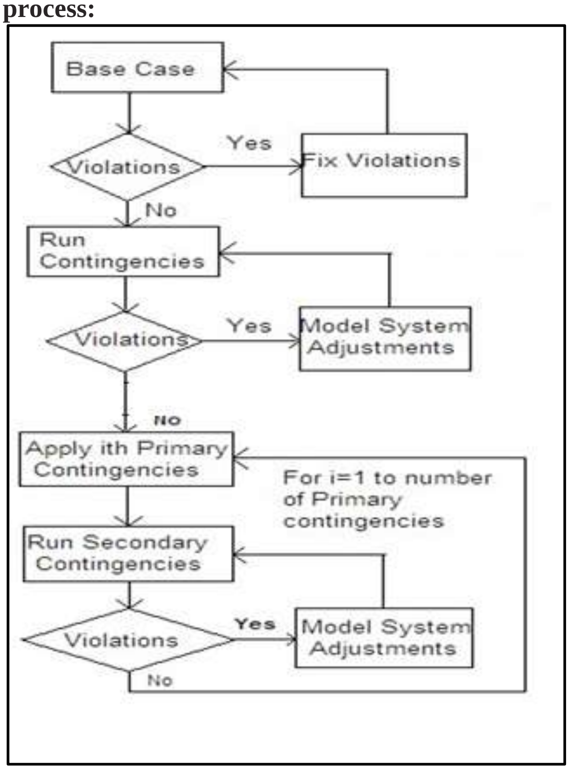


Figure 1 – Multiple Contingency Analysis process

In the corrective action mode the system changes between the first and second primary contingencies are performed. In corrective action mode each couple of secondary (N-1-1) contingencies a group of system changes is decided. In case of single contingency solution and also for primary and multiple contingency solutions the corrective action analysis is run[10] [11].

V. STATIC MODELLING OF FACTS DEVICES

FACTS as Flexible Alternating Current Transmission Systems incorporating power electronic-based and other static controllers to improve the quality of controllability and increase power transfer capability. FACTS devices are can be broadly divided as shunt, series, combined series-series and combined series-shunt. Some benefits of FACTS devices are

- Increase the loading of lines to their thermal capabilities.
- Reduce the power flows inheavily loaded lines.
- Improve the stability, reliability, quality of supply, availability and load ability of the power system.
- Reduce the reactive power flows and loop flows.
- Limits the short circuit currents and overloads.

The main device used here is Thyristor Controlled Series Capacitor (TCSC) for becoming better of transfer capability.

Thyristor Controlled Series Compensator:

TCSCs are connected in series with the lines. By inserting the series capacitance the voltage profile is improved in the line. The net reactance is to make smaller and control to increase in power transfer ability. A basic set up of a TCSC is shown in figure 2 [8] [9].

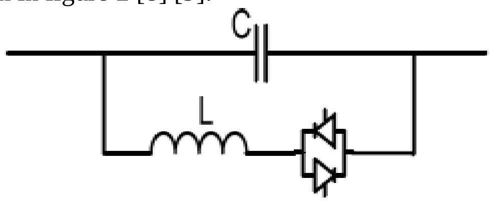


Figure 2: Basic TCSC scheme

The impedance of this circuit is that for a parallel LC circuit and is given by:

$$X_{TCSC}\ (\alpha) = \frac{X_c X_t(\alpha)}{X^l(\alpha) - X_c}$$

Where

$$X_l(\alpha) = X_L \frac{\pi}{\pi - 2\alpha - \sin\alpha}$$

α is the firing angle,

X_L is the Inductor reactance and $X_l$is the Inductor effective reactance at firing angle α and is very small thus:

$X_L \leq X_l(\alpha) \leq \infty$

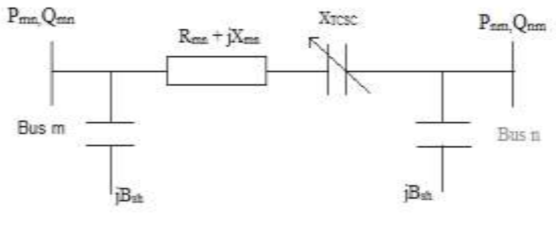


Figure 3: TCSC Model

Let the complex voltages at bus mand bus NbE denoted as $V_m\angle\delta$mand $V_n\angle\delta n$, respectively. The complex power flowing from bus mto bus *n*can be expressed as

$S_{mn}^* = P_{mn} - jQ_{mn} = V_m^* I_{mn}$

$= V_m^*[(V_m - V_n)\ Y_{mn} + V_m\ (jB_{sh})]$

$= V_m^2\ [G_{mn} + j\ (B_{mn} + B_{sh})] - V_m^* V_n\ (G_{mn} + jB_{mn})$

Where

$G_{mn} + jB_{mn} = 1/(R_L + jX_L - jX_{sh})$

Equating the real and imaginary parts of the above equations the expressions for real and reactive power flows can be written as

$P_{mn}=V_m^2G_{mn}-V_mV_nG_{mn}\cos(\delta_m-\delta_n)-V_mV_nB_{mn}\sin(\delta_m-\delta_n)$
$Q_{mn}=-V_m^2(B_{mn}+B_{sh})-V_mV_nG_{mn}\sin(\delta_m-\delta_n)+V_mV_nB_{mn}\cos(\delta_m-\delta_n)$

Similarly, the real and reactive power flows from bus *m* to bus *n* can be expressed as

$P_{mn}=V_m^2G_{mn}-V_mV_nG_{mn}\cos(\delta_m-\delta_n)+V_mV_nB_{ij}\sin(\delta_m-\delta_n)$
$Q_{mn}=-V_m^2(B_{mn}+B_{sh})+V_mV_nG_{mn}\sin(\delta_m-\delta_n)+V_mV_nB_{mn}\cos(\delta_m-\delta_n)$

The active and reactive power loss in the line can be calculated as

$P_L = P_{mn}+ P_{nm}$
$\quad = V_m^2G_{mn} + V_n^2G_{mn} - 2V_mV_nG_{mn}\cos(\delta_m-\delta_n)$
$Q_L = Q_{mn}+ Q_{nm}$
$=-V_m^2(B_{mn}+B_{sh})-V_n^2(B_{mn}+B_{sh})+ 2V_mV_nB_{mn}\cos(\delta_m-\delta_n)$

TCSC have two modes of operation in the direction of the circuit resonance depending on the value of firing angle. Those two modes are Inductive mode and capacitive mode.
Main purposes of the TCSC are to minimize the total power loss, generation cost and reactive power generation limits.

VI. POWER TRANSFER DISTRIBUTION FACTOR (PTDF)

The Power Transfer Distribution Factor (PTDF) display is used to calculate the incremental distribution factors connected with power transfers between two regions. If single contingency or multiple contingency occurs in the power system the power is get rid of to the very near lines. To abstain from that position the overloaded lines must have to be lightening from the overload.

The Power Transfer Distribution Factor is given by

$$\mathbf{PTDF_{mn,\,ab}}=\frac{X_{ma}-X_{na}-X_{mb}+X_{nb}}{X_{mn}}$$

Where
$\mathbf{X_{mn}}$ Transmission line reactance connecting zone m and zone n
$\mathbf{X_{ma}}$ Entry in the m^{th} row a^{th} column of the bus reactance matrix X
$\mathbf{PTDF_{mn,ab}}$Is the part of a whole of transmission from bus a to b that flows over a transmission line connecting bus m to bus n.

The Power Transfer Distribution Factor (PTDF) is formulated by two types they are

- ACPTDF Computation
- DCPTDF Computation

VII. LINE OUTAGE DISTRIBUTION FACTOR (LODF)

Line outage distribution factors are linear guess of the change in flow on very near lines when transmission lines are lost and are normally used for checking overloads on the lines following the fault.Line Outage Distribution Factors (LODFs) are a sensitivity measure of how does the change in a line's position pretend the flows on other lines in the system. On a brisk line, the LODF reckon decide the percentage of the present line flow that will be show up on other transmission lines after the outage of the line [6][7].

VIII. SIMULATION RESULTS AND DISCUSSIONS

- **For Primary contingency (N-1) Analysis:**

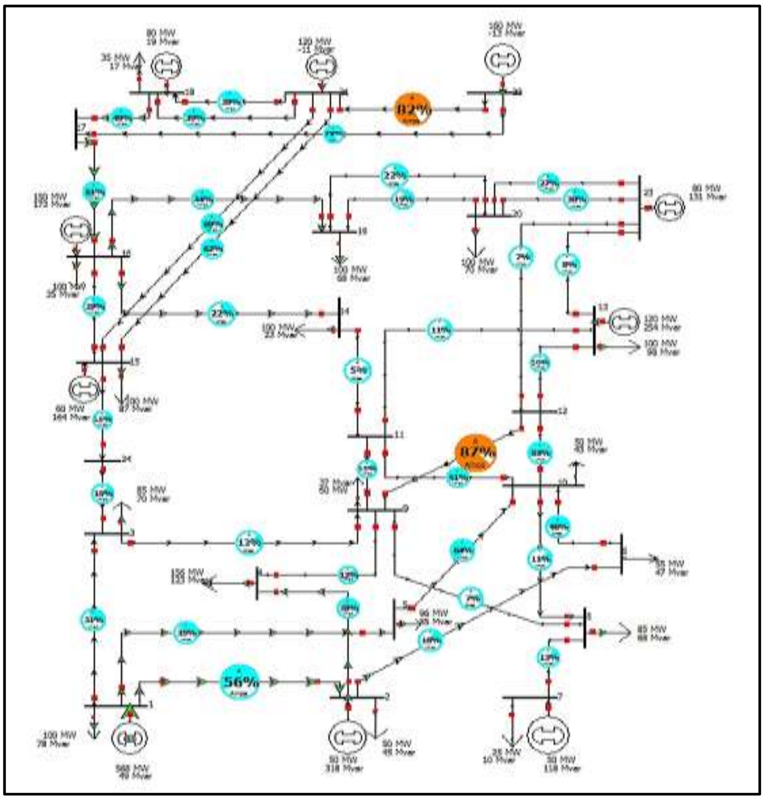


Figure 4: Base case for 24 bus system

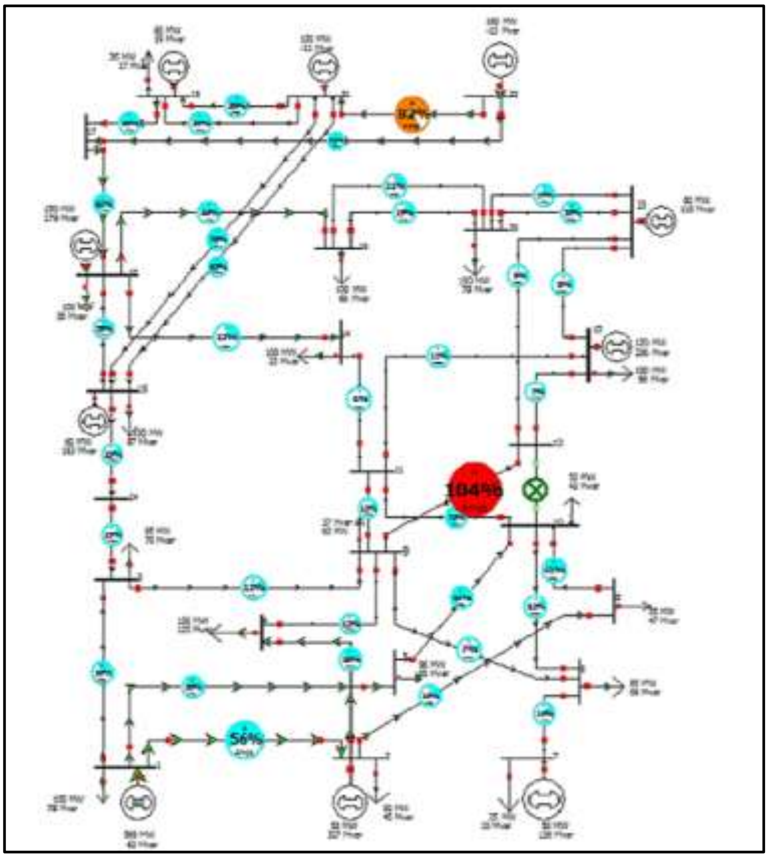


Figure 5: N-1 Line contingency on 24 bus system

A. Result and Discussion for 24 bus system:

TABLE 1Contingency Analysis of 24 bus system

S.NO	line details	Violations	Max Branch %
1	L_0000011-0000022C1	9	222.7
2	L_0000011-0000033C1	6	109.4
3	L_0000011-0000055C1	11	182.4
4	L_0000022-0000044C1	10	205.6
5	L_0000022-0000066C1	6	107.3
6	L_0000033-0000099C1	5	107.2
7	L_0000033-00002424C1	6	127.4
8	L_0000044-0000099C1	3	
9	L_0000055-00001010C1	5	101.7
10	L_0000066-00001010C1	3	
11	L_0000077-0000088C1	8	136
12	L_0000088-0000099C1	5	100.6
13	L_0000088-00001010C1	5	106.1
14	L_0000099-00001111C1	5	134.2
15	L_0000099-00001212C1	5	
16	L_00001010-00001111C1	4	
17	L_00001010-00001212C1	5	101.1
18	L_00001111-00001313C1	5	118.8
19	L_00001111-00001414C1	5	106.6
20	L_00001212-00001313C1	4	
21	L_00001212-00002323C1	4	
22	L_00001313-00002323C1	5	101.1
23	L_00001414-00001616C1	5	120.2
24	L_00001515-00001616C1	5	100.4
25	L_00001515-00002121C1	6	110.5
26	L_00001515-00002121C2	6	122.8
27	L_00001616-00001717C1	8	180.3
28	L_00001616-00001919C1	5	103.1
29	L_00001717-00001818C1	6	137.6
30	L_00001717-00002222C1	6	160.4
31	L_00001818-00002121C1	5	100.9
32	L_00001818-00002121C2	5	100.9
33	L_00001919-00002020C1	5	100.4
34	L_00001919-00002020C2	5	100.4
35	L_00002020-00002323C1	5	101.5
36	L_00002020-00002323C2	5	101.5
37	L_00002121-00002222C1	6	160
38	L_00002424-00001515C1	7	127.4

TABLE 2 Results of Contingency Analysis

Total no of contingencies	**38**	**Start time**	**14 jun 14,03:33:08 pm**
No of processed	**38**	**end time**	**14 jun 14,03:33:08 pm**
No of unsolvable	**0**	**Total run time**	**0.36 sec**
No of violations	**219**	**Avg time per ctg**	**0.009 sec**

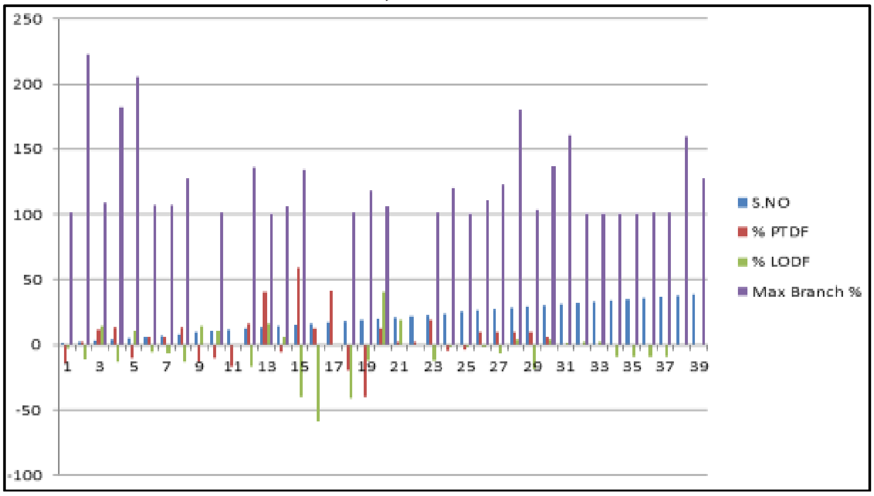
TABLE 3 LODF of 24 Bus System

S.NO	FROM LINE	TO LINE	% LODF	MW From	MW To
1	1	2	-2.3	242.4	-241.9
2	1	3	-11.4	71.5	-68.4
3	1	5	13.8	154.7	-147.2
4	2	4	-12.9	155.9	-144.1
5	2	6	10.6	86	-81.4
6	3	9	-5.3	38.4	-37.8
7	3	24	-6.2	-55	55.1
8	4	9	-12.9	-11.9	13.5
9	5	10	13.8	51.2	-50.4
10	6	10	10.6	26.4	-26.1
11	7	8	0	25	-22.7
12	8	9	-16.5	-27.8	28.3
13	8	10	16.5	-34.5	35.4
14	9	11	5.7	-31.7	31.8
15	9	12	-40.4	-32.2	32.4
16	10	11	-59.1	-9	9.1
17	10	12	0	0	0
18	11	13	-41	-17.6	18
19	11	14	-12.5	-23.4	23.4
20	12	13	40.3	-14.3	14.5
21	12	23	19.3	-18.1	18.2
22	13	23	-0.7	-12.5	12.5
23	14	16	-12.5	-123.4	124.4
24	15	16	-1.9	28.4	-28.4
25	15	21	-2.2	-62	62.2
26	15	21	-2.2	-62	62.2
27	24	15	-6.2	-55.1	55.5
28	16	17	4.3	-197.6	198.9
29	16	19	-18.6	151.7	-150.9
30	17	18	3.7	-121.1	121.3
31	17	22	0.6	-77.8	78.6
32	18	21	1.9	-38.2	38.2
33	18	21	1.9	-38.2	38.2
34	19	20	-9.3	25.5	-25.4
35	19	20	-9.3	25.5	-25.4
36	20	23	-9.3	-24.6	24.7
37	20	23	-9.3	-24.6	24.7
38	21	22	-0.6	-80.9	81.4

TABLE 4 PTDF of 24 Bus System

S.NO	FROM LINE	TO LINE	% PTDF From	% PTDF To
1	1	5	-13.79	13.79
2	1	2	2.34	-2.34
3	1	3	11.45	-11.45
4	2	4	12.95	-12.95
5	2	6	-10.61	10.61
6	3	24	6.17	-6.17
7	3	9	5.28	-5.28
8	4	9	12.95	-12.95
9	5	10	-13.79	13.79
10	6	10	-10.61	10.61
11	8	10	-16.49	16.49
12	8	9	16.49	-16.49
13	9	12	40.39	-40.39
14	9	11	-5.67	5.67
15	10	11	59.11	-59.11
16	11	14	12.46	-12.46
17	11	13	40.99	-40.99
18	12	23	-19.3	19.3
19	12	13	-40.32	40.32
20	14	16	12.46	-12.46
21	15	21	2.16	-2.16
22	15	21	2.16	-2.16
23	16	19	18.63	-18.63
24	16	17	-4.32	4.32
25	17	18	-3.73	3.73
26	19	20	9.31	-9.31
27	19	20	9.31	-9.31
28	20	23	9.31	-9.31
29	20	23	9.31	-9.31
30	24	15	6.17	-6.17

B. Graph between Max Branch % MVA Limit, %LODF and %PTDF.



The Table 1 show the contingency analysis when 10 to 12 line is open. The Overloaded Line is as shown in fig 5,the number of violations are 219 are shown in table 2. The LODF and PTDF calculations for 24 bus system are shown in tables 3 and 4.

After optimal location of FACTS device (TCSC) is placed on most positive sensitive line i.e. 6 to10, the preventive and corrective actions taken to solve the violations are given below.

IX. AFTER REMIDIAL ACTION TAKEN ON 24 BUS SYSTEM

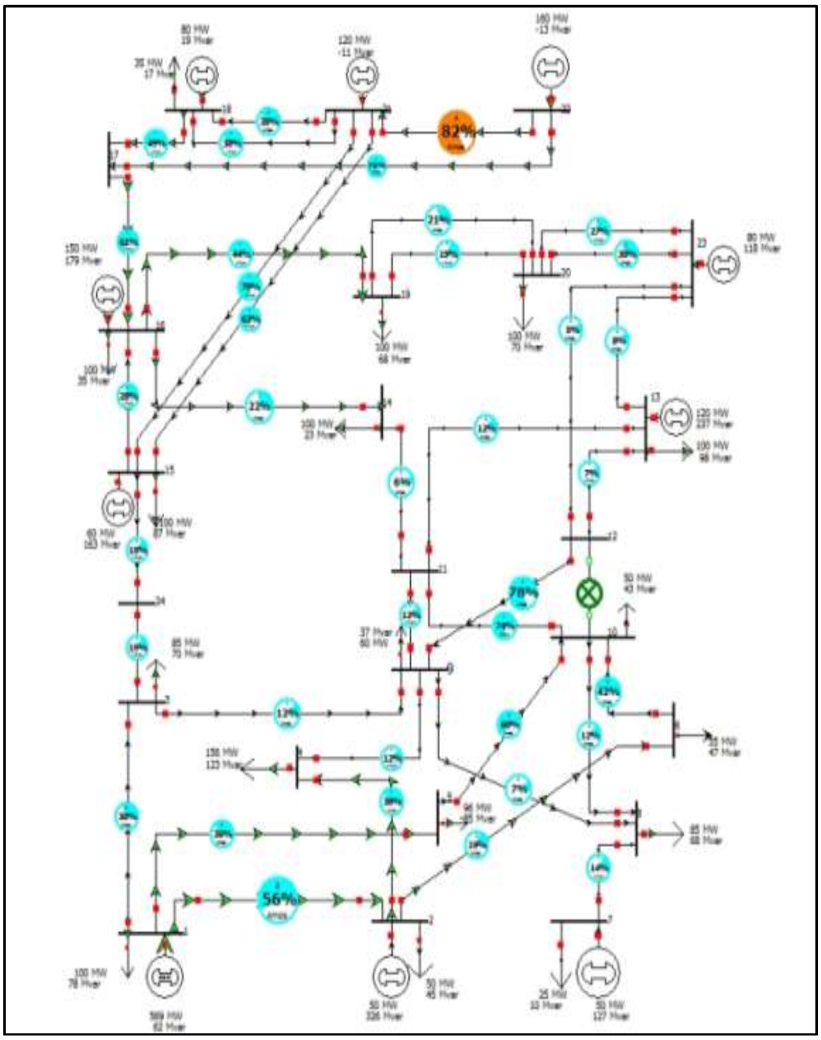


Figure 6: N-1 Line violations solved after placing the FACTS device on line 6 to 10.

C. Result and Discussion for violations solved after placing FACTS device on 24 bus system:

TABLE 5 Contingency Analysis of 24 bus system

S.NO	Label	Violations	Max Branch %
1	L_0000011-0000022C1	7	223.5
2	L_0000011-0000033C1	5	
3	L_0000011-0000055C1	10	182.5
4	L_0000022-0000044C1	10	154.2
5	L_0000022-0000066C1	5	102.6
6	L_0000033-0000099C1	4	
7	L_0000033-00002424C1	5	
8	L_0000044-0000099C1	2	
9	L_0000055-00001010C1	4	
10	L_0000066-00001010C1	3	
11	L_0000077-0000088C1	8	102.1
12	L_0000088-0000099C1	4	
13	L_0000088-00001010C1	4	
14	L_0000099-00001111C1	5	100.7
15	L_0000099-00001212C1	5	
16	L_00001010-00001111C1	4	
17	L_00001010-00001212C1	4	
18	L_00001111-00001313C1	4	
19	L_00001111-00001414C1	4	
20	L_00001212-00001313C1	4	
21	L_00001212-00002323C1	4	
22	L_00001313-00002323C1	4	
23	L_00001414-00001616C1	4	
24	L_00001515-00001616C1	4	
25	L_00001515-00002121C1	5	110.6
26	L_00001515-00002121C2	5	122.9
27	L_00001616-00001717C1	8	180.3
28	L_00001616-00001919C1	4	
29	L_00001717-00001818C1	6	137.6
30	L_00001717-00002222C1	5	160.4
31	L_00001818-00002121C1	4	
32	L_00001818-00002121C2	4	
33	L_00001919-00002020C1	4	
34	L_00001919-00002020C2	4	
35	L_00002020-00002323C1	4	
36	L_00002020-00002323C2	4	
37	L_00002121-00002222C1	5	160
38	L_00002424-00001515C1	6	

TABLE 6 Result of Contingency Analysis Violations solved after placing FACTS device on 24 bus system.

Total no of contingencies	**38**	**Start time**	**14 jun 14,03:33:08 pm**
No of processed	**38**	**end time**	**14 jun 14,03:33:08 pm**
No of unsolvable	**0**	**Total run time**	**0.23 sec**
No of violations	**189**	**Avg time per ctg**	**0.007sec**

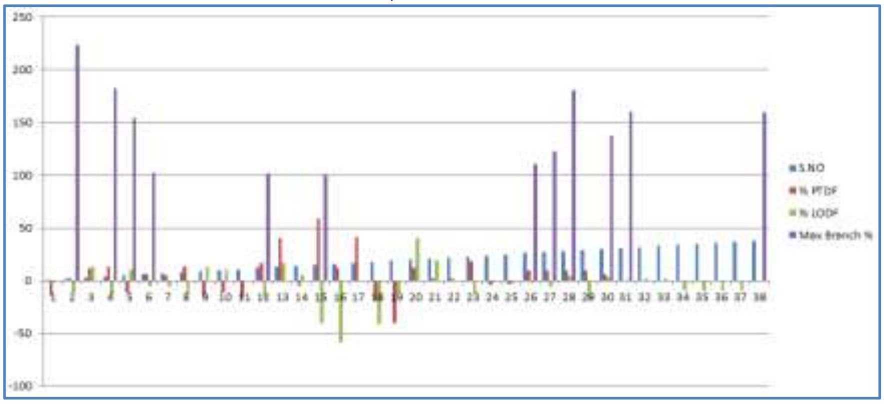
TABLE 7 LODF of 24 Bus systems after placing FACTS device in line 6-10.

S.NO	FROM LINE	TO LINE	% LODF	MW From	MW To
1	1	2	-2.1	243	-242.4
2	1	3	-11.5	71.4	-68.3
3	1	5	13.6	154.2	-146.8
4	2	4	-13	155.8	-143.9
5	2	6	11	86.7	-82.1
6	3	9	-5.3	38.3	-37.8
7	3	24	-6.2	-55.1	55.2
8	4	9	-13	-12.1	13.7
9	5	10	13.6	50.8	-50
10	6	10	11	27.2	-26.8
11	7	8	0	25	-22.7
12	8	9	-16.4	-27.8	28.2
13	8	10	16.4	-34.5	35.5
14	9	11	5.6	-31.8	31.9
15	9	12	-40.4	-32.3	32.4
16	10	11	-59	-8.7	8.9
17	10	12	0	0	0
18	11	13	-41	-17.5	18
19	11	14	-12.4	-23.3	23.4
20	12	13	40.3	-14.4	14.5
21	12	23	19.3	-18.1	18.2
22	13	23	-0.7	-12.5	12.5
23	14	16	-12.4	-123.4	124.3
24	15	16	-1.9	28.4	-28.4
25	15	21	-2.2	-62	62.3
26	15	21	-2.2	-62	62.3
27	24	15	-6.2	-55.2	55.6
28	16	17	4.3	-197.5	198.8
29	16	19	-18.6	151.6	-150.9
30	17	18	3.7	-121	121.3
31	17	22	0.6	-77.8	78.6
32	18	21	1.9	-38.1	38.2
33	18	21	1.9	-38.1	38.2
34	19	20	-9.3	25.5	-25.4
35	19	20	-9.3	25.5	-25.4
36	20	23	-9.3	-24.6	24.7
37	20	23	-9.3	-24.6	24.7
38	21	22	-0.6	-80.9	81.4

TABLE 8 PTDF of 24 bus system after placing FACTS device in line 6-10.

S.NO	FROM LINE	TO LINE	% PTDF From	% PTDF To
1	1	5	-13.6	13.6
2	1	2	2.08	-2.08
3	1	3	11.52	-11.52
4	2	4	13.03	-13.03
5	2	6	-10.95	10.95
6	3	24	6.2	-6.2
7	3	9	5.32	-5.32
8	4	9	13.03	-13.03
9	5	10	-13.6	13.6
10	6	10	-10.95	10.95
11	8	10	-16.45	16.45
12	8	9	16.45	-16.45
13	9	12	40.41	-40.41
14	9	11	-5.62	5.62
15	10	11	59	-59
16	11	14	12.43	-12.43
17	11	13	40.96	-40.96
18	12	23	-19.29	19.29
19	12	13	-40.29	40.29
20	14	16	12.43	-12.43
21	15	21	2.17	-2.17
22	15	21	2.17	-2.17
23	16	19	18.63	-18.63
24	16	17	-4.34	4.34
25	17	18	-3.75	3.75
26	19	20	9.32	-9.32
27	19	20	9.32	-9.32
28	20	23	9.32	-9.32
29	20	23	9.32	-9.32
30	24	15	6.2	-6.2

D. Graph between Max Branch %MVA Limit, % LODF and % PTDF.



The table 5 shows the Contingency Analysis of 24 bus system when 10-12 line is open after placing the FACTS device on the line 6-10i.e. (Compensating the line reactance 70% to its natural value). The overloaded line is 9-12 is comes into normal condition which is shown in figure 6. The number of violations are reduced to 219 to 189 are shown in table 6.The LODF, PTDF calculations for 24 bus system as shown in tables 7 and 8. The graph between Max Branch % MVA Limit, %LODF and %PTDF are shown in D. Some of the lines are carrying more power than its limit. Action should be taken to solve these MVA violations.

After reducing the reactance of 6-10 line is 0.03334 to 0.023338 (70% compensation) and MVA limit of 9-12 line is changed to 75% to 100% then the lines have come back to within its operational limits.

- **For Multiple Contingency (N-1-1) Analysis:**

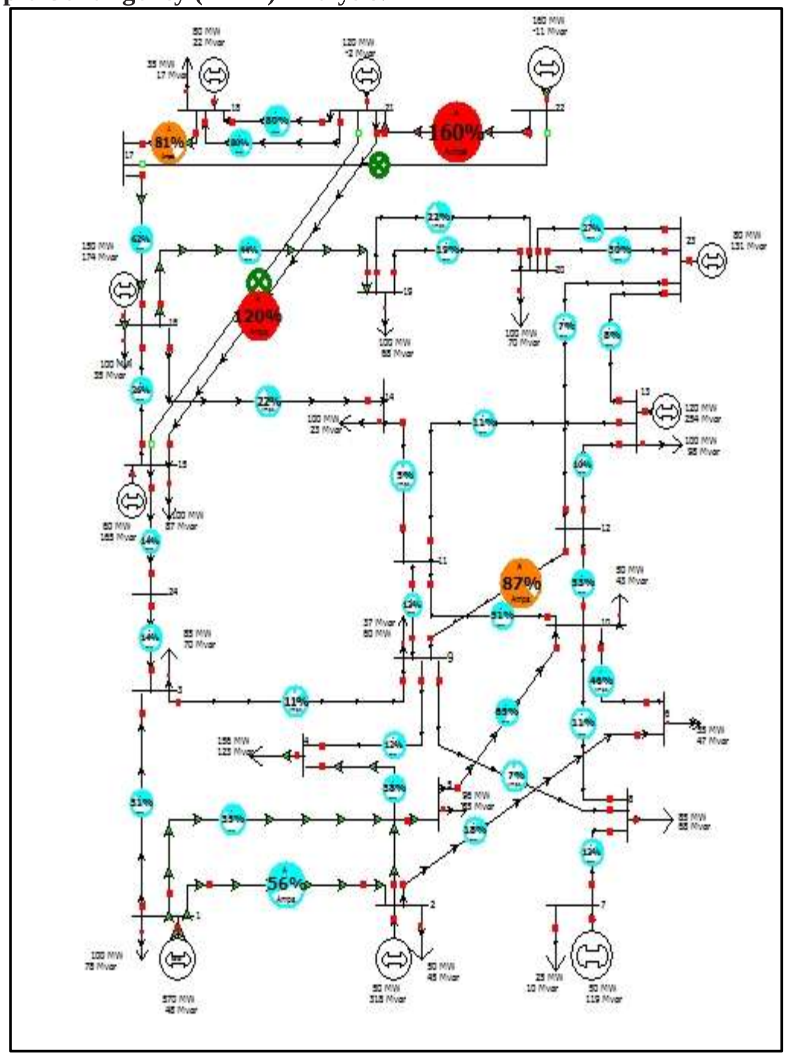


Figure 7: N-1-1 Line contingency on 24 bus system

E. Result and Discussion for 24 Bus system:

TABLE 9 N-1-1 Contingency Analysis of 24 bus system

Total no of contingencies	**38**	**Start time**	**24 jun 14,1:51:28 pm**
No of processed	**38**	**end time**	**24 jun 14,1:51:28 pm**
No of unsolvable	**0**	**Total run time**	**0.43 sec**
No of violations	**177**	**Avg time per ctg**	**0.011 sec**

TABLE 10 Results of Multiple Contingency Analyses.

S.NO	Label	Violations	Max Branch %
1	L_0000011-0000022C1	10	233
2	L_0000011-0000033C1	5	160.4
3	L_0000011-0000055C1	12	160.4
4	L_0000022-0000044C1	10	191.7
5	L_0000022-0000066C1	6	160.4
6	L_0000033-0000099C1	3	160.4
7	L_0000033-00002424C1	5	160.4
8	L_0000044-0000099C1	3	160.4
9	L_0000055-00001010C1	4	160.4
10	L_0000066-00001010C1	4	160.4
11	L_0000077-0000088C1	9	160.4
12	L_0000088-0000099C1	3	160.4
13	L_0000088-00001010C1	3	160.4
14	L_0000099-00001111C1	5	160.4
15	L_0000099-00001212C1	4	160.4
16	L_00001010-00001111C1	6	160.4
17	L_00001010-00001212C1	7	160.4
18	L_00001111-00001313C1	4	160.4
19	L_00001111-00001414C1	3	160.4
20	L_00001212-00001313C1	4	160.4
21	L_00001212-00002323C1	3	160.4
22	L_00001313-00002323C1	3	160.4
23	L_00001414-00001616C1	4	160.4
24	L_00001515-00001616C1	3	160.4
25	L_00001515-00002121C1	3	160.4
26	L_00001515-00002121C2	5	160.4
27	L_00001616-00001717C1	5	323.1
28	L_00001616-00001919C1	4	160.4
29	L_00001717-00001818C1	5	323.1
30	L_00001717-00002222C1	3	160.4
31	L_00001818-00002121C1	4	160.4
32	L_00001818-00002121C2	4	160.4
33	L_00001919-00002020C1	3	160.4
34	L_00001919-00002020C2	3	160.4
35	L_00002020-00002323C1	3	160.4
36	L_00002020-00002323C2	3	160.4
37	L_00002121-00002222C1	3	103.6
38	L_00002424-00001515C1	6	160.4

TABLE 11 LODF of 24 Bus System.

- **N-1-1 Contingency with 15-21(1) Line open.**

S.NO	From Line	To Line	% LODF	MW From	MW To
1	1	2	-1.5	242.7	-242.1
2	1	3	2.8	73.4	-70.1
3	1	5	-1.3	153.8	-147
4	2	4	-0.4	157	-145
5	2	6	-1	85.1	-81
6	3	9	-5.8	37.4	-36.9
7	3	24	8.7	-52.3	52.4
8	4	9	-0.4	-11	12.6
9	5	10	-1.3	51	-50
10	6	10	-1	26	-25.5
11	7	8	0	25	-23
12	8	9	0.4	-25.1	25.5
13	8	10	-0.4	-36.9	37.7
14	9	11	-3.3	-31.2	31.2
15	9	12	-2.6	-30.1	30.2
16	10	11	-1.7	-6.6	6.7
17	10	12	-1.1	-5.6	5.6
18	11	13	-0.3	-15.1	15.5
19	11	14	-4.7	-22.8	22.9
20	12	13	-1.4	-16.7	17
21	12	23	-2.3	-19.2	19.4
22	13	23	-1.7	-12.5	12.5
23	14	16	-4.7	-122.9	123.8
24	15	16	-14.6	25.7	-25.7
25	15	21	0	0	0
26	15	21	-76.7	-118.5	119.4
27	24	15	8.7	-52.4	52.8
28	16	17	-23.3	-201	202.3
29	16	19	4	152.9	-152.1
30	17	18	-23.3	-202.3	203
31	17	22	0	0	0
32	18	21	-11.6	-79	79.2
33	18	21	-11.6	-79	79.2
34	19	20	2	26.1	-26
35	19	20	2	26.1	-26
36	20	23	2	-24	24.1
37	20	23	2	-24	24.1
38	21	22	0	-157.9	160

TABLE 12 LODF of 24 Bus System.

- **N-1-1 Contingency with 17-22 Line open.**

S.NO	From Line	To Line	% LODF	MW From	MW To
1	1	2	0.8	242.7	-242.1
2	1	3	-1.6	73.4	-70.1
3	1	5	0.8	153.8	-147
4	2	4	0.2	157	-145
5	2	6	0.6	85.1	-81
6	3	9	3.3	37.4	-36.9
7	3	24	-4.8	-52.3	52.4
8	4	9	0.2	-11	12.6
9	5	10	0.8	51	-50
10	6	10	0.6	26	-25.5
11	7	8	0	25	-23
12	8	9	-0.2	-25.1	25.5
13	8	10	0.2	-36.9	37.7
14	9	11	1.8	-31.2	31.2
15	9	12	1.5	-30.1	30.2
16	10	11	1	-6.6	6.7
17	10	12	0.6	-5.6	5.6
18	11	13	0.2	-15.1	15.5
19	11	14	2.6	-22.8	22.9
20	12	13	0.8	-16.7	17
21	12	23	1.3	-19.2	19.4
22	13	23	1	-12.5	12.5
23	14	16	2.6	-122.9	123.8
24	15	16	8.2	25.7	-25.7
25	15	21	0	0	0
26	15	21	-13	-118.5	119.4
27	24	15	-4.8	-52.4	52.8
28	16	17	13	-201	202.3
29	16	19	-2.2	152.9	-152.1
30	17	18	-87	-202.3	203
31	17	22	0	0	0
32	18	21	-43.5	-79	79.2
33	18	21	-43.5	-79	79.2
34	19	20	-1.1	26.1	-26
35	19	20	-1.1	26.1	-26
36	20	23	-1.1	-24	24.1
37	20	23	-1.1	-24	24.1
38	21	22	-100	-157.9	160

TABLE 13 PTDF of 24 Bus System.

- **N-1-1 Contingency with 15-21(1) Line open.**

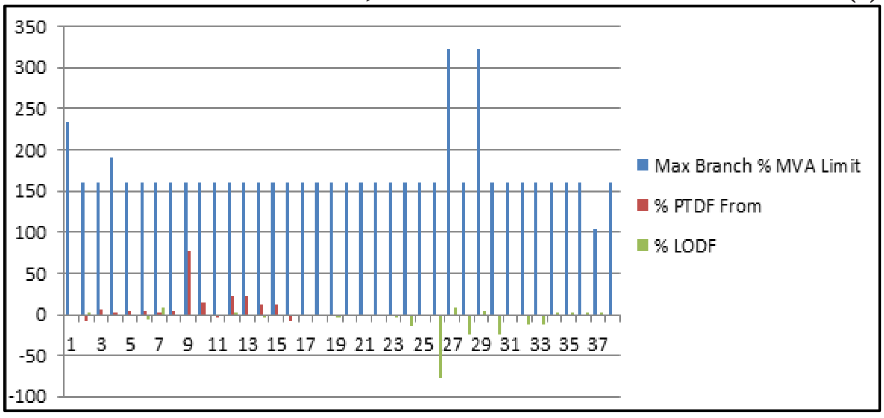
S.NO	From Line	To Line	% PTDF From	% PTDF To
1	1	3	-2.81	2.81
2	3	24	-8.65	8.65
3	3	9	5.84	-5.84
4	9	12	2.62	-2.62
5	9	11	3.26	-3.26
6	11	14	4.67	-4.67
7	12	23	2.25	-2.25
8	14	16	4.67	-4.67
9	15	21	76.75	-76.75
10	15	16	14.6	-14.6
11	16	19	-3.98	3.98
12	16	17	23.25	-23.25
13	17	18	23.25	-23.25
14	18	21	11.63	-11.63
15	18	21	11.63	-11.63
16	24	15	-8.65	8.65

TABLE 14 PTDF of 24 Bus System.

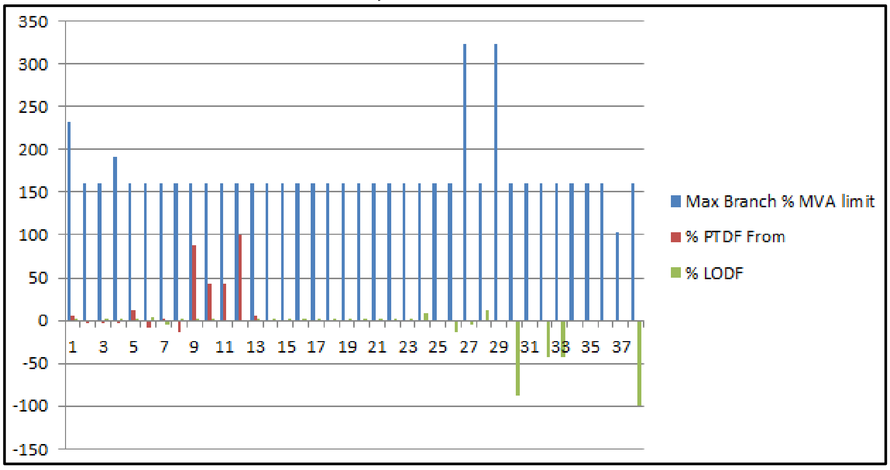
- **N-1-1 Contingency with 17-22 Line open.**

S.NO	From Line	To Line	% PTDF From	% PTDF To
1	3	24	4.83	-4.83
2	3	9	-3.26	3.26
3	11	14	-2.61	2.61
4	14	16	-2.61	2.61
5	15	21	12.99	-12.99
6	15	16	-8.16	8.16
7	16	19	2.22	-2.22
8	16	17	-12.99	12.99
9	17	18	87.01	-87.01
10	18	21	43.5	-43.5
11	18	21	43.5	-43.5
12	21	22	100	-100

F.Graph Between Max Branch % MVA Limit, % LODF and % PTDF for the line 15-21(1).



G. Graph between Max Branch % MVA Limit, % LODF and % PTDF for the line 17-22.



For the Contingency Analysis of a 24 bus power system, the table 9 represents Multiple Contingency Analysis of a24 bus system. When the lines 15-21(1) and 17-22 were opened before placing the FACTS device in the most positive sensitivity line 6-10. The overloaded lines were 15-21(2) and 21-22 is shown in figure 7.The total number of violations in the Multiple Contingency Analysis were 177 which is shown in table 10. The LODF and PTDF values calculated for both lines 15-21(1) and 17-22 were shown in tables 11, 12, 13 and 14. The graphs were drawn between the values of Max Branch % MVA Limit, % LODF and % PTDF is shown in F and G.

X. AFTER REMEDIAL ACTION TAKEN ON 24 BUS SYSTEM

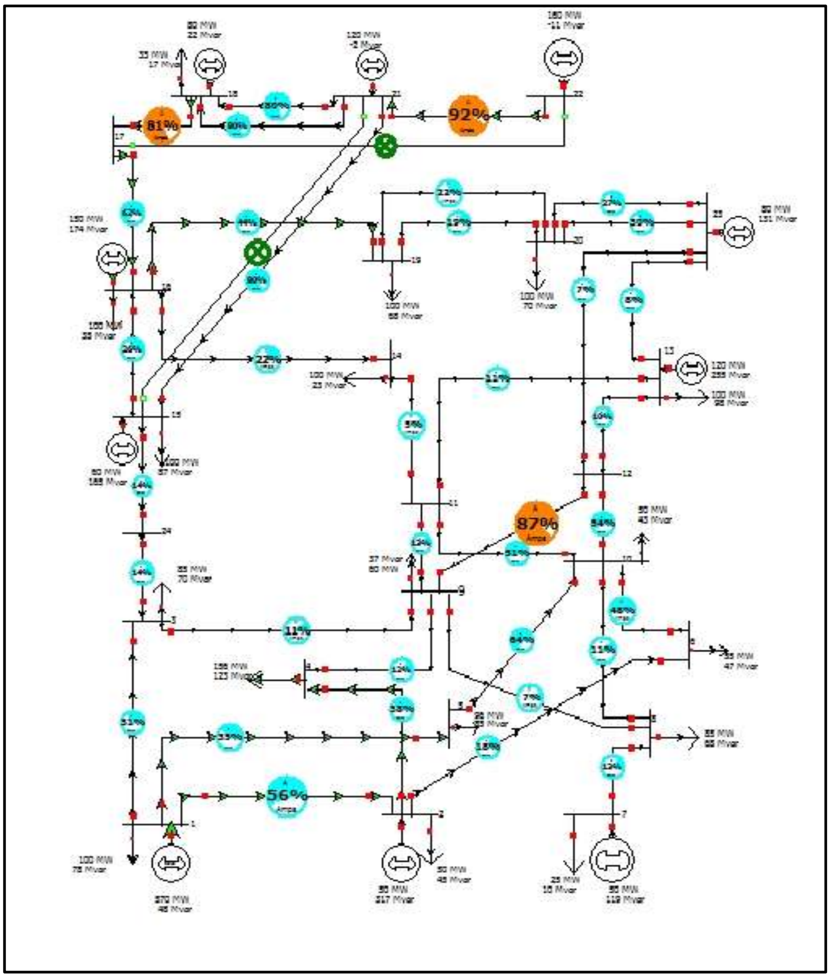


Figure 8. Multiple Contingency (N-1-1) Line violations solved after placing the FACTS device on line 6-10.

H. Result and Discussion for violations solved after placing FACTS device on 24 bus system:

TABLE 15 N-1-1 Contingency Analysis of 24 Bus System.

S.NO	Label	Violations	Max Branch % MVA Limit
1	L_0000011-0000022C1	8	228.4
2	L_0000011-0000033C1	5	108.9
3	L_0000011-0000055C1	9	152.8
4	L_0000022-0000044C1	8	192.2
5	L_0000022-0000066C1	5	100.3
6	L_0000033-0000099C1	2	
7	L_0000033-00002424C1	4	109.2
8	L_0000044-0000099C1	2	
9	L_0000055-00001010C1	3	
10	L_0000066-00001010C1	2	
11	L_0000077-0000088C1	7	108.3
12	L_0000088-0000099C1	2	
13	L_0000088-00001010C1	2	
14	L_0000099-00001111C1	4	122.5
15	L_0000099-00001212C1	3	
16	L_00001010-00001111C1	3	
17	L_00001010-00001212C1	4	100.6
18	L_00001111-00001313C1	3	
19	L_00001111-00001414C1	2	
20	L_00001212-00001313C1	3	
21	L_00001212-00002323C1	2	
22	L_00001313-00002323C1	2	
23	L_00001414-00001616C1	4	111.2
24	L_00001515-00001616C1	2	
25	L_00001515-00002121C1	2	
26	L_00001515-00002121C2	5	139.8
27	L_00001616-00001717C1	4	258.5
28	L_00001616-00001919C1	3	113.1
29	L_00001717-00001818C1	4	258.5
30	L_00001717-00002222C1	2	
31	L_00001818-00002121C1	4	151
32	L_00001818-00002121C2	4	151
33	L_00001919-00002020C1	2	
34	L_00001919-00002020C2	2	
35	L_00002020-00002323C1	2	
36	L_00002020-00002323C2	2	
37	L_00002121-00002222C1	4	117.5
38	L_00002424-00001515C1	5	109.2

TABLE 16 Result of N-1-1 Contingency Analysis Violations solved after placing FACTS device on 24 bus system.

Total no of contingencies	**38**	**Start time**	**25 jun 14,1:51:28 pm**
No of processed	38	end time	25 jun 14,1:51:28 pm
No of unsolvable	0	Total run time	0.33 sec
No of violations	136	Avg time per ctg	0.009 sec

TABLE 17 LODF of 24 Bus system after placing FACTS device in line 6-10.

- **N-1-1 Contingency with 15-21(1) line open.**

S.NO	From Line	To Line	% LODF	MW From	MW To
1	1	2	-1.2	235.9	-235.4
2	1	3	2.7	75.7	-72.2
3	1	5	-1.6	158.5	-151.5
4	2	4	-0.5	159.4	-147.1
5	2	6	-0.6	76	-72.1
6	3	9	-5.9	38.4	-37.8
7	3	24	8.6	-51.2	51.3
8	4	9	-0.5	-8.9	10.5
9	5	10	-1.6	55.5	-54.3
10	6	10	-0.6	17.1	-16.9
11	7	8	0	25	-23.1
12	8	9	0.4	-25.4	25.9
13	8	10	-0.4	-36.5	37.3
14	9	11	-3.3	-29.8	29.9
15	9	12	-2.7	-28.7	28.8
16	10	11	-1.6	-8.6	8.7
17	10	12	-1	-7.5	7.5
18	11	13	-0.3	-15.1	15.5
19	11	14	-4.7	-23.5	23.5
20	12	13	-1.4	-16.9	17.2
21	12	23	-2.2	-19.5	19.7
22	13	23	-1.7	-12.7	12.7
23	14	16	-4.7	-123.5	124.4
24	15	16	-14.6	26.1	-26.1
25	15	21	0	0	0
26	15	21	-76.8	-117.8	118.7
27	24	15	8.6	-51.3	51.7
28	16	17	-23.2	-201.7	203
29	16	19	4	153.4	-152.6
30	17	18	-23.2	-203	203.7
31	17	22	0	0	0
32	18	21	-11.6	-79.4	79.6
33	18	21	-11.6	-79.4	79.6
34	19	20	2	26.3	-26.3
35	19	20	2	26.3	-26.3
36	20	23	2	-23.7	23.8
37	20	23	2	-23.7	23.8
38	21	22	0	-157.9	160

TABLE 18 LODF of 24 Bus system after placing FACTS device on line 6-10.

- **N-1-1 Contingency with 17-22 line open.**

S.NO	From Line	To Line	% LODF	MW From	MW To
1	1	2	0.7	235.9	-235.4
2	1	3	-1.5	75.7	-72.2
3	1	5	0.9	158.5	-151.5
4	2	4	0.3	159.4	-147.1
5	2	6	0.4	76	-72.1
6	3	9	3.3	38.4	-37.8
7	3	24	-4.8	-51.2	51.3
8	4	9	0.3	-8.9	10.5
9	5	10	0.9	55.5	-54.3
10	6	10	0.4	17.1	-16.9
11	7	8	0	25	-23.1
12	8	9	-0.2	-25.4	25.9
13	8	10	0.2	-36.5	37.3
14	9	11	1.9	-29.8	29.9
15	9	12	1.5	-28.7	28.8
16	10	11	0.9	-8.6	8.7
17	10	12	0.6	-7.5	7.5
18	11	13	0.2	-15.1	15.5
19	11	14	2.6	-23.5	23.5
20	12	13	0.8	-16.9	17.2
21	12	23	1.3	-19.5	19.7
22	13	23	1	-12.7	12.7
23	14	16	2.6	-123.5	124.4
24	15	16	8.2	26.1	-26.1
25	15	21	0	0	0
26	15	21	-13	-117.8	118.7
27	24	15	-4.8	-51.3	51.7
28	16	17	13	-201.7	203
29	16	19	-2.2	153.4	-152.6
30	17	18	-87	-203	203.7
31	17	22	0	0	0
32	18	21	-43.5	-79.4	79.6
33	18	21	-43.5	-79.4	79.6
34	19	20	-1.1	26.3	-26.3
35	19	20	-1.1	26.3	-26.3
36	20	23	-1.1	-23.7	23.8
37	20	23	-1.1	-23.7	23.8
38	21	22	-100	-157.9	160

TABLE 19 PTDF of 24 Bus system after placing FACTS device on line 6-10.

- **N-1-1 Contingency with 15-21(1) line open.**

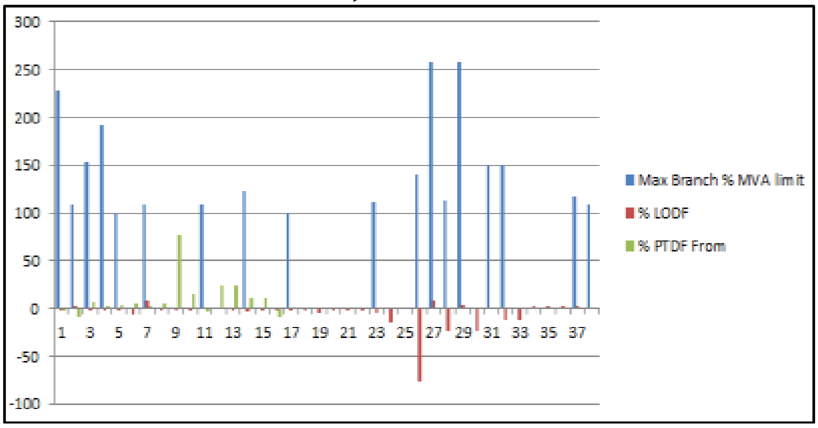
S.NO	From Line	To Line	% PTDF Fro	% PTDF To
1	1	3	-2.72	2.72
2	3	24	-8.61	8.61
3	3	9	5.89	-5.89
4	9	12	2.68	-2.68
5	9	11	3.32	-3.32
6	11	14	4.65	-4.65
7	12	23	2.24	-2.24
8	14	16	4.65	-4.65
9	15	21	76.77	-76.77
10	15	16	14.62	-14.62
11	16	19	-3.96	3.96
12	16	17	23.23	-23.23
13	17	18	23.23	-23.23
14	18	21	11.61	-11.61
15	18	21	11.61	-11.61
16	24	15	-8.61	8.61

TABLE 20 PTDF of 24 Bus system after placing FACTS device on line 6-10.

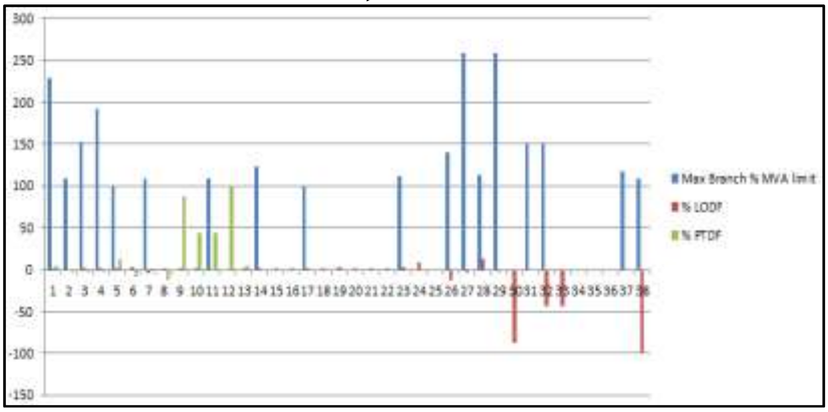
- **N-1-1 Contingency with 17-22 line open.**

S.NO	From Line	To Line	% PTDF From	% PTDF To
1	3	24	4.81	-4.81
2	3	9	-3.29	3.29
3	11	14	-2.6	2.6
4	14	16	-2.6	2.6
5	15	21	12.98	-12.98
6	15	16	-8.17	8.17
7	16	19	2.21	-2.21
8	16	17	-12.98	12.98
9	17	18	87.02	-87.02
10	18	21	43.51	-43.51
11	18	21	43.51	-43.51
12	21	22	100	-100
13	24	15	4.81	-4.81

I. Graph Between Max Branch %MVA Limit, %LODF and %PTDF for the line 15-21(1).



J. Graph Between Max Branch % MVA Limit, %LODF and %PTDF for the line 17-22.



The table 15 shows the Multiple Contingency (N-1-1) Analysis of a 24 bus power system when the lines 15-21(1) and 17-22 were opened after placing the FACTS device on the most positive sensitive line 6-10. The overloaded lines 15-21(2), 17-22 were comes into normal condition which is shown in figure 8.

The number of violations is reduced to 177 to 136 which is shown in table 16. The LODF, PTDF calculations for 24 bus power system is shown in tables 17, 18, 19 and 20.The graphs between the Max Branch %MVA Limit, % LODF, %PTDF are shown in figures I and J.

Some of the lines are carrying more power than its limit. Actions should be taken to solve these MVA violations. After reducing the reactance of 6-10 line is 0.033340 to 0.023338 (70% compensation) and MVA limits are changes in the lines 15-21(1) as 100% to 175% and 17-22 line as 100% to 150% then the lines are comeback to within its operational limits.

XI. CONCLUSION

Contingency analysis is used to foretell the result of outages caused line outage in a power transmission system. FACTS devices like TCSC by limit the flows in the network will help to bring down the flows in solidly loaded lines. The limit violations in the power system are effectivelytakenaway after using the corrective actions.The security limits give an account from maximum violations of the element of test system and sensitivity analysis of both line outage distribution factor and power transfer distribution factor. Contingency Analysis helps particularly in the busy power system operators.In power world simulator the contingency analysis is not difficult to run the power system as compared to the other contingency analysis and it is more trustworthy.

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