POWER SYSTEM DISTURBANCES AND SENSITIVITY ANALYSIS METHODS AS A PART OF CONTINGENCY ANALYSIS

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Abstract: There is maximum amount of restructuring, regulation and deregulation and privatization of Electric companies. So, required quantity of energy is not supplied by the utilities to the customers. So, blocking occurs in the market of electrical power system. Due to this reason, transmission lines are operated above their rated limits and also bus voltages are not in a range of their limits. This paper is all about with the types of the changes and disturbances in the electrical deregulated market and solution methods for contingency analysis as a load flow study and sensitivity factor analysis methods. Also case study of IEEE-14 bus test system is carried out with the solution mentioned by sensitivity analysis under the condition of contingency to improve the GSF and LODF of lines. For that purpose AC load flow and real power flow performance index was found out.

Index Terms - **Load flow study, violations and outages, contingency analysis, sensitivity factors, performance indices, FACTS devices.**

1. Introduction

1.1 Distributed Transmission System

Electrical power is generated from the steam power plant, hydro power plant and nuclear power plant mostly. 11 kV power is generated from these all the power stations and then it is stepped up for the purpose of transmission and distribution. These all power generating plants are such where load centers are very far from the power plants, so it is necessary to step down the power for the distribution level. For the distribution level, it supplies power at different voltage levels for the use of suburban, business and industrialized levels. According to the demand of load like peak load and off peak load, the various amount of load is transmitted to the consumers.[8]

1.2 Conditions for balanced power system

Following conditions must be obtained for the balanced and secure power system[8]:

1. Loads and losses are supplied by the generators.
2. Buses are operated within the limit of their rated voltage value.
3. All the generators are operated within their real power and reactive power limits.
4. Transformers and power transmission lines are not overloaded.

1.3 Load Flow Analysis

For the contingency control actions load flow and power flow must be known, so entire power system is converted into digital system and load flow study is applied to the system for the analysis of powers. This method is known as a load flow study. From this study, bus voltages, line currents, real power flow and reactive power flow is obtained for the particular power system, which will be used for the following[8]:

1. Peak and off peak loading situations..
2. With line and generator outages.
3. For the parallel operations of generators.
4. For the new transmission line construction.
5. Interconnected power system.
6. Load expansions analysis.
7. Line losses analysis.

1.4 Various types of Violations

Due to line outages and generator outages, mainly two types of violations are occured[2]:

1. Low Voltage Violations: If bus voltages are operated under the rated voltages, then this condition occurs. Bus voltages operating range is 0.950 pu to 1.050 pu. So if voltages are higher than 1.05 pu then it is a over voltage problem and the voltages are under than 0.95 pu, then it is an under voltage problem. These all the problems are solved by reactive power addition and reactive power supplied respectively. Voltage profile can be changed by this method.

2. Apparent power of line Violations: When the transmission lines are operated beyond their rated current limits, the MVA violations occurs on the transmission lines. The lines are operated in 125 % of higher current maximum, but if lines are operated above than 80-90% of current, it is insecure operating or alarm conditions.

1.5 Loads on transmission lines[7], [11]

1. Thermal Limits: When current flows in a line, due to heat production phenomenon of electric current, line temperature increases. Thermal limits are the limits with lines are operated in maximum current condition without overheating.

2. Voltage Limits: Enough voltage level must be mentioned with the transmission lines. Due to resistive and inductive limits

3. Stability Limits: Every electrical power system must be capable for the maximum power transfer within their static and dynamic limits.

1.6 Contingency Analysis

When the system is operated beyond the rated limits, the system is in the insecure condition and it may be happened that the system would be fall down to the emergency system and after that the contingency occurs due to sudden changes in the generating voltages, line currents, bus voltages and all. The methods of the solution for this situation is known as contingency analysis or contingency study.[2].

Contingency analysis is the online as well off line selection apparatus for the solution of emergency conditions. The ability of the system to stay alive equipment failure is known as a secure power system. Contingency occurs by week elements in the power system. If single outage is there is known as a single contingency (N-1) and if multiple outages are there is known as a secondary or multiple contingency (N-1-1 or N-2). From the contingency analysis, system operator can predict for the future outages.[2].

1.7 Classification of Contingencies

There are two types of contingencies[6]:

1. Single/Primary/N-1 Contingency: If loss of one or multiple part of the system happens first time is known as a primary of N-1 contingency. It is intended or unintended situation. Where, N is the total numbers of the equipments of the power system. It is the secure or normal state of the power system.

2. Multiple/Secondary/N-1-1 Contingency: It is unintended event. After the single contingency, a secondary contingency occurs in a power system. It is like loss of transmission line component, loss of an generator, or the failure of any two components. It is known as an insecure condition of power system.

1.8 Operating states of the power system

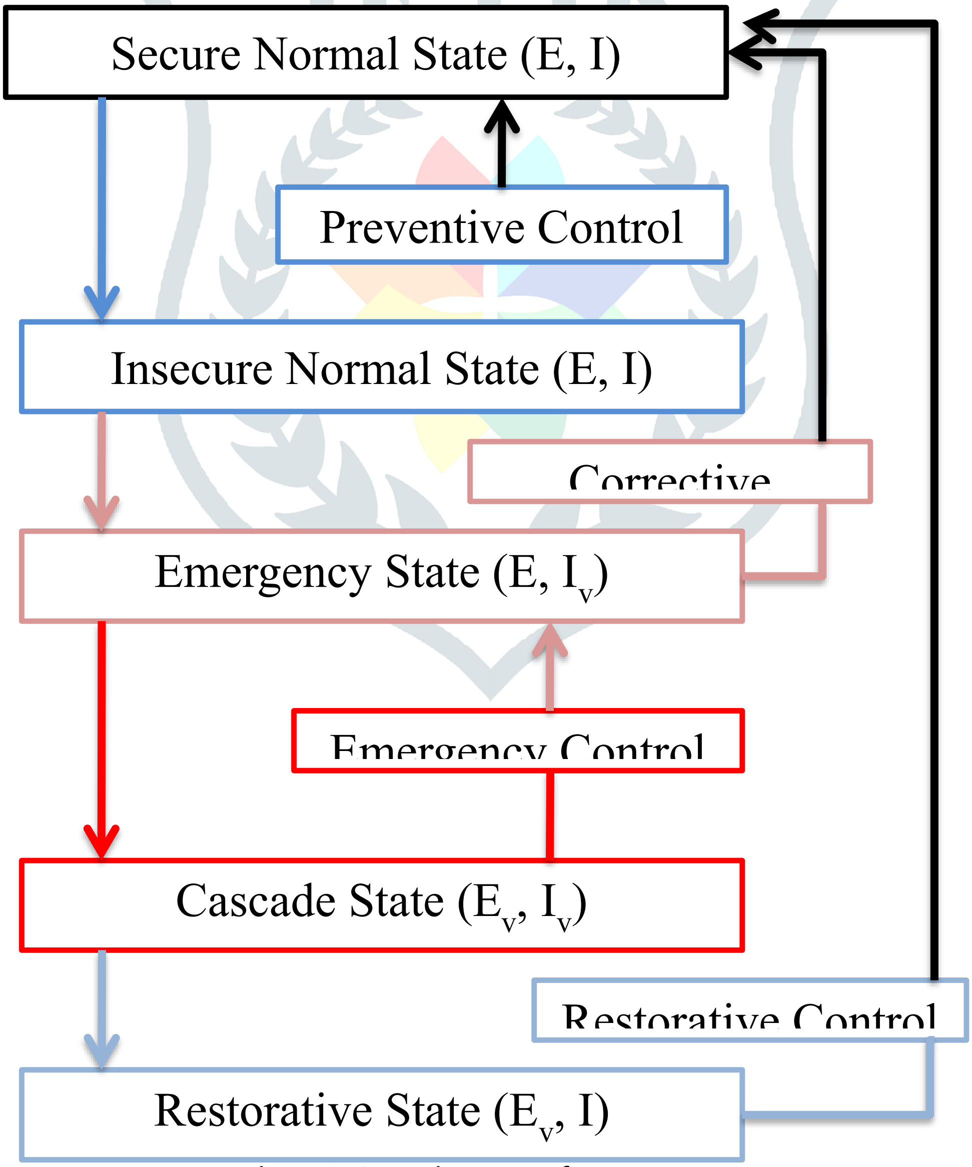

Figure 1: Operating states of power system

E = Equality constraints = Equality between Generation and demand, Power balance & flow equations are satisfied and I = Inequality constraints = Components are operated within their limits. Subscript 'v' refers to the violation.

1.9 Power system security and Procedure for the contingency analysis

A secure power system is known as it is free from danger or risk System security involves practices designed to keep the system operating in emergency state when components fail and to restore it to its preventive state. Secure power system is one with near to the ground possibility of system black out (collapse) or equipment damage. Most power systems are operated in such a way that any single contingency will not leave other components heavily overloaded, so that cascading failures are avoided.

Contingency analysis procedure involves power system security analysis as follows[7]:

Table 1: Contingency analysis steps for security

Power System Security Functions				
Security Assessments				Corrective Control Actions
System Monitoring	Contingency Analysis: Study of outage events			
	Definition	Selection	Evaluation	
>>Supplies up-to-date information to operators. >>Measure, monitor & Transmit the data, voltage, line flow, load & generation changes, etc. Digital computers inform about overloads.	>>Prepare a list of possible contingencies. >>Includes line and generator outages.	>>Select the set of most possible contingency in terms of risk to the system.	>>Selected contingencies are rank in order to their security.	>>Operator changes the operation of the power system if CA predicts a serious problem. >>Provide a protective and post-contingency control. Ex., Change in generation, Load shedding, etc.

1.10 Sensitivity factors and performance indices for contingency analysis

Generator Outage Sensitivity Factor (GOSF)

Shows estimated change in power flow on line m-n because of generator outage of bus l[13],

$$a_{mn}^{l} = \frac{\Delta pf_{mn}}{\Delta p_l} \quad \text{--------(1)}$$

where, a_{mn}^{k} is GOSF of line 'm-n' for generation alteration at bus 'k'

Δpf_{mn} is alteration in power flow in line 'm-n'

Δp_l is alteration in generation at bus 'l'

Line Outage Distribution Factor (LODF)

Shows estimated change in power flow on line m because of k-ith line outage[13],

$$b_{xy,kl} = \frac{\Delta pf_{xy}}{f_{kl}^{0}} \quad \text{--------(2)}$$

Where,

$b_{xy,\,kl}$ is Line outage distribution factor for line 'x-y' under outage of line 'k-l'.

f_{kl}^{0} is Power flow over line 'k-l' in the pre-outage condition.

Therefore, for the outage of line 'k-l', the new flow over line 'x-y' is given by,

Power Transfer Distribution Factor (PTDF)

Shows power transfer distribution factors of k-l elements, for the transaction between x-y will be given as[2], [6],

$$pd_{kl(xy)} = \frac{\Delta Pf_{kl}}{\Delta Tf_{xy}} \quad \text{---------(3)}$$

Where,

$pd_{kl(xy)}$ -Power Transfer Distribution Factors for line k-l for transaction between x-y buses

ΔPf_{kl} - Change in real power flow of line k-l for transaction between x-y buses

ΔTf_{xy} - Change in transaction between x and y buses

1.11 Contingency Ranking by Performance Indices

When big power system is concerned, sensitivity factors and DC load flow method is not used for the contingency analysis, AC load flow method is used and for that performance indices methods are used. By calculating the performance index, the system contingency is ranked in terms of the higher to lower violations and then the solutions are preferred by contingency analysis methods[1].

Real power performance index (P_{kw}): It reflects the violation of line real power flow and is given by (4)[1],

$$P_{kw} = \sum_{k=1}^{M} \left(\frac{Pk}{P_{kmax}}\right)^{2x} \quad \text{---------(4)}$$

where, P_k = Real Power flow in line k,

P_{kmax} = Maximum real power flow in line k,

x is the specified exponent,

M is the total number of transmission lines in the system.

If n is a large number, the PI will be a small number if all flows are within limit, and it will be large if one or more lines are overloaded, here the value of x has been kept unity.

The value of maximum power flow in each line is calculated using the formula (5),

$$P_{kmax} = \frac{V_m * V_n}{Xmn} \quad \text{----------(5)}$$

where, V_m= Voltage at bus m obtained from Load Flow solution

V_n= Voltage at bus n obtained from Load Flow solution
X_{mn} = Reactance of the line connecting bus 'm' and bus 'n'

Reactive power performance index (P_{kvar}): It corresponds to bus voltage magnitude violations. It mathematically given by (6)[1],

$$P_{kvar} = \sum_{x=1}^{M_{pq}} \left(\frac{2(V_x - V_{xnom})}{V_{xmax} - V_{xmin}}\right)^2 \qquad \text{---------(6)}$$

where,

V_x= Voltage of bus x,
V_{xmax} and V_{xmin} are maximum and minimum voltage limits,
V_{xnom} is average of V_{xmax} and V_{xmin},
M_{pq} is total number of load buses in the system.

Real Power Loading Performance Index (P_{kwl}): It will increase while there may be another case which is one line filled to capacity but the value of the P_{kwl} is small. It is given by (7)[4]

$$P_{kwl} = \sum_{k=1}^{M} W_{pk} \left(\frac{P_{kpc}}{P_{kLim}}\right)^{2x} \qquad \text{----------(7)}$$

Where, P_{kpc} = The post-contingency active power flow on line k
P_{kLim} = The active power flow limit on line k
W_{pk} = The weight factor of active power flow on line k
M is number of transmission lines.
X is a positive integer in the range from 2 to 30 to avoid masking errors.

System Line Overload Index (P_{ol}): It helps tell the system designer at a glance, the lines that should be given utmost attention in terms of protection. P_{ol} is found by (8)[7],

$$P_{ol} = 1.00\text{-}\left(\left(\frac{V_s}{V_p}\right)\min\right)^{l} \qquad \text{----------(8)}$$

Where, V_s, V_p are the receiving end and sending end voltages respectively,
l the number of lines with $V_s/V_p < 0.950$

1.12 Corrective Measures

The following steps are required for the system to return it back into the normal condition[2].

1. Shunt capacitor switching
2. Generation Re-scheduling
3. Load shedding
4. By using Under load tap changing (ULTC) Transformer
5. Distributed Generation
6. Islanding
7. Using FACTS devices[7]

1.13 FACTS Devices

FACTS as Flexible Alternating Current Transmission Systems are power electronics based static controllers for the improvement in quality and controllability of power and also increase power transfer capacity. It is classified as shunt, series, shunt and series combinations.

Advantages:

- Raise in the thermal capacity of the line
- Decrease the burden of heavily loaded lines
- Provide improvement in stability, reliability, quality of supply, availability and load ability of the power system
- Reduction in the reactive power flow
- Reduction in short circuit currents and over loading[6]
- Power system losses are also reduced
- Lower costing[5]
- Secure inter connection of power system
- Widely used for power system security[12]

1.14 Sensitivity Analysis

For the power system security, the perfect location of FACTS devices is very important. But because of large number of contingencies, it is not possible to run the optimal power flow to find exact location of FACTS devices. So, sensitivity analysis method is used for the location of FACTS devices. The real power flow P_{kw} sensitivity factors with respect to the parameters of FACTS can be defined as[5],

$$\gamma_k^m = \frac{\partial P_{kw}}{\partial x_k} \qquad \text{------------(9)}$$

Where, P_{kw} = Real power flow performance index,
X_k = FACTS device parameter,
γ_k^m = Sensitivity Factor

2. IEEE-14 Bus test system, results and discussions

Following are the results of IEEE-14 bus test system. Bus no. 1 & 2 are considered because of larger network. GSF & LODF of all N-1 contingencies are observed with and without TCSC (FACTS). TCSC sensitivity analysis carried out with the help of real power flow performance index to find the proper location of TCSC, line having most negative sensitivity analysis factor is the best location to locate FACTS. So after location of TCSC, GSF and LODF was observed and it is also observed that after location of TCSC, there is an improvement on GSF and LODF. These all results was carried out in matpower 5.0.[5]

Table 2: Sensitivity analysis with and without TCSC

Line No.	From Bus	To Bus	GSF for N-1 (G=2)	LODF FOR N-1																			
				L=1	L=2	L=3	L=4	L=5	L=6	L=7	L=8	L=9	L=10	L=11	L=12	L=13	L=14	L=15	L=16	L=17	L=18	L=19	L=20
1	1	2	-0.8	0.0	1.0	-0.2	-0.3	-0.4	-0.2	-0.3	0.0	0.0	0.1	0.0	0.0	0.0	-1.5	0.0	0.0	0.0	0.0	0.0	0.0
2	1	5	-0.2	3.8	0.0	0.8	1.0	1.4	0.8	1.1	0.1	0.1	-0.2	-0.1	0.0	0.0	-3.0	0.1	0.1	0.1	0.1	0.0	-0.1
3	2	3	0.0	-0.6	0.6	0.0	1.0	0.7	-3.3	-0.8	-0.1	-0.1	0.2	0.1	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1	0.0	0.1
4	2	4	0.1	-1.1	1.1	1.4	0.0	1.3	1.4	-1.5	-0.2	-0.1	0.3	0.2	0.0	0.1	0.0	-0.2	-0.2	-0.2	-0.2	0.0	0.2
5	2	5	0.1	-1.4	1.4	1.0	1.3	0.0	1.0	1.4	0.1	0.1	-0.3	-0.2	0.0	0.0	-1.5	0.1	0.2	0.1	0.2	0.0	-0.1

Line No.	From Bus	To Bus	αkTCSC (at 82°, Cap)	GSF for N-1 (G=2)	LODF FOR N-1																			
					L=1	L=2	L=3	L=4	L=5	L=6	L=7	L=8	L=9	L=10	L=11	L=12	L=13	L=14	L=15	L=16	L=17	L=18	L=19	L=20
1	1	2	$-3.204 X 10^{-7}$	-1.1	0.0	1.0	0.2	0.2	0.4	0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	1	5	$-4.698 X 10^{-6}$	0.1	-10.9	0.0	1.8	2.6	4.1	1.8	3.1	0.2	0.2	-0.5	-0.3	0.0	-0.1	0.0	0.2	0.3	0.2	0.3	0.0	-0.2
3	2	3	$-2.794 X 10^{-6}$	0.0	-0.6	0.6	0.0	1.5	1.5	-3.3	-0.7	-0.1	0.0	0.1	0.1	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1	0.0	0.1
4	2	4	$-5.692 X 10^{-7}$	0.0	-1.1	1.1	1.8	0.0	2.8	1.8	-1.3	-0.1	-0.1	0.2	0.1	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1	0.0	0.1
5	2	5	$-1.593 X 10^{-7}$	-0.1	-1.4	1.4	1.6	2.4	0.0	1.6	2.8	0.2	0.2	-0.4	-0.3	0.0	-0.1	0.0	0.2	0.3	0.2	0.3	0.0	-0.2

Conclusion

It is concluded from the above discussions, for AC load flow methods, sensitivity analysis and performance indices are count and then the system is ranked according to the higher dangerous level to the lower dangerous level. Again for the improvement of the system security FACTS devices are used for the purpose of the better planning of electrical networks in the power systems. After installing FACTS device, it is observed that the GSF and LODF of the system are improved, from the above IEEE-14 bus test system case.

References

[1] Roy A. K., Jain S. K.. (2013). Improved Transmission Line Contingency Analysis in Power System Using Fast Decoupled Load Flow. *International Journal of Advances in Engineering & Technology*, *6(5),* 2159-2170.

[2] Mishra V. J., Prof. Khardenvis M. D., (2012). Contingency Analysis of Power System. *International Conference on Emerging Frontiers in Technology for Rural Area (EFITRA)* Proceedings published *in International Journal of Computer Applications (IJCA)*, *4,* 31-34.

[3] Manikandan R., Bhoopathi M., (2013). Contingency Analysis in Deregulated Power Market. *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, *2(12),* 6310-6317.

[4] Mohamed S. E. G., Mohamed A. Y., Abdelrahim Y. H., (2012). Power System Contingency Analysis to detect Network Weaknesses. *Zaytoonah University International Engineering Conference on Design and Innovation in Infrastructure*, *Amman, Jordan, I3*, I3-1 to I3-11.

[5] Sayyed A. L., Gadge P. M., Sheikh R. U., Contingency Analysis and Improvement of Power System Security by locating Series FACTS Devices 'TCSC and TCPAR' at Optimal Location. *IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE) e-ISSN: 2278-1676, p-ISSN: 2320-3331*, 19-27.

[6] Ramanaiah P., Rao J. S., (2014). Contingency Analysis in Deregulated Power System Using Facts Device (TCSC). *International Journal of Engineering Research and Development e-ISSN: 2278-067X, p-ISSN: 2278-800X*, *10(10),* 44-64.

[7] Joseph N. C. Prof. Madueme T. C., (2013). Power System Contingency Analysis: A Study of Nigeria's 330KV Transmission Grid", 1-9.

[8] Patel N. J., Sinha M. N., (2014). Power flow analysis of power system network using Power World Simulator. *IJSRD - International Journal for Scientific Research & Development*, *2(2),* ISSN (online): 2321-0613, 479-482.

[9] Chengjun Fu, Bose A., (1999). Contingency Ranking Based on Severity Indices in Dynamic Security Analysis. *IEEE Transactions on Power Systems*, *14(3),* 980-986.

[10] Sharma N. K., Phulambrikar S. P., Prajapati M., Sharma A., (2013). Contingency Ranking and Analysis using Power System Analysis Toolbox (PSAT). *Innovative Systems Design and Engineering ISSN 2222-1727 (Paper) ISSN 2222-2871 (Online)*, *4(6),* 59-63.

[11] Bhesdadiya R. H., Patel C. R., (2014). Transmission Line Loadability Improvement by Reactive Support. *IJSRD - International Journal for Scientific Research & Development*, *2(3),* ISSN (online): 2321-0613, 1127-1129.

[12] Singh B., Verma K. S., Mishra P., Maheshwari R., Srivastava U., Baranwal A., (2012). Introduction to FACTS Controllers: A Technological Literature Survey. *International Journal of Automation and power engineering,1(9),* 193-234.

[13] *Contingency Analysis.* Retrieved from NPTEL, MHRD, Govt. of India
Website: http://nptel.ac.in/courses/108107028/module5/lecture1/lecture1.pdf