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Establishing Contingency Analysis with FACTS Devices Using Power World Simulator

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Contingency analysis is the protection of power system operation under the loss of one or more of the major power system components. It is widely used to predict the effect of outages of transmission lines and generators. To calculate the number of violation, contingency analysis is the most preferable choice. Power systems use contingency analysis to foretell the result of any component failure. Contingency analysis is an application that uses a simulated model of power system to judge the result and calculate any overload. The proposed method approaches the flexible AC transmission system (FACTS) device to reduce the power flow in heavily loaded line and also increase the system performance. In this work, FACTS devices were implemented in IEEE 6-bus and IEEE 14-bus system and it is simulated by using Power World Simulator Software.

Keywords: Contingency analysis; Flexible AC transmission system (FACTS); Single contingency; Multiple contingency; Line outage distribution factors (LODFs)

Introduction

The power system security is the most difficult work because of great rivalry in open approach network. The most challenging task in security estimation is that gives knowledge about the system state in the event of contingency. By designing and operation, the main role is to control all areas in order to give protection, because any outage of equipment leads to transient instability. By using the line outage distribution factor (LODF), the outage of second line can cause small changes in the power flow. As compared with the pre-contingency taken with LODF with similar data [1], usually contingency analysis is segregated in three parts of contingency definition, selection and evaluation [2]. Contingency analysis results in line flow, voltage or reactive power violations that are simulated with hypothetical tests [3].

The effective way that we use is Flexible AC Transmission System (FACTS), which can make smaller the transmission congestion and control the devices by modeling their approximate sizes, optimal locations, settings and cost. A series compensator (Thyristor-Controlled Series Compensation, TCSC) is connected in series with transmission line in order to control the 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 [4].

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In present work, the effort has been given on contingency analysis with D-FACTS devices in order to reduce the number of violations that take place in transmission line by a respond based on current. The respond based on current has auto configure characteristic curve parameters, like max compensation, initial current and limit current. In this paper two different bus systems are compared with different cases and it results in multiple contingency that will be more effective than single in each system.

Contingency Analysis

Contingency analysis classifies the power system into two stages as secure and insecure states. When the number of contingency is more, contingency analysis took a time-consuming process. Contingency may possibly cause harmful disturbances that exit under the control state of power system. Contingency referring to interrupts like generator, transformer and transmission line outages will cause quick and big changes in both the outline and the state of the system [4, 5]. The contingency list is chosen by the help of contingency ranking.

The main objective is to find out the line overload and violations under such contingencies and to mitigate the violations. Voltage violation will take place in two methods, namely single contingency and multi contingency. AC load flow is more accurate than DC load flow analysis [6]. Single contingency will take less time as compared to thousands of outages that take place in the system. Contingency analysis is studies in two types of tools namely on line and off line analysis [5]. In contingency analysis, two types of contingency are generator contingency and line contingency, which can occur due to two types of violations.

1. Low voltage violation
2. Line MVA limit violation.

Low voltage violation occurs due to insufficient reactive power, while line MVA limit violation takes place when it goes beyond its actual rating.

The line outage distribution factors are also defined similarly. The LODF is defined by,

$$\beta_{ij,mn} = \frac{\Delta f_{ij}}{f(0)_{mn}}$$

where $\beta_{ij,\,mn}$ is the line outage distribution factor for line 'i-j' under outage of line 'm-n', and f (0) mn is the power flow over line 'm-n' in the pre-outage condition. Therefore, for the outage of line 'm-n', the new flow over line 'i-j' is given.

Static Modelling of FACTS Devices

FACTS is a power electronic based system and other static equipment that provide control of one or more AC transmission system parameters to enhance controllability and increase power transfer capability [7]. Some benefits of FACTS devices are

- Increase the loading of line to thermal capability.
- Reduce power flow in heavily loaded line.
- Improve the stability, quality of supply, availability, reliability and load ability of the power system.
- Reduce reactive power flows and load flows.
- Limit the short circuit current and overloads.

Series compensator (TCSC) is used in system for reducing the violation. It is connected to the transmission line where the voltage rating is beyond its rating in order to reduce the rating.

Thyristor Controlled Series Compensator (TCSC)

In transmission line, it is connected in series where it improves the voltage profile of the system line [8]. A basic setup of TCSC is shown in Figure 1.

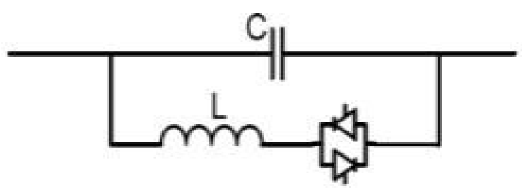

Figure 1. Basic setup of TCSC

The impedance of this circuit is

$$X_{TCSC}(\alpha)=\frac{XcXt(\alpha)}{X1(\alpha)-Xc}$$

Where α is the firing angle, X_L is the inductor reactance and X1 is inductor effective reactance at firing angle α

$X_L \leq X_{1(\alpha)} \leq \infty$

Let the complex power flowing from bus m to bus n can be expressed as

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

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

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 losses in the line can be calculated as

$P_L=P_{mn}+P_{nm}$

$Q_L=Q_{mn}+Q_{nm}$

TCSC have two modes of operation in direction of the circuit resonance depending on the value of firing angle. Main purposes of the TCSC are to minimize the total power loss, generation cost and reactive power generation limits [9, 10].

Power World Simulator

Power world simulator was founded in 1996 by professor Thomas J. Overbye of the University of Illinois at Urbana-Champaign [11]. Simulator 5.0 is the first version. Recently, simulator 17 is used with new ribbon interface and it is a very advanced version used in all type of systems.

The steps taken for optimal power flow in power world simulator include [12]:

STEP 1: In ‘Edit Mode’, sketch single line diagram of given power system network with specified data.

STEP 2: During ‘Run Mode’, run the optimal power flow and find out the power flow in each transmission line.

STEP 3: Single Contingency is applied to power system and number of violations found in each transmission line without connecting FACTS devices.

STEP 4: Optimal placement of FACTS device can be found, in which the number of violations is in line.

STEP 5: After placing FACTS devices, run the power system with single contingency and compare the results.

STEP 6: The above steps are repeated for multi contingency case also.

The main advantage of contingency in power world simulator is that it automatically runs through a list of 1000’s of contingency, creates a list of system overloads and voltage problems seen during these contingencies and compares the results of two contingencies runs [13, 14].

Results and Discussion

The IEEE-6 bus system and IEEE-14 bus system are simulated in the power world simulator, which involve contingency analysis. There are different cases in bus systems and it is differentiated below.

Case I

IEEE 6 Bus System- Single Contingency (without D-FACTS)

The single line diagram for IEEE-6 bus system is shown in Figure 2 and the bus output data, generator data and load data values are given in Table 1.

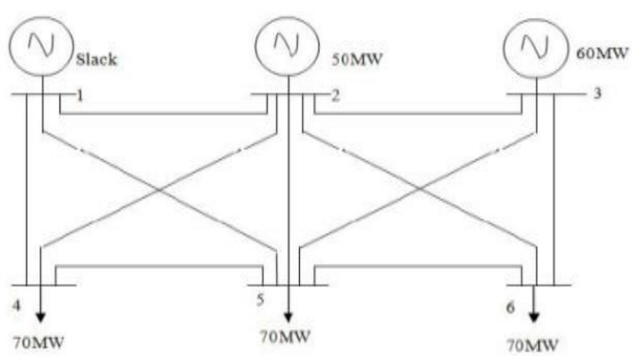

Figure 2. One line diagram of 6-bus system

Table 1. Bus data of IEEE 6-bus system

Bus no	Bus type	V(p.u)	Pd (MW)	Qd (Mvar)	Pg (MW)	Qg (Mvar)
1	Slack	1.05	0	0	0	0
2	PV	1.05	0	0	50	0
3	PV	1.07	0	0	60	0
4	PQ	1.0	70	70	0	0
5	PQ	1.0	70	70	0	0
6	PQ	1.0	70	70	0	0

The generator real and reactive power outputs for the test system is shown in Table 2. The maximum and minimum MW and MVR ranges are also specified in this table.

Table 2. Generator data of IEEE 6-bus system

BUS NO	P min (MW)	P max (MW)	Q min (Mvar)	Q max (Mvar)	ai $/MW² - h	bi $/MW² - h	ci $/MW² – h
1	50	200	-20	100	0.0107	11.669	213.1
2	37.5	150	-20	100	0.0178	10.333	200
3	45	180	-15	100	0.0148	10.833	240

The line data of IEEE-6 for the test system is shown in Table 3. The real, reactive power and suspectance values are specified in this table.

Table 3. Line data for IEEE-6 bus system

FROM BUS	TO BUS	R(p.u)	X(p.u)	Half line charging suspectance (p.u)	Thermal limit (MVA)
1	2	0.1	0.2	0.02	40
1	4	0.05	0.2	0.02	60
1	5	0.08	0.3	0.03	50
2	3	0.05	0.25	0.03	40
2	4	0.05	0.1	0.01	70
2	5	0.10	0.3	0.02	30
2	6	0.07	0.2	0.025	90
3	5	0.12	0.26	0.025	70
3	6	0.02	0.1	0.01	80
4	5	0.2	0.4	0.04	20
5	6	0.1	0.3	0.03	40

The contingency analysis of 6-bus test system is shown in Figure 3, when the power flow is running on the power world simulator.

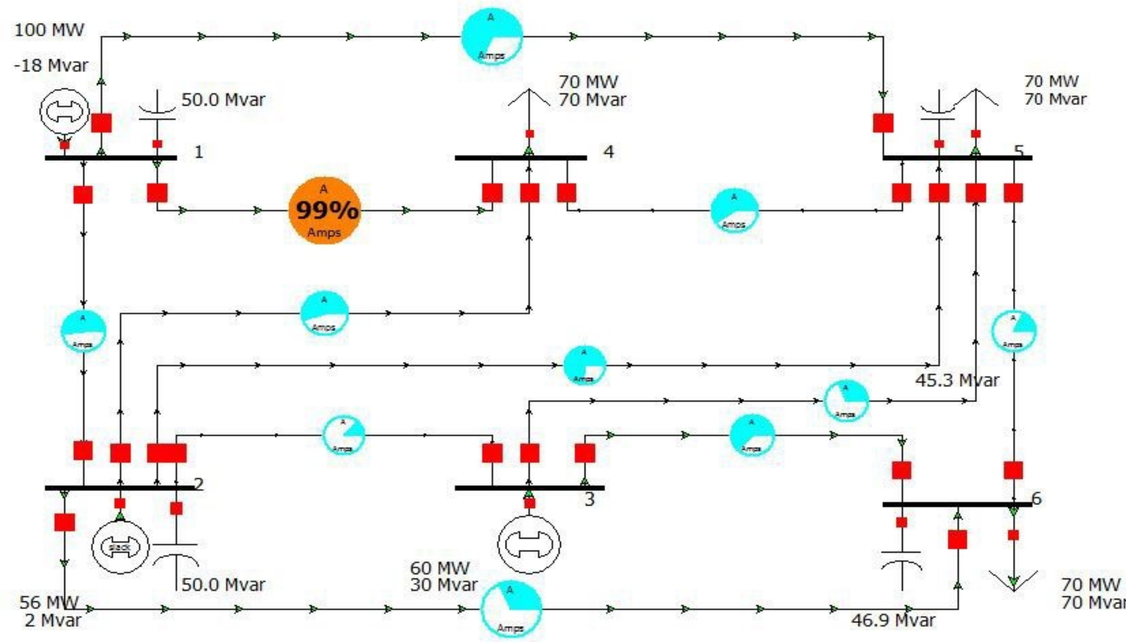

Figure 3. Simulink one line diagram of 6-bus system without D-Facts

Base Case Power Flow List

Table 4 shows the base case power flow values for IEEE-6 bus system without D-FACTS.

Table 4. Base case power flow list

From bus	To bus	MW	Mvar	From bus	To bus	MW	Mvar
1	2	18.27	-9.61	2	1	-17.86	8.43
1	4	48.53	34.76	4	1	-46.71	-29.32
1	5	33.28	7.31	5	1	-32.33	-6.61
2	3	4.40	-2.35	3	2	-4.39	-0.60
2	4	21.88	31.36	4	2	-21.70	-30.20
2	5	19.97	8.95	5	2	-19.47	-9.36
2	6	27.88	5.17	6	2	-27.31	-5.96
3	5	19.61	8.66	5	3	-19.03	-9.79
3	6	44.78	22.37	6	3	-44.27	-20.81
4	5	-2.18	-10.48	5	4	2.38	7.43
5	6	-1.55	-6.39	6	5	1.58	3.72

No. of Overloads Occurred when Each Line is Opened

Table 5 shows the total no. of overloads that occurred in IEEE-6 bus system with single contingency. The total no. of overloads taken is 15 without D-FACTS in transmission line.

Table 5. Overload in each line

FROM BUS	TO BUS	NO OF OVERLOAD
1	2	1
1	4	4
1	5	3
2	3	0
2	4	2
2	5	1
2	6	0
3	5	1
3	6	1
4	5	1
5	6	1
Total no of overloads		**15**

Ranking of lines

The transmission line 1-4 shows that it is ranked first due to maximum number of overloads.

Table 6. Ranking for 6 bus system without D-FACTS

LINE	RANKING
1-4	I (1009%)
4-5	II (295%)
1-2	III (229%)
2-4	IV (126%)
2-5	V (112%)

IEEE 6 Bus System - Single Contingency (with D-FACTS)

The contingency analysis of 6-bus test system is shown in Figure 4.

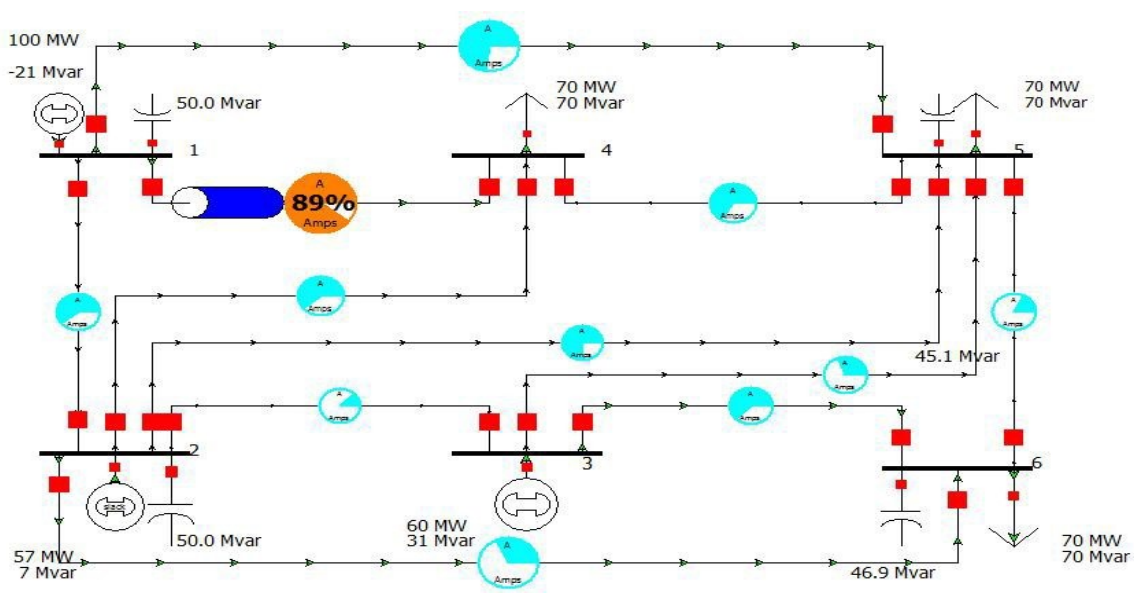

Figure 4. Simulink one line diagram of 6-bus system with D-Facts

Base Case Power Flow List

Table 7 shows the base case power flow values for IEEE-6 bus system with D-FACTS.

Table 7. Base case power flow list

From bus	To bus	MW	Mvar	From bus	To bus	MW	Mvar
1	2	18.23	-9.61	2	1	-17.82	8.42
1	4	48.51	34.75	4	1	-46.69	-29.32
1	5	33.26	7.31	5	1	-32.32	-6.62
2	3	4.41	-2.36	3	2	-4.4	-0.59
2	4	21.90	31.37	4	2	-21.12	-30.20
2	5	19.98	8.95	5	2	-19.48	-9.36
2	6	27.89	5.17	6	2	-27.31	-5.95
3	5	19.62	8.66	5	3	-19.04	-9.79
3	6	44.78	22.38	6	3	-44.27	-20.82
4	5	-2.19	-10.48	5	4	2.39	7.43
5	6	-1.56	-6.39	6	5	1.59	3.72

No. of Overloads Occurred when Each Line is Opened

Table 8 shows the total no. of overloads that occurred in IEEE-6 bus system with single contingency. The total no. of overloads taken is 10 with D-FACTS in transmission line.

Table 8. Overload occurred in each line

From bus	To bus	No of overload
1	2	1
1	4	3
1	5	1
2	3	0
2	4	1
2	5	2
2	6	0
3	5	0
3	6	0
4	5	2
5	6	0
Total no of overloads		**10**

Ranking of Lines

The transmission line 1-4 shows that it is ranked first due to maximum number of overloads (Table 9).

Table 9. Ranking of line

LINE	RANKING
1-4	I (362%)
2-5	II(332%)
1-2	III(246%)
2-5	IV(218%)
2-4	V(126%)

Comparison of IEEE 6 bus system

The comparison of IEEE-6 bus systems with D-FACTS and without D-FACTS between the connection of transmission lines is shown in Table 10 and Figure 5.

Table 10. Comparison of 6 bus system

From bus	To bus	No. of overload without D-FACTS	No. of overload with D-FACTS
1	2	1	1
1	4	4	3
1	5	3	1
2	3	0	0
2	4	2	1
2	5	1	2
2	6	0	0
3	5	1	0
3	6	1	0
4	5	1	2
5	6	1	0
Total no. of overloads		**15**	**10**

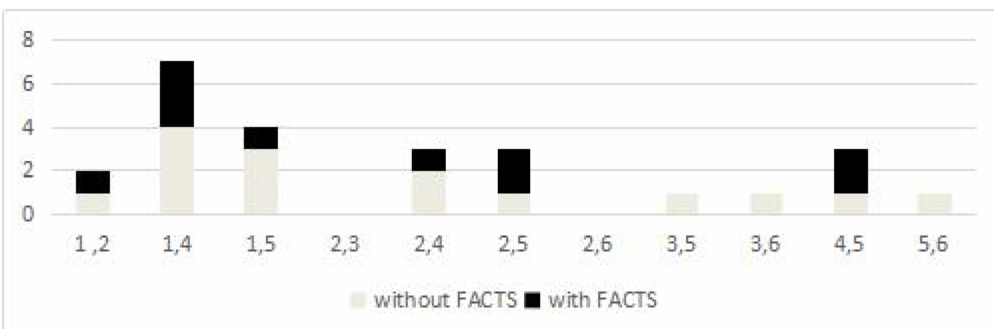

Figure 5. Bar chat for the IEEE 6 bus system comparison

CASE II

IEEE-6 Bus System - Multi Contingency (without D-FACTS)

Multiple contingency is that we calculate the number of overloaded lines in each case and ranking for line, when two or more lines are opened simultaneously

No. of Overloads when Double Contingency Take Place

Table 11. No. of overload for double contingency

LINES OPENED	NO OF OVERLOADS
(1-2,1-4)	3
(2-3,2-4)	3

No. of Overloads Occurred in Each Line

Number of overloads in double contingency for each line is shown in Table 12, in which only two cases are taken.

Table 12. Overload occurred in each line (double contingency)

From bus	To bus	No of overload
1	2	0
1	4	1
1	5	1
2	3	0
2	4	1
2	5	1
2	6	0
3	5	0
3	6	0
4	5	2
5	6	0
No of overloads		**6**

Ranking of Lines

The overall ranking is shown in Table 13. The line 4-5 is ranked first with the highest overload in two cases in double contingency.

Table 13. Ranking for double contingency

Line	Ranking
4-5	I
1-5	II
1-4	III
2-4	IV
2-5	V

CASE III

IEEE-14 Bus System- Single Contingency (without D-FACTS)

The single line diagram for IEEE-14 bus system is shown in Figure 6 and the bus output data, generator data and load data values are given in Table 14.

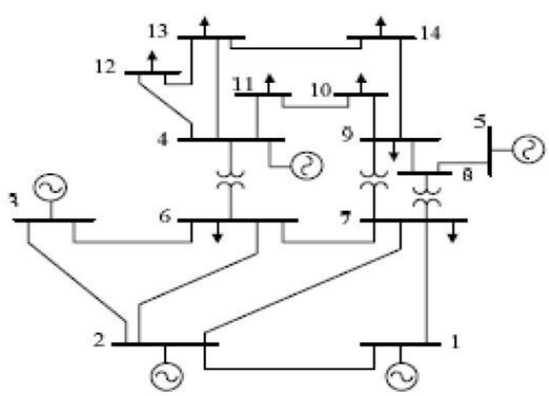

Figure 6. Single line diagram for IEEE-14 bus system

Table 14. Bus, generator and load value for IEEE-14 bus system

Bus no	Bus code	Voltage Magnitude	Angle	Load		Generator				Injected Mvar
				MW	Mvar	MW	Mvar	Q min	Q max	
1	1	1.06	0	30.38	17.78	40	-40	0	0	0
2	2	1.045	0	0	0	232	0	-40	50	0
3	3	1.01	0	131.88	26.6	0	0	0	40	0
4	4	1	0	66.92	10	0	0	0	0	0
5	5	1	0	10.64	2.24	0	0	0	0	0
6	6	1.07	0	15.68	10.5	0	0	-6	24	0
7	7	1	0	0	0	0	0	0	0	0
8	8	1.09	0	0	0	0	0	-6	24	0
9	9	1	0	41.3	23.24	0	0	0	0	0
10	1	1	0	12.6	8.12	0	0	0	0	0
11	11	1	0	4.9	2.52	0	0	0	0	0
12	12	1	0	8.54	2.24	0	0	0	0	0
13	13	1	0	18.9	8.12	0	0	0	0	0
14	14	1	0	20.86	7	0	0	0	0	0

Line Data for IEEE-14 Bus System

The line data value for IEEE-14 bus system is given in Table 15 with resistance, reactance, suspectance and thermal value.

Table 15. Line data of IEEE-14 bus system

From bus	To bus	R (p.u)	X (p.u)	B (p.u)	Thermal limit
1	2	0.01938	0.05917	0.0264	120
2	3	0.4699	0.19797	0.0219	65
2	4	0.05811	0.17632	0.0187	36
1	5	0.05403	0.22304	0.0246	65
2	5	0.05695	0.17388	0.017	50
3	4	0.06701	0.17103	0.0173	65
4	5	0.01335	0.04211	0.0064	45
5	6	0	0.25202	0	55
4	7	0	0.20912	0	32
7	8	0	0.17615	0	45
4	9	0	0.55618	0	18
7	9	0	0.11001	0	32
9	10	0.03181	0.0845	0	32
6	11	0.09498	0.1989	0	32
6	12	0.12291	0.25581	0	32
6	13	0.06615	0.13027	0	32
9	14	0.12711	0.27038	0	32
10	11	0.08205	0.19201	0	12
12	13	0.22092	0.19988	0	12
13	14	0.17093	0.34802	0	12

The contingency analysis of the 14-bus test system without D-FACTS contingency is shown in Figure 7 when the power flow is running on the power world simulator.

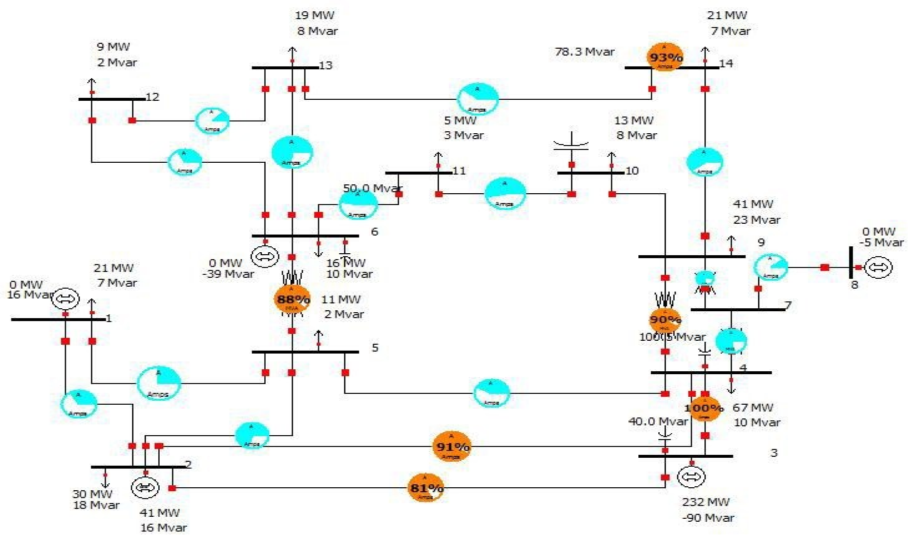

Figure 7. Simulink one line diagram of 14-bus system without D-Facts

Base Case Power Flow Analysis

Table 16 shows the base case power flow values for IEEE-14 bus system without D-FACTS.

Table 16. Base case power flow list

Between bus	MW	Mvar	Between bus	MW	Mvar
1-2	-37.73	11.68	2-1	38.04	-13.38
1-5	16.93	-2.84	5-1	-16.77	1.03
2-3	-91.84	30.57	3-2	96.28	-14.08
2-4	30.61	-11.44	4-2	-30.01	11.41
2-5	34.03	-8.11	5-2	-33.34	8.52
3-4	135.72	-36.13	4-3	-122.55	68.02
4-5	12.94	12.91	5-4	-12.89	-13.41
4-7	46.13	-0.57	7-4	-46.13	5.00
4-9	26.56	-1.26	9-4	-26.56	5.18
5-6	52.37	1.61	6-5	-52.37	5.37
6-11	4.52	-14.37	11-6	-4.31	14.83
6-12	10.07	2.88	12-6	-9.94	-2.60
6-13	22.10	7.04	13-6	-21.74	-6.34
7-8	0	4.77	8-7	0	-4.73
7-9	46.13	-9.77	9-7	-46.13	12.18
9-10	14.26	-50.08	10-9	-13.43	52.28
9-14	17.13	9.49	14-9	-16.67	-8.49
10-11	0.83	17.90	11-10	-0.59	-17.35
12-13	1.40	0.36	13-12	-1.39	-0.36
13-14	4.23	-1.42	14-13	-4.19	1.49

No. of Overload in Each Line

Table 17 shows the total no. of overloads that occurred in IEEE-14 bus system with single contingency. The total no. of overloads taken is 41 without D-FACTS in transmission line.

Table 17. Overload for each line

Between line	overloads
1-2	0
1-5	1
2-3	1
2-4	4
2-5	3
3-4	4
4-5	3
4-7	2
4-9	3
5-6	5
6-11	1
7-8	0
7-9	2
9-10	3
9-14	1
10-11	2
12-13	1
13-14	3
Total no of overloads	**41**

Ranking for Lines

From Table 18, the transmission line 5-6 is ranked first with the maximum number of overloads, when D-FACTS is not connected to any of lines.

Table 18. Ranking for IEEE-14 bus system (without D-FACTS)

BETWEEN LINES	RANKING
5-6	I
3-4	II
2-4	III
9-10	IV
2-5	V

IEEE-14 Bus system - Single Contingency (with D-FACTS)

The contingency analysis of the 14-bus test system with D-FACTS is shown Figure 8, in which the power flow is running on the power world simulator.

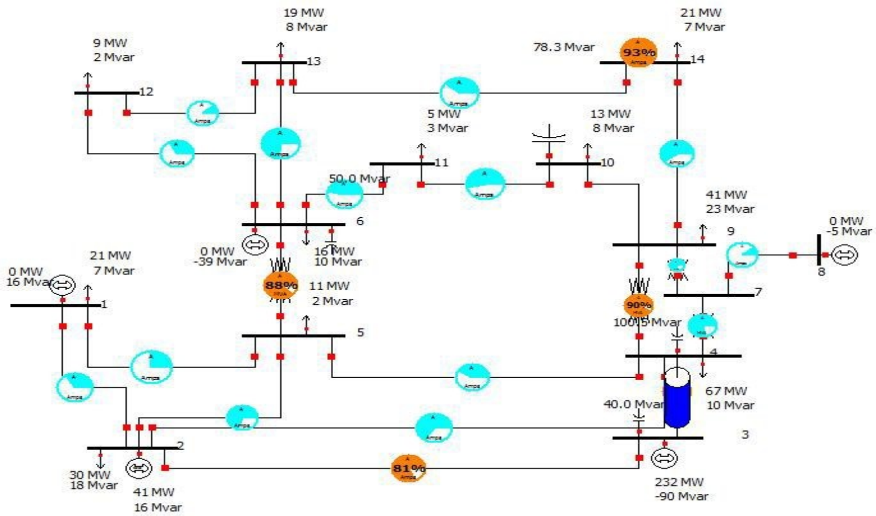

Figure 8. Simulink one line diagram of iEEEE-14 bus system with D-FACTS

Base Case Power Flow List (with D-FACTS)

Table 19 shows the base case power flow values for IEEE-14 bus system with D-FACTS.

Table 19. Base case power flow list

Between bus	MW	MVAR	Between bus	MW	MVAR
1-2	-38.45	11.82	2-1	38.77	-13.48
1-5	17.59	-3.56	5-1	-16.76	1.05
2-3	-95.44	32.33	3-2	96.28	-14.08
2-4	32.06	-12.96	4-2	-30.01	11.41
2-5	35.07	-9.09	5-2	-33.35	8.52
3-4	135.72	-36.12	4-3	-122.55	68.92
4-5	12.94	12.92	5-4	-12.90	-13.42
4-7	46.13	-0.58	7-4	-46.13	5.01
4-9	26.56	-1.26	9-4	-26.56	5.18
5-6	52.37	1.61	6-5	-52.37	5.38
6-11	4.52	-14.37	11-6	-4.31	14.83
6-12	10.07	2.88	12-6	-9.94	-2.60
6-13	22.10	7.04	13-6	-21.74	-6.34
7-8	0	4.77	8-7	0	-4.73
7-9	46.13	-9.77	9-7	-46.26	12.13
9-10	14.26	-50.08	10-9	-13.43	52.28
9-14	17.13	9.49	14-9	-16.67	-8.49
10-11	0.83	17.90	11-10	-0.59	-17.35
12-13	1.40	0.36	13-12	-1.39	-0.36
13-14	4.23	-1.42	14-13	-4.19	1.49

No. of Overload in Each Line

Table 20 shows the total no. of overloads that occurred in the IEEE-14 bus system with single contingency. The total no. of overloads taken is 32 with D- FACTS in transmission line.

Table 20. Overload for each line

Between line	Overloads
1-2	0
1-5	0
2-3	1
2-4	1
2-5	3
3-4	1
4-5	2
4-7	2
4-9	2
5-6	5
6-11	1
6-12	1
6-13	2
7-8	0
7-9	0
9-10	3
9-14	1
10-11	2
12-13	1
13-14	4
Total no of overloads	**32**

Ranking

From Table 21, it is noted that the transmission line 5-6 is ranked first with the maximum number of overloads, when D-FACTS is connected.

Table 21. Ranking for IEEE-14 bus system with D-FACTS

Between bus	Ranking
5-6	I
13-14	II
9-10	III
2-5	IV

Comparison of IEEE 14 Bus System

The comparison of IEEE-14 bus systems with D-Facts and without D-Facts between the connection of transmission lines is shown in Table 22 and Figure 9.

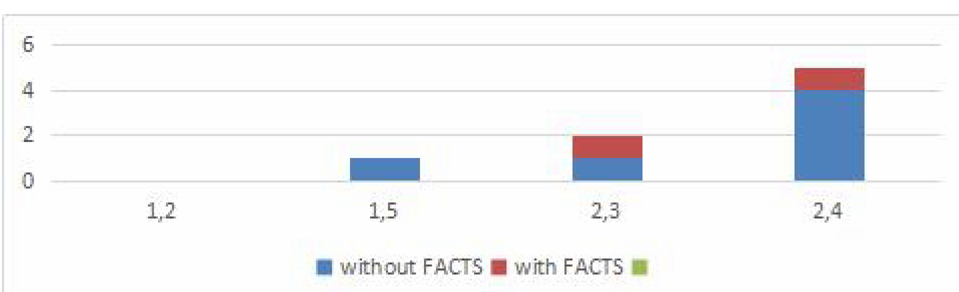

Figure 9. Bar chat for IEEE 14 bus system comparison

Table 22. Comparison of IEEE-14 bus systems with and without D-FACTS

Between line	No. of overloads without D-FACTS	No. of overloads with D-FACTS
1-2	0	0
1-5	1	0
2-3	1	1
2-4	4	1
2-5	3	3
3-4	4	1
4-5	3	2
4-7	2	2
4-9	3	2
5-6	5	5
6-11	1	1
6-12	0	1
6-13	2	2
7-8	0	0
7-9	2	0
9-10	3	3
9-14	1	1
10-11	2	2
12-13	1	1
13-14	3	4
Total no of overloads	**41**	**32**

CONCLUSIONS

Contingency analysis is used to foretell the results of outages that are caused in the transmission line. FACTS devices are used to bring down the flows within the limit in solidly loaded lines. The limit violations in the power system are effectively taken away after using the corrective actions. The security limits give an account from maximum violations of the element of test systems of both 6-bus and 14-bus system. In power world simulator, contingency analysis is not difficult to run the power system. Compared to other contingency analysis, it is more trustworthy.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this paper.

REFERENCES

[1] T. Guler, G. Gross, M. Liu, “Generalized Line Outage Distribution Factors”, IEEE Trans. Power System, vol. 22, no.2, pp. 879-881, May 2007.

[2] K.R. Rani, J. Amarnath, S.Kamakshaiah, “Contingency Analysis under Deregulated Power systems”, Automatic Control and Systems Engineering Journal, vol. 11, no. 2, pp. 1-8, November 2011.

[3] M. Ishimaru, R. Yokoyama, G. Shirai, K.Y. Lee, “Allocation and Design of Robust TCSC Controllers Based on Power System Stability Indec”, in Proceedings of 2002 IEEE Power Engineering Society Winter Meeting, vol.1, pp.573-578, November 2002. DOI: 10.1109/PESW.2002.985067

[4] N.K. Sharma, S.P. Phulambrikar, M. Prajapati, A. Sharma, “Contingency Ranking and Analysis using Power System Analysis Toolbox (PSAT)”, Innovative Systems Design and Engineering, vol. 4, no. 6, pp. 59-63, 2013.

[5] EPRI, “Contingency Analysis-Baseline”, IECSA vol. II, D38-1, 2010. http://smartgrid.epri.com/UseCases/ContingencyAnalysis-Baseline.pdf (accessed on 5/12/2018)

[6] D.M. Chary, “Contingency Analysis in Power Systems, Transfer Capability Computation and Enhancement Using Facts Devices in Deregulated Power Syste”, Ph.D. diss., Jawaharlal Nehru Technological University, 2011.

[7] P. Preeedavichit, S.C. Srivtsava, “Optimal Reactive Power Dispatch considering FACTS devices,” Electric Power Syste. Res., vol. 46, pp. 251-257, Sep. 1998.

[8] G.M. Huang, Y. Li, “Impact of Thyristor Controlled Series Capacitor on Bulk Power System Reliability”, in Proceedings of IEEE Power Engineering Society Summer Meeting, vol.2, pp.975-980, November 2002. DOI: 10.1109/PESS.2002.1043518

[9] D.S. Javan, H.R. Mashhadi, M. Rouhani, “Fast Voltage and Power Flow Contigencies Ranking using Enhanced Radial Basis Function Neural Network”, Iranian Journal of Electrical & Electronic Engineering, vol. 7, no. 4, pp. 273-282, Dec. 2011.

[10] A.J. Wood, B.F. Wallenberg, “Power Generation, Operation and Control”. 2nd ed., New York, USA:John Wiley&Sons, pp. 410-432,1996.

[11] S.R. Dahman, “N-1-1 Contingency Analysis using Power World Simulator”, PowerWorld Corporation, 2012. https://www.powerworld.com/files/SimulatorN-1-1.pdf (accessed 5/12/2018)

[12] Power World Corporation, “Simulator Version 16 user’s guide”, December 22, 2011. https://www.powerworld.com/files/Simulator16_Help_Printed.pdf (accessed on 5/12/2018).

[13] J. Odom, “Transmission Planning Standards”, 2012. https://www.nerc.com/pa/Stand/Project%20200602%20Assess%20Transmission%20Future%20Needs1/footnoteb_webinar_20121018_final_wjk.pdf (accessed on 5/12/2018)

[14] Siemens PTI, “PSS®E Program Manual, Version 32”, June 2009.