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CONTINGENCY ANALYSIS IN 14-BUS POWER SYSTEM WITH TCSC

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ABSTRACT: Power system security is one of challenging task for the power system engineers. Contingency analysis is being widely used to predict the effect of outages like failures of transmission lines and generator etc. Contingency analysis is a computer application that uses a simulated model of the power system to evaluate the effects and to calculate any overloads. A FACT device TCSC can be alternative to reduce overloads and increasing line load ability, to reduce the system loss, to improve stability of power system network. This paper shows a 14-bus power system which gives the information of violations and novel method proposed

KEYWORDS: contingency analysis, power transfer distribution factor(PTDF), line outage distribution factor(LODF), FACTs devices, single contingency, multiple contingency.

I.INTRODUCTION

The power system is a market there is the manufacturers (power plants) and the consumers. The grid is the way to connect the producers to the consumers monopole means that there is but one electric utility that control the whole process of generation transmission and distribution of electrical energy and all the consumers have to buy from this function.Power system protection is a main factor of consideration in all sectors of a power system during both planning and operation stages. This is because of any loss of component leads to transient instability of the system and can be checked immediately by the help of protective devices put in place. To maintain and ensure a secure operation of any delicate system, the need for contingency analysis cannot be occur emphasized.

An power transfer distribution factor (PTDF) is the comparative change in power flow on a particular line due to a change in injection and corresponding withdrawal at a pair of busses.

The Line Outage Distribution Factor (LODF) is one of the important linear sensitivity factors which play a key role in result the effect of the critical contingencies and hence suggesting possible preventive and corrective actions to solve the violations in the system. LODFs are used to approximate change in the flow on one line caused by the outage of a second line. Typically they are only used to determine the change in the MW flow compared to the pre contingency flow. Flexible Alternating Current Transmission Systems are inject in transmission lines so to minimize the problems and FACTS used for control of voltage, phaseangle andimpedance of highvoltage transmission lines.The strategic benefitsof incorporating FACTS devices are improved reliability, better utilization of existing transmission system,improvedavailability,increased transientanddynamicstability and increased quality of supply Thyristor Controlled Switching Compensator (TCSC) is connected in series with transmission lines and which transport not intermittent and variable 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.

II. CONTINGENCY ANALYSIS

A contingency analysis is the loss or failure of a small part of the power system (e.g. transmission line or generator or transformer. this is a planned or unplanned event. Therefore contingency analysis is an application that uses a computer simulation to evaluate the effects of removing individual elements from a power system.

Power system engineers use contingency analysis to learning the performance of the system and to assess the need for new transmission developments due to load increase or generation developments. In power system operation contingency analysis cares engineers to operate at a secured operating point where equipment are loaded within their safe limits and power is carried to customers with acceptable quality values. Real time implementation of power system

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analysis and security observing is still a inspiring task for the operators. Voltage stability is defined as the facility of a power system to maintain steadily acceptable bus voltage at each node under normal operating conditions, after load variation following a change in system conformation or when the system is subjected to contingencies like line outage or generator outage. Single or multiple contingencies reason voltage violations which are known as voltage contingencies.

The contingencies are more contingency analysis appropriated more time consuming process. The transmission line outage large changes both outline and the state of the system. The contingency list is indicating by the help of contingency ranking. Contingency analysis main use is to find out the line overloads or voltage violations and to start complete measures that are creating necessary to remove these violations. The voltage violations are two types single and several contingencies. AC load flow method is more truthful as compared to DC load flow method. In contingency analysis coming to the outages single outage case is calculated in 60 seconds and for thousands of outages it 16 minutes. Contingency analysis is two types are off-line analysis and on-line analysis. Contingency analysis two type's violations occur one is the low voltage violations and other line MVA limit violations.

Low voltage violations occur due to the unsatisfactory reactive power. These are occurs at the bus. . Low voltage means falls below 0.95 p.u at the MVA limit. High voltage means falls above 1.05 p.u at the bus. Line MVA limit violations happens in the system when the line MVA rating go outside its actually rating. In general lines are designed for bright to withstand 125% of buses.

III. . N-1 CONTINGENCY ANALYSIS

Is the loss of any power system portion that has only one of the transmission apparatus or power plant tripped but not include 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 the power system. This system is secure.

IV. N-1-1 CONTINGENCY ANALYSIS

A sequence of events containing of the initial loss of a single generator or transmission component (primary contingency), shadowed by the system modifications, followed by another loss of a single generator or transmission component (secondary contingency).

The term N-0 or 1 or 2 refers to the failure of significant equipment. Though these terms sound complex, they are actually pretty simple. 'N' is the total number of components of the power system trusts on operate properly. The number of subtracted from N is the number of components that fail in a given situation. Therefore N-0 means that two components have filled and the system is a normal condition.N-1 means that only one module failed. N-1-1 means that two modules have failed, which is generally poorer than having only one fail.

As per NERC principles the group is N-1-1 then the system is stable and the loss of demand is planned or controlled and no cascading outages.The secondary contingency will occur before primary contingency, initial loss of a transmission line (single contingency), followed by the system adjustments, and monitored by the loss of a transmission component (secondary contingency).

The base case condition is stop and changes are necessary. To make clear of a secure primary contingency base case to modification required and automatically explains the N-1-1 contingencies. Power system variations of N-1-1 contingencies are automatically analyze and instant reports are created for documentation

Overview of N-1-1 Analysis process:

The corrective action mode in the system changes between the first and second primary contingency are accomplished. In each couple of secondary (N-1-1) contingencies a group of system changes is decided. Primary and multiple contingency results are corrective action analysis is run.

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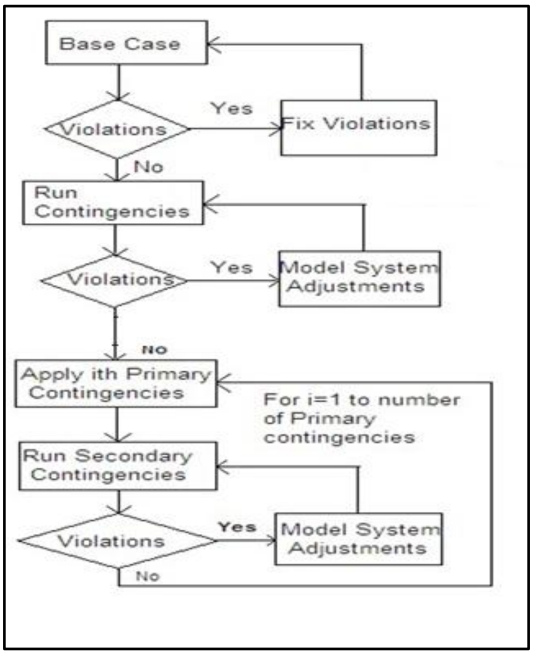

Figure 1 – Multiple Contingency Analysis process

V. MODELLING OF FACTS DEVICES

Flexible Alternating Current Transmission Systems are placed in transmission lines. The FACTS devices are used including power electronic-based and other static controllers to improve the quality of controllability and increase power transfer capability. Used for control of voltage, phaseangle andimpedance of highvoltage transmission lines.The planned profitsof including FACTS devices are improved reliability, better utilization of remaining transmission system,improvedavailability,increased transientanddynamicstability and increased quality of source.Due to dynamic natureof loadand generation measures, heavier line flows and higher losses are occurred causingsecurityandstabilityproblems. To overcome these problems in the present deregulated situation more learned control using FACTS devices is indispensable.

Withthecomingofflexible actransmissionsystem(FACTS)devices power utilitiesall over the world areableto improve the system stability limit, control the power flow, improve the transmission system security andprovidestrategic benefitsfor better utilizationofthe existingpower system.The operation ofFACTS devices is based on power electronic controllers.Thesedevicesarealsousedtoimprovetransfercapability andtominimizethetotalpowerloss. The main device considered here is Thyristor controlled series capacitor (TCSC) for improvement of transfer capability.

RenderingtoIEEE definitionFACTSdevicesis power electronic base or other static controllers combined in AC transmission systems to improve controllability and increase power transfer capability.

The FACTS devices are can be about divided as shunt, series, combined series-series and combined series-shunt. The advantages of the facts devices are increase the loading capability of lines to their thermal capabilities, including short term and periodic. Increase the system security through raising the transient stability limit, limiting short circuit currents and overloads, managing cascading blackouts and damping electromechanical oscillations of power systems and machines. Deliver secure tie line connections to neighboring utilities and regions there by decreasing overall generation reserve requirements on both sides. Provide greater flexibility in siting new generation. Advancement of lines. Reduce reactive power flows, thus allowing the lines to transport more reactive power. Reduce loop flows.

THYRISTOR CONTROLLED SERIES COMPENSATOR:

Thyristor controlled seriescompensator(TCSC) are connected in serieswithtransmission lines. It is equivalent to a controllable reactance inserted in series with a line to reimburse the effect of the line inductance. The net transfer

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reactance is reduced and leads to an increase in power transfer capability. The voltage profile is also improved due to pullout of series capacitance in the line. Series compensation is usually a preferable alternative for increasing power flow capability of lines as compared to shunt compensators as the ratings required for series compensators are meaningfully smaller.

The IEEE describes the TCSC as capacitive reactance compensator which consists of a series capacitor bank shunted by a Thyristor- controlled reactor in direction to provide a smooth variable series capacitive reactance. Series capacitive compensation works by reducing the effective series impedance of the transmission line by discontinuing Part of inductive reactance.

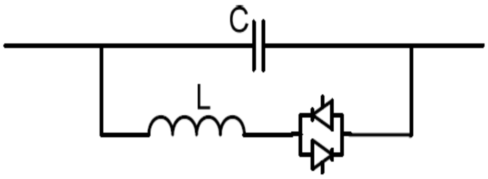

Figure 2: diagram of TCSC

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:

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

Care is occupied for the circuit in Figure not to resonate otherwise the transmission line would be an open circuit! In our simulations the TCSC is taken as continuous varying capacitor. The effective series transmission impedance is given by

$$X_{eff} = (1 - k) * X$$

Where k is the degree of series compensation

$$k = \frac{X_{TCSC}}{X} \qquad 0 \le k \le 1$$

As the delay angle is varied X_l varies as given by and also X_{TCSC} varies as in. The TCSC has two modes of operation around the circuit resonance depending on the value of the firing angle. The TCSC can operate in the inductive mode, *i.e.* for firing angles greater than zero but less than the upper limit, verbalized by the resonance band but less than 90 degrees. In the capacitive mode, the firing angle is greater than a lower limit, dictated by the resonance band and less than 90 degrees.

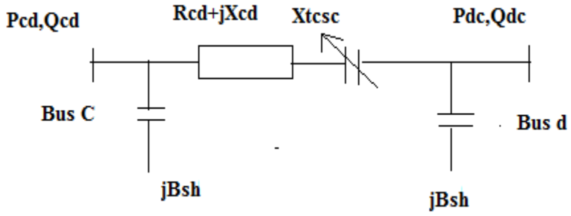

Figure 3: TCSC Model

The following equations are used to modelTCSC.
Let the complex voltages at bus cand bus dis denoted as Vc∠δcand Vd∠δd, respectively.
The complex power flowing from bus c to bus *d* can be expressed as

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$S_{cd}^{*} = P_{cd} - jQ_{cd} = V_c^{*} I_{cd}$
$= V_c^{*}[(V_c - V_d)\, Y_{cd} + V_c\,(jB_{sh})]$
$= V_c^{2}\,[G_{cd} + j\,(B_{cd}+B_{sh})] - V_c^{*} V_d\,(G_{cd} + jB_{cd})$
Where
$G_{cd} + jB_{cd} = 1/\,(R_L + jX_L - jX_{sh})$
Equating the real and imaginary parts of the above equations the expressions for real and reactive power flows can be transcribed as

$P_{cd} = V_c^2 G_{cd} - V_c V_d G_{cd} \cos(\delta_c - \delta_d) - V_c V_d B_{cd} \sin(\delta_c - \delta_d$
$Q_{cd} = -V_c^2 (B_{cd}+B_{sh}) - V_c V_d G_{cd} \sin(\delta_c - \delta_d) + V_c V_d B_{cd} \cos(\delta_c - \delta_d)$
Similarly, the real and reactive power flows from bus *c* to bus *d* can be expressed as

$P_{cd} = V_c^2 G_{cd} - V_c V_d G_{cd} \cos(\delta_c - \delta_d) + V_c V_d B_{ij} \sin(\delta_c - \delta_d)$
$Q_{cd} = -V_c^2 (B_{cd}+B_{sh}) + V_c V_d G_{cd} \sin(\delta_c - \delta_d) + V_c V_d B_{cd} \cos(\delta_c - \delta_d)$
The active and reactive power loss in the line can be calculated as
$P_L = P_{cd} + P_{dc} = V_c^2 G_{cd} + V_c^2 G_{cd} - 2V_c V_d G_{cd} \cos(\delta_c - \delta_d)$ $Q_L = Q_{cd} + Q_{dc}$
$= -V_c^2 (B_{cd}+B_{sh}) - V_d^2 (B_{cd}+B_{sh}) + 2V_c V_d B_{cd} \cos(\delta_c - \delta_d)$
When the TCSC is implanted in a line, it modifies the series reactance of the line. Since the reactance controls the series impedance of the line, the TCSC therefore reduces the impedance of the line. The line therefore becomes electrically shorter and this increases the maximum power flow on the line. 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)

An power transfer distribution factor (PTDF) is the comparative change in power flow on a particular line due to a change in vaccination and conforming withdrawal at a pair of busses. PTDFs depend on the topology of the electric power system, the behavior of controllable transmission system elements as their parameters are advanced, and on the operating point. That is, PTDFs change when an outage of a line happens, if a controllable element reaches its control limits, and also as the pattern of injections and withdrawals change the loadings on the lines in the system. For the case of undistinguishable radial parallel lines, however, the PTDFs are completely autonomous of line loading. Moreover, it is known empirically that, given a fixed topology and disregarding controllable device limits, the PTDFs are relatively insensitive to the levels of injections and withdrawals.
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 mth row ath 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 belief of the change in flow on very near lines when transmission lines are lost and are normally used for checking overloads on the lines succeeding the fault. Line Outage Distribution Factors (LODFs) are a sensitivity measure of how prepares the change in a line's position make-believe the flows on other lines in the system. On a brusque line, the LODF calculate decide the percentage of the present line flow that will be expression up on other transmission lines after the outage of the line.

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VIII. SIMULATION RESULTS AND DELIBERATIONS

Primary contingency (N-1) Analysis:

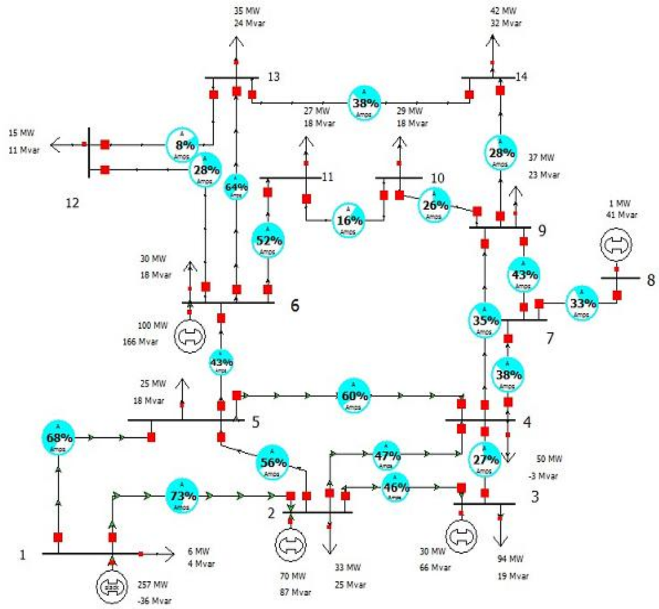

Figure 4: Base case for 14-Bus system

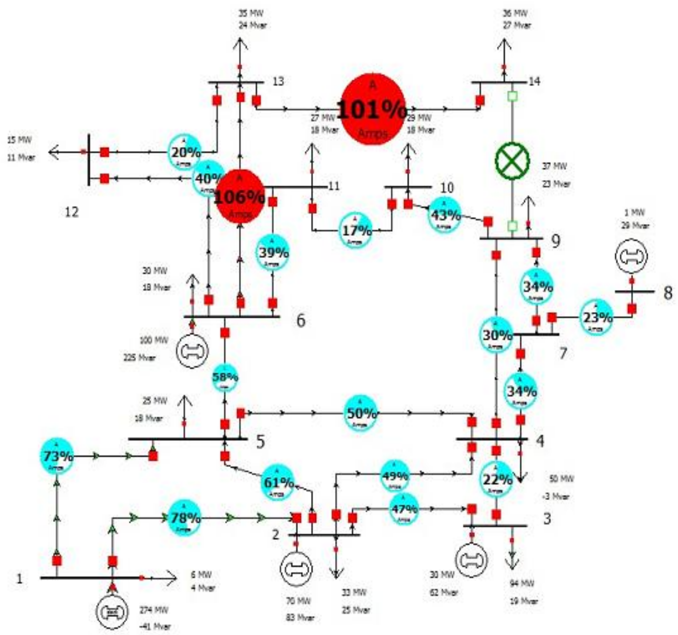

Figure 5: N-1 Line contingency on 14-Bus system

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A .Result and Discussion for 14 bus system:

TABLE 1: Contingency Analysis of 14 bus system:

S.no	Line details	Violations	Max branch %
1	L_0000011-0000022c1	5	105.5
2	L_0000011-0000055c1	7	126.4
3	L_0000022-0000033c1	5	105.5
4	L_0000022-0000044c1	5	105.6
5	L_0000022-0000055c1	5	105.5
6	L_0000033-0000044c1	5	105.6
7	L_0000044-0000055c1	5	105.5
8	L_0000044-0000077c1	6	105.5
9	L_0000044-0000099c1	6	105.5
10	L_0000055-0000066c1	12	130
11	L_0000066-000001111c1	8	105.5
12	L_0000066-000001212c1	5	105.5
13	L_0000066-000001313c1	5	131.4
14	L_0000077-0000088c1	8	105.5
15	L_0000077-0000099c1	7	105.5
16	L_0000099-000001010c1	7	107.6
17	L_0000099-000001414c1	5	105.5
18	L_000001010-000001111c1	6	105.5
19	L_000001212-000001313c1	4	124.5
20	L_000001313-000001414c1	1	

Table 1: Contingency analysis of 14-bus system

TABLE 2 : Results of contingency analysis

Total no of contingencies	20	Start time	08/11/2015 03:53:13 pm
No of processed	20	end time	08/11/2015 03:53:13 pm
No of unsolvable	0	Total run time	0.72 sec
No of violations	117	Avg time per Contg	0.036 sec

TABLE 3: LODF's of 14-bus system

S.NO	FROM LINE	TO LINE	% LODF	MW from	MW to
1	1	2	-36.1	172.6	-166.4
2	1	5	36.1	95.3	-90.4
3	2	3	20.7	69.3	-67
4	2	4	43.2	73.1	-70
5	2	5	-100	61.1	-58.9
6	3	4	20.7	2.8	-2.5
7	4	5	61.1	-52.5	52.9
8	4	7	1.8	47.9	-47.9
9	4	9	1	27.1	-27.1
10	5	6	-2.8	71.4	-59.7
11	6	11	-2.8	19.3	-17.9

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12	6	12	0	30.8	-28.8
13	6	13	0	79.6	-70.7
14	7	8	0	-1	1
15	7	9	1.8	48.9	-48.9
16	9	10	2.8	38.9	-38.3
17	9	14	0	0	0
18	10	11	2.8	9.3	-9.1
19	12	13	0	13.8	-13
20	13	14	0	48.6	-36

TABLE 4: PTDF's of 14-Bus System

S.NO	FROM LINE	TO LINE	% PTDF from	% PTDF to
1	1	2	-21.22	21.22
2	1	5	21.22	-21.22
3	2	3	14.34	-14.34
4	2	4	30.01	-30.01
5	2	5	34.43	-34.43
6	3	4	14.34	-14.34
7	4	5	16.51	-16.51
8	4	7	17.69	-17.69
9	4	9	10.15	-10.15
10	5	6	72.16	-72.16
11	6	11	-27.84	27.84
12	6	12	22.23	-22.23
13	6	13	77.77	-77.77
14	7	9	17.69	-17.69
15	9	10	27.84	-27.84
16	10	11	27.84	-27.84
17	12	13	22.23	-22.23

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

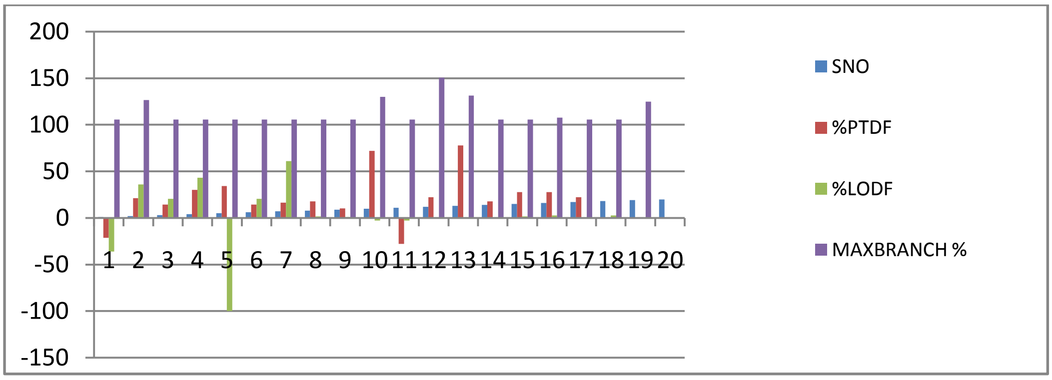

Table 1displays the contingency analysis when 9 to 14line is open. The Overloaded Lines are as shown in fig 5, the number of violations are 117 are shown in table 2. The LODF and PTDF calculations for 14 bus system are exposed in tables 3 and 4.

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After optimal location of FACTS device (TCSC) is placed on most positive sensitive line i.e. 4 to7, the preventive and corrective actions taken to solve the violations are given below.

AFTER REMIDIAL ACTION TAKEN ON 14-BUS SYSTEM

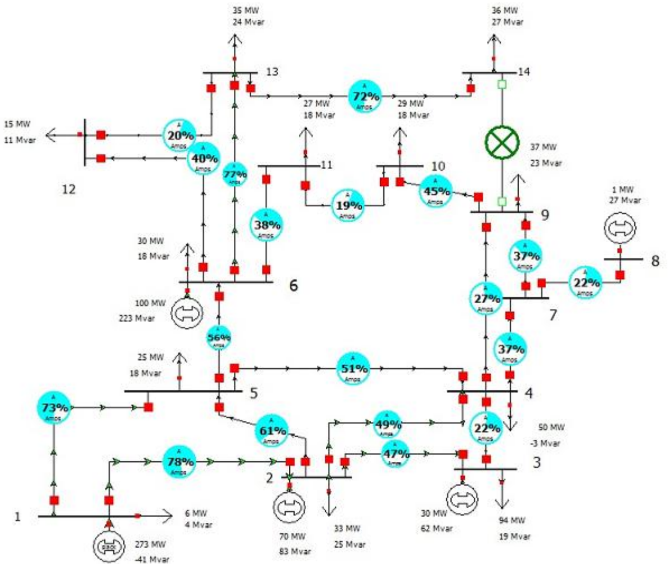

Figure 6: N-1 Line violations solved after placing the FACTS device on line 4 to 7.

C. Result and Discussion for violations solved after placing FACTS device on 14 bus system:

TABLE 5: Contingency Analysis of 14 bus system

S.NO	Line details	Violations	Max branch %
1	L_0000011-0000022c1	7	265.5
2	L_0000011-0000055c1	6	126
3	L_0000022-0000033c1	4	
4	L_0000022-0000044c1	4	
5	L_0000022-0000055c1	4	
6	L_0000033-0000044c1	4	
7	L_0000044-0000055c1	4	
8	L_0000044-0000077c1	5	
9	L_0000044-0000099c1	4	
10	L_0000055-0000066c1	9	126.1
11	L_0000066-000001111c1	6	
12	L_0000066-000001212c1	5	110.4
13	L_0000066-000001313c1	5	131.4
14	L_0000077-0000088c1	5	
15	L_0000077-0000099c1	6	
16	L_0000099-000001010c1	6	107.6
17	L_0000099-000001414c1	4	

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18	L_000001010-000001111c1	4	
19	L_000001212-000001313c1	3	
20	L_000001313-000001414c1	1	

TABLE 6: Result of Contingency Analysis Violations solved after placing FACTS device on 14 bus system.

Total no of contingencies	20	Start time	08/11/2015 3:53:13 pm
No of processed	20	end time	08/11/2015 3:53:13 pm
No of unsolvable	0	Total run time	0.64 sec
No of violations	96	Avg time per ctg	0.032 sec

TABLE 7: LODF of 14 Bus systems after placing FACTS device in line 4-7.

S.NO	FROM LINE	TO LINE	% LODF	MW from	MW to
1	1	2	-100	172.3	-166.2
2	1	5	100	94.9	-90
3	2	3	-16.9	69.3	-67
4	2	4	-35.3	73.1	-70
5	2	5	-47.9	60.7	-58.6
6	3	4	-16.9	2.8	-2.5
7	4	5	-49.8	-54.3	54.7
8	4	7	-1.6	52.7	-52.7
9	4	9	-0.7	24.1	-24.1
10	5	6	2.3	68.9	-57.9
11	6	11	2.3	17.5	-16.1
12	6	12	0	30.8	-28.8
13	6	13	0	79.6	-70.7
14	7	8	0	-1	1
15	7	9	-1.6	53.7	-53.7
16	9	10	-2.3	40.8	-40.2
17	9	14	0	0	0
18	10	11	-2.3	11.2	-10.9
19	12	13	0	13.8	-13
20	13	14	0	48.6	-36

TABLE 8: PTDF of 14 bus system after placing FACTS device in line 4-7.

S.NO	FROM LINE	TO LINE	% PTDF from	% PTDF to
1	1	2	-21.17	21.17
2	1	5	21.17	-21.17
3	2	3	14.38	-14.38
4	2	4	30.1	-30.1
5	2	5	34.35	-34.35
6	3	4	14.38	-14.38
7	4	5	15.83	-15.83
8	4	7	19.61	-19.61
9	4	9	9.04	-9.04
10	5	6	71.35	-71.35

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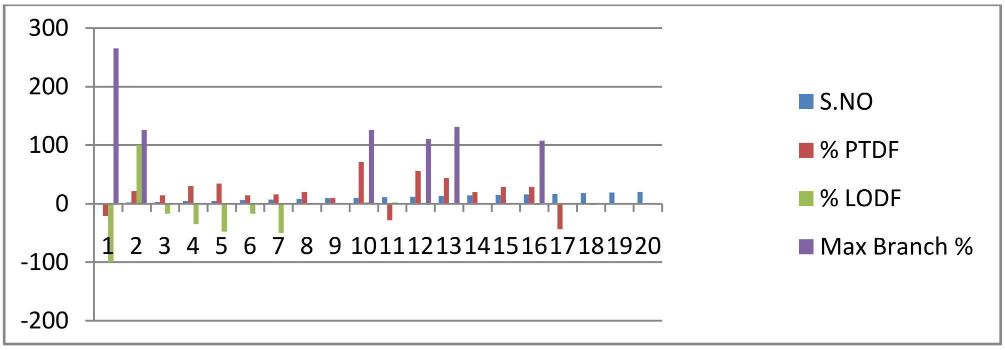
11	6	11	-28.65	28.65
12	6	12	56.34	-56.34
13	6	13	43.66	-43.66
14	7	9	19.61	-19.61
15	9	10	28.65	-28.65
16	10	11	28.65	-28.65
17	12	13	-43.66	-43.66

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



The table 5 shows the Contingency Analysis of 14 bus system when 9-14 line is open after placing the FACTS device on the line 4-7 i.e. (Compensating the line reactance 70% to its natural value). The overloaded lines 6-13 and 13-14 are comes into normal condition which is shown in figure 6. The number of violations are reduced to 117to 96 are shown in table 6.The LODF, PTDF calculations for 14 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 4-7 line is 0.20912 to 0.146385 (70% compensation) and MVA limit of 6-13 line is changed to 110% to 150% and 13-14 line is changed to 13-14 then the lines have come back to within its operational limits.

For Multiple Contingency (N-1-1) Analysis

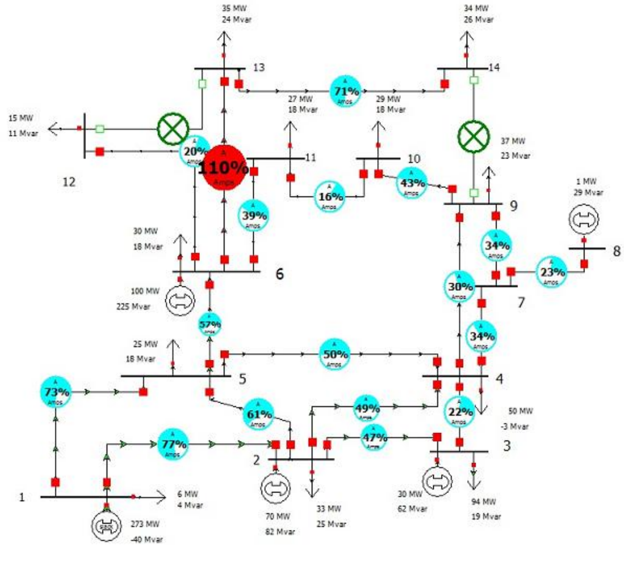


Figure 7: N-1-1 Line Contingency on 14 bus system

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E. Result and Discussion for 14 Bus system:

TABLE 9: Results of Multiple Contingency Analyses.

S.NO	Line details	Violations	Max branch %
1	L_0000011-0000022c1	4	109.8
2	L_0000011-0000055c1	6	125.7
3	L_0000022-0000033c1	4	109.8
4	L_0000022-0000044c1	4	109.8
5	L_0000022-0000055c1	4	109.8
6	L_0000033-0000044c1	4	109.8
7	L_0000044-0000055c1	4	109.8
8	L_0000044-0000077c1	5	109.8
9	L_0000044-0000099c1	5	109.8
10	L_0000055-0000066c1	10	126.1
11	L_0000066-000001111c1	7	109.8
12	L_0000066-000001212c1	4	109.8
13	L_0000066-000001313c1	1	
14	L_0000077-0000088c1	7	109.8
15	L_0000077-0000099c1	6	109.8
16	L_0000099-000001010c1	6	109.8
17	L_0000099-000001414c1	4	109.8
18	L_000001010-000001111c1	5	109.8
19	L_000001212-000001313c1	4	109.8
20	L_000001313-000001414c1	1	

TABLE10 : N-1-1 Contingency Analysis of 14 bus system

Total no of contingencies	20	Start time	08/22/201511:25:52AM
No of processed	20	end time	08/22/201511:25:52AM
No of unsolvable	0	Total run time	0.28 sec
No of violations	89	Avg time per ctg	0.014 sec

Table 11: LODF of 14 bus system when the line 9-14 open

S.NO	FROM LINE	TO LINE	% LODF	MW from	MW to
1	1	2	2.9	171.8	-165.6
2	1	5	-2.9	94.8	-89.9
3	2	3	2.5	69.1	-66.8
4	2	4	5.2	72.8	-69.7
5	2	5	-4.8	60.7	-58.6
6	3	4	2.5	2.6	-2.3
7	4	5	-41.5	-52.6	53

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8	4	7	31.3	47.7	-47.7
9	4	9	17.9	27	-27
10	5	6	-49.2	70.5	-59.1
11	6	11	50.8	19.6	-18.2
12	6	12	0	15.5	-15
13	6	13	-100	94	-81.5
14	7	8	0	-1	1
15	7	9	31.3	48.7	-48.7
16	9	10	-50.8	38.6	-38
17	9	14	0	0	0
18	10	11	-50.8	9	-8.8
19	12	13	0	0	0
20	13	14	-100	46.5	-34

Table 12: LODF of 14 bus system when the line 12-13 open

S.NO	FROM LINE	TO LINE	% LODF	MW from	MW to
1	1	2	0	171.8	-165.6
2	1	5	0	94.8	-89.9
3	2	3	0	69.1	-66.8
4	2	4	0	72.8	-69.7
5	2	5	0	60.7	-58.6
6	3	4	0	2.6	-2.3
7	4	5	0	-52.6	53
8	4	7	0	47.7	-47.7
9	4	9	0	27	-27
10	5	6	0	70.5	-59.1
11	6	11	0	19.6	-18.2
12	6	12	100	15.5	-15
13	6	13	-100	94	-81.5
14	7	8	0	-1	1
15	7	9	0	48.7	-48.7
16	9	10	0	38.6	-38
17	9	14	0	0	0
18	10	11	0	9	-8.8
19	12	13	0	0	0
20	13	14	0	46.5	-34

The tables 11 and 12 represent LODF's of a 14 bus
Power system when the lines 9-14 and 12-13 are opens

Table 13: PTDF of 14 bus system when the line 9-14open

S.NO	FROM LINE	TO LINE	% PTDF from	% PTDF to
1	1	2	-2.94	2.94
2	1	5	2.94	-2.94
3	2	3	-2.49	2.49
4	2	4	-5.21	5.21
5	2	5	4.77	-4.77
6	3	4	-2.49	2.49

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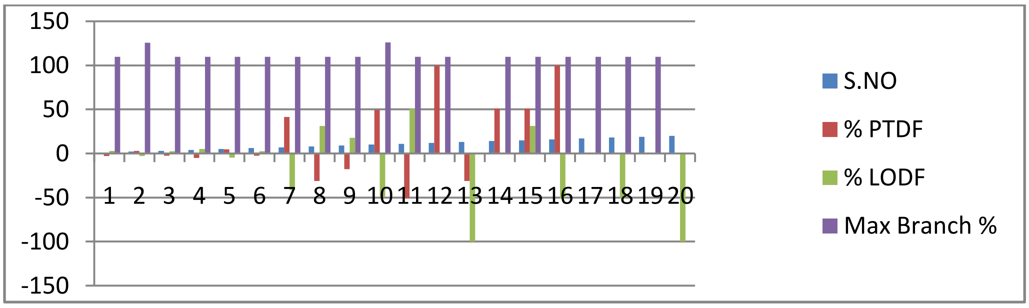
7	4	5	41.52	-41.52
8	4	7	-31.28	31.28
9	4	9	-17.95	17.95
10	5	6	49.23	-49.23
11	6	11	-50.77	50.77
12	6	13	100	-100
13	7	9	-31.28	31.28
14	9	10	50.77	-50.77
15	10	11	50.77	-50.77
16	13	14	100	-100

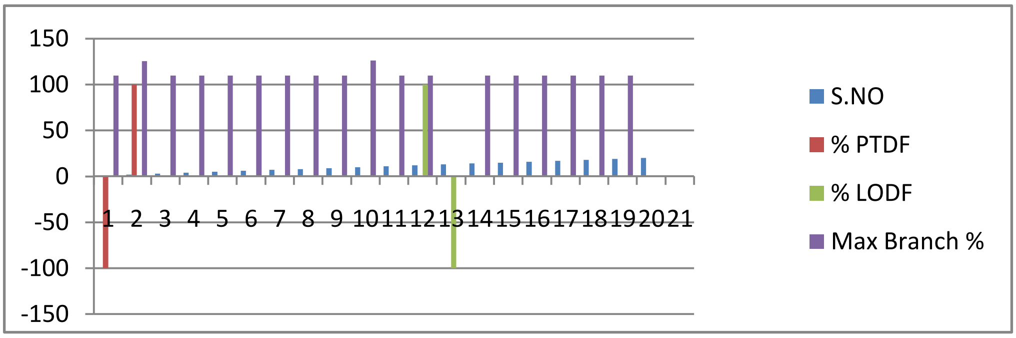
Table 14: PTDF of 14 bus system when the line 12-13 open

S.NO	FROM LINE	TO LINE	% PTDF from	% PTDF to
1	6	12	-100	100
2	6	13	100	-100

The tables 13 and 14 represent PTDF's of a 14 bus power system when the lines 9-14 and 12-13 are opens.

F. Comparison of Max branch %MVA limit, LODF and PTDF for the line 9-14





Comparison of Max branch %MVA limit, LODF and PTDF for the line 12-13

The figure represents Multiple Contingency Analysis of 14 bus system when the multiple lines 9-14 and 12-13 are opens. When the lines 9-14 and 12-13 were opened before placing the FACTS device in the most positive sensitivity line 4-7. The overloaded line 6-13 is shown in figure7 .The total number of violations in the Multiple Contingency Analysis was 89 which are shown in table10. The LODF and PTDF values calculated for both lines 9-14 and 12-13 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 figures F.

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7.4.4 After Remedial action taken on 14-bus system:

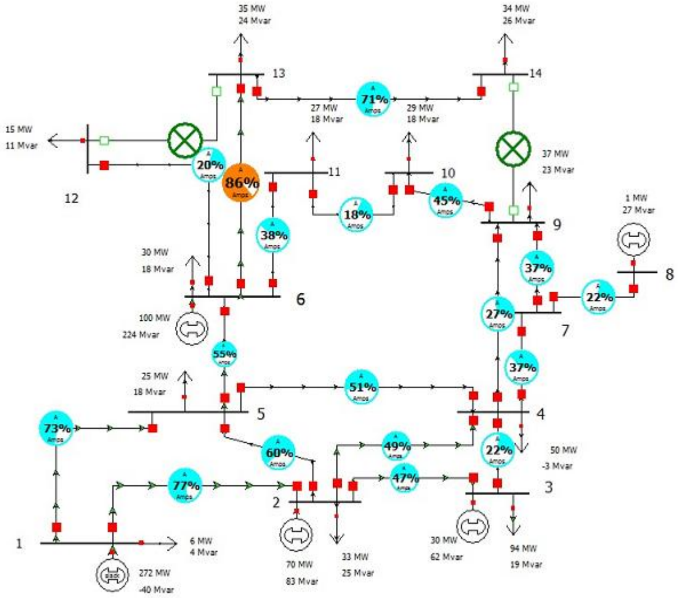

Figure 8: Multiple Contingency (N-1-1) Line violations solved after placing the FACTS device on line 4-7.

Table 15: Summary of N-1-1 Contingency Analysis Violations solved after placing FACTS device on 14 bus system.

Total no of contingencies	20	Start time	08/22/201511:25:52AM
No of processed	20	end time	08/22/201511:25:52AM
No of unsolvable	0	Total run time	0.33 sec
No of violations	71	Avg time per ctg	0.016 sec

Table 16: N-1-1 Contingency Analysis of 14 Bus System:

S.NO	FROM LINE	TO LINE	% LODF	MW from	MW to
1	1	2	3	171.5	-165.4
2	1	5	-3	94.4	-89.9
3	2	3	2.6	69.2	-66.9
4	2	4	5.4	72.8	-69.8
5	2	5	-4.9	60.3	-58.3
6	3	4	2.6	2.7	-2.3
7	4	5	-42.7	-54.4	54.8
8	4	7	34.7	52.5	-52.5
9	4	9	16	24	-24
10	5	6	-50.7	68	-57.3
11	6	11	49.3	17.8	-16.4
12	6	12	0	15.5	-15
13	6	13	-100	94	-81.5
14	7	8	0	-1	1
15	7	9	34.7	53.5	-53.7

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16	9	10	-49.3	40.5	-39.8
17	9	14	0	0	0
18	10	11	-49.3	10.8	-10.6
19	12	13	0	0	0
20	13	14	-100	46.5	-34

The table 15 denotes summary of N-1-1 Contingency Analysis violations solved after placing FACTS device on 14 bus system. The total numbers of violations were reduced from 89 to 71 and the total run time and average time per contingency is also reduced. The table 16 shows Multiple Contingency Analysis (N-1-1) of 14 bus system when the lines 9-14 and 12-13 lines were opened after placing the FACTS device on the most sensitive line 4-7. The overloaded line 6-13 is comes into within the operational limits which is shown in figure 8.

Table 17: LODF of 14 bus system after placing FACTS device when the line 9-14 open

S.NO	FROM LINE	TO LINE	% LODF	MW from	MW to
1	1	2	3	171.5	-165.4
2	1	5	-3	94.4	-89.9
3	2	3	2.6	69.2	-66.9
4	2	4	5.4	72.8	-69.8
5	2	5	-4.9	60.3	-58.3
6	3	4	2.6	2.7	-2.3
7	4	5	-42.7	-54.4	54.8
8	4	7	34.7	52.5	-52.5
9	4	9	16	24	-24
10	5	6	-50.7	68	-57.3
11	6	11	49.3	17.8	-16.4
12	6	12	0	15.5	-15
13	6	13	-100	94	-81.5
14	7	8	0	-1	1
15	7	9	34.7	53.5	-53.7
16	9	10	-49.3	40.5	-39.8
17	9	14	0	0	0
18	10	11	-49.3	10.8	-10.6
19	12	13	0	0	0
20	13	14	-100	46.5	-34

Table 18: LODF of 14 bus system after placing FACTS device when the line 12-13 opens

S.NO	FROM LINE	TO LINE	% LODF	MW from	MW to
1	1	2	0	171.5	-165.4
2	1	5	0	94.4	-89.6
3	2	3	0	69.2	-66.9
4	2	4	0	72.8	-69.8
5	2	5	0	60.3	-58.3
6	3	4	0	2.7	-2.3
7	4	5	0	-54.4	54.8
8	4	7	0	52.5	-52.5
9	4	9	0	24	-24
10	5	6	0	68	-57.3
11	6	11	0	17.8	-16.4
12	6	12	100	15.5	-15
13	6	13	-100	94	-81.5

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14	7	8	0	-1	1
15	7	9	0	53.5	-53.5
16	9	10	0	40.5	-39.8
17	9	14	0	0	0
18	10	11	0	10.8	-10.6
19	12	13	0	0	0
20	13	14	0	46.5	-34

Table 19: PTDF of 14 bus system after placing FACTS device when the line 9-14 opens

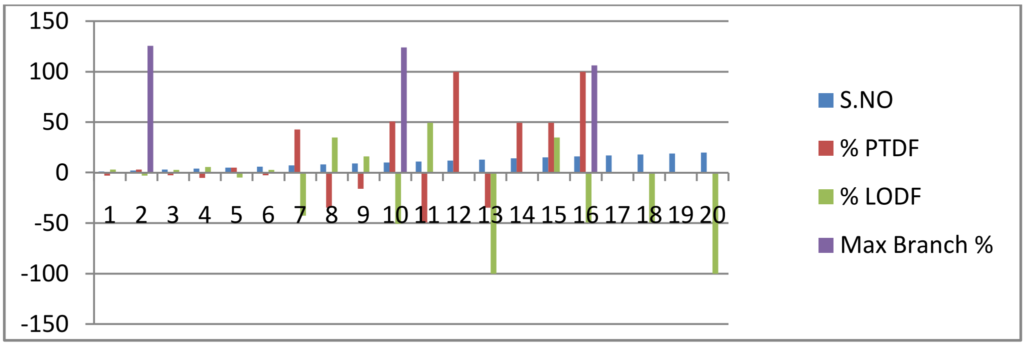
S.NO	FROM LINE	TO LINE	% PTDF from	% PTDF to
1	1	2	-3.02	3.02
2	1	5	3.02	-3.02
3	2	3	-2.56	2.56
4	2	4	-5.37	5.37
5	2	5	4.91	-4.91
6	3	4	-2.56	2.56
7	4	5	42.73	-42.73
8	4	7	-34.68	34.68
9	4	9	-15.99	15.99
10	5	6	50.66	-50.66
11	6	11	-49.34	49.34
12	6	13	100	-100
13	7	9	-34.68	34.68
14	9	10	49.34	-50.77
15	10	11	49.34	-49.34
16	13	14	100	-100

Table 20: PTDF of 14 bus system after placing FACTS device when the line 12-13 opens

S.NO	FROM LINE	TO LINE	% PTDF from	% PTDF to
1	6	12	-100	100
2	6	13	100	-100

The tables 17, 18, 19 and 20 are represents LODF and PTDF of 14 bus power system when the lines 9-14 and 12-13 lines were opens.

G :Comparison of Max branch %MVA limit, LODF and PTDF for the line 9-14



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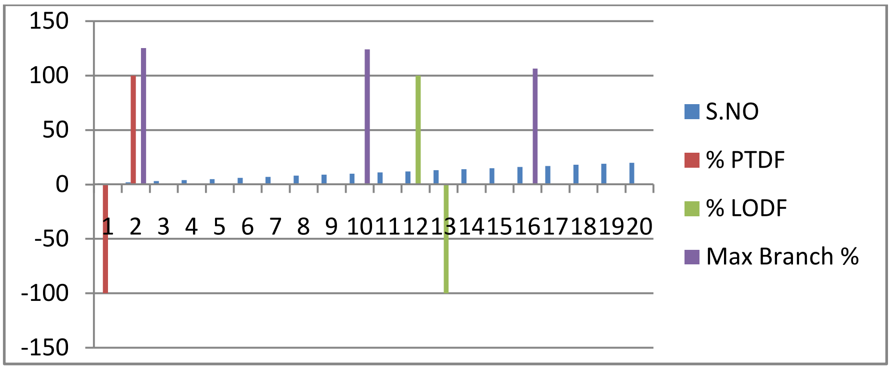

Figure : Comparison of Max branch %MVA limit, LODF and PTDF for the line 12-13

The comparison of Max Branch % MVA Limit, % LODF, %PTDF for the multiple lines 9-14 and 12-13 were shown in figures.
Some of the lines are resonant more power than its limit. Remedial Actions should be taken to solve these MVA violations which are by placing the FACTS device, Thyristor Controlled Series Capacitor in most positive sensitivity line in the power system i.e. 4-7. After reducing the reactance of 4-7 line is 0.20912 to 0.146384 (70% compensation) and MVA limits are changes in the line 6-13 as 160% to 125% is comeback to within its operational limits.

IX. CONCLUSION

In this project contingency analysis technique is used to predict the effect of outages caused by line outage in a power transmission system. For each outage tested, the contingency analysis procedure checks all power flows and violations in the network against their respective limits. Contingencies may results in severe violations of the operating constraints. Consequently, planning for contingencies forms an important aspect of secure operation. The contingency analysis was successfully tested on modified IEEE 14 bus systems. . FACTS devices like TCSC by limit the flows in the network will help to bring down the flows in solidly loaded lines.

X. FUTURE SCOPE

A arrangement of events consisting of the initial loss of a single generator or transmission component (Primary Contingency), followed by system modifications, followed by another loss of a single generator or transmission element (Secondary Contingency) is called N-1-1 Contingency. A system that happens N-1-1 standards would not expose any violations during any of the Primary Contingencies, or during any of the Secondary Contingencies, with each of the Primary Contingencies as the orientation case. Contingency analysis may be used to model the outages and the system modifications. If all effective system modifications are well-understood, contingency analysis may be the only tool wanted. The N-1-1 process contains logic to select the system modifications most likely to benefit the post contingency conditions of all of the N-1-1 contingencies and applies them to the N-1 base case.

The sensitivity factor methods implemented for location of TCSC as these devices are already in operation. This slant can be extended to other FACTS devices also as they can shift the method from 'preventive' approach requiring large standbys for emergency purpose to a 'corrective' approach by creating instant corrections with fewer multipurpose, controllable and manageable devices.

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