

Steady state Contingency Analysis of IEEE-39 Bus system Using PSS/E

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Abstract – Nowadays the stable, secure and reliable power system operation is the main objective of any electric power utility. The Power system is vulnerable to any contingency i.e. loss of Transmission line, Transformer, Generating unit etc. The power system control engineer should have detail analysis of at least the most probable and sever contingencies of the system and accordingly devise the remedial action plan. Thus, Power system contingency analysis and evaluation play vital role in ensuring power system stability and reliability. Keeping in view the importance of contingency analysis in power system operation and control, this research focuses on steady state Contingency analysis of IEEE-39 bus system using newton Raphson method. PSS/E is used for the analysis, different contingencies are evaluated and ranked based upon the Power flow (Overloading), Voltage and phase angle deviation. Once the ranking is performed, the PV and QV analysis is performed for most severe contingencies. Remedial Actions is proposed for the most severe contingencies and this research could be applied to any real time network.

Keywords – Contingency Ranking; Contingency Screening; Steady State; PSS/E; Newton-Raphson; (N-1) Contingency; Voltage Stability And Power Flow

I. INTRODUCTION

Every power system operator aims at maximizing the output performance of the system's components due to the rise in the amount spent on these components Today, increase in the size of power system network which has also increased the amount spent on the components, has proportionately increase the complexity of its operation thereby becoming a major source of worry to engineers [1]. Because of this, engineers have had a difficult time building power systems that efficiently transmit energy at a very low cost [2]. A situation where the system no longer remains in the secure operating region will result from power

systems operating close to their thermal limits, either because of increased loads or because of severe emergencies. [3]. For controlling the power system operation, we used Energy management system which consist of various function. One of them is N-1 Contingency analysis in actuality, the N-1 contingency analysis examines how the failure of a single power system components effects the operating condition of the power system. One prevalent role in the design and management of power system is Contingency analysis [4]. Contingencies in an electric power system is the disturbance as a result of the outages or loss of one or more multiple equipment's such as a generator, transmission line, or transformer. Contingencies if

unplanned can pose sever threat to power system operation which may leads to cascaded tripping's and ultimately power system blackout [5]. Contingency analysis is one of the most important tasks encounter by the planning and operation engineers of bulk power system. Power system engineer can use contingency analysis to examine the performance of the system. And to assess the need of new transmission expansions due to load increase or generation expansions. [6] Interference in the power system operation is an unavoidable problem. The aim to ensure system security is a key element in power system. Designing the system to continue functioning in the events of interference or failure is a part of system security [7]. therefore, contingency analysis plays vital role in safe, secure and stable operation of power system. Steady-state contingency analysis simulates different single or multiple outages and based on the results these contingencies are ranked using various techniques required for short term power system planning and operations [8]. Being a dynamic in nature, the failure of transmission lines, transformers and generating units is part of the power systems operation and could not be avoided. Tripping's of transmission lines and transformers affect power flows, bus voltages and phase angle and rotor angle etc. [9]. The sole purpose of contingency analysis is carry out operational planning, in order to ensure reliability and stability of the system which is otherwise a challenging task due to dynamic nature of the power system [12]. With integration of Variable Renewable Energy resources, the generation mix in modern power system becomes very dynamic in nature due to intermittent nature of these generation facilities [13]. The intermittent nature of today's generation mix, further intensify the need of contingency analysis to avoid possible future failure in the operation of the power system. As test case the steady-state contingency is performed on standard IEEE-39 Bus system [14].

II. RELATED WORK

The contingency ranking methodology is based on an offline simulation of IEEE 39 bus base case using PSS/E. The Newton Raphson iterative algorithm is used for load flow solution. This algorithm approximates nonlinear equations as linear using Taylor series. The contingency analysis provides active power, reactive power and bus voltages. Single (N-1) contingency is considered i.e.

the outage of all lines one by one and simulating the effect of the outage on the network [20]. The contingencies are ranked in descending order considering their severity. Three approaches are devised to ranked down the severity of contingencies i.e. Power Flow violations, voltage range violations and voltage deviations violations.

A. Newton Raphson Method

The most popular iterative procedure for resolving load flow issues is the Newton-Raphson method. It approximates non-linear equations to linear equations based on Taylor's series. The NR technique is expressed as an n-bus system with bus 1 acting as a slack bus [21].

A power system's incoming current to a specific bus i can be expressed as follows:

$$I_i = \sum_{j=1}^n Y_{ij} V_j \quad \text{for } i = 1, 2, 3, \dots, n \dots (1)$$

In polar form, the above equation can be expressed as follows.

$$I_i = \sum_{j=1}^n Y_{ij} V_j < \theta_{ij} + \delta_j \dots (2)$$

The complex power delivered to the bus i is given by equation.

$$P_i - jQ_i = V_i^* I_i \dots (3)$$

The real and reactive powers are given by:

$$P_i = \sum_{j=1}^n |V_i| |V_j| |Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j)$$

$$Q_i = \sum_{j=1}^n |V_i| |V_j| |Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j)$$

III. PROPOSED METHOD

In this paper Steady state contingency Analysis of IEEE-39 Bus system is carried out by Using PSS/E, The power flow analysis under N-1 contingencies and typical situations is carried out. The single-line diagram of IEEE-39 Bus three-phase power system is shown in Fig. 1.

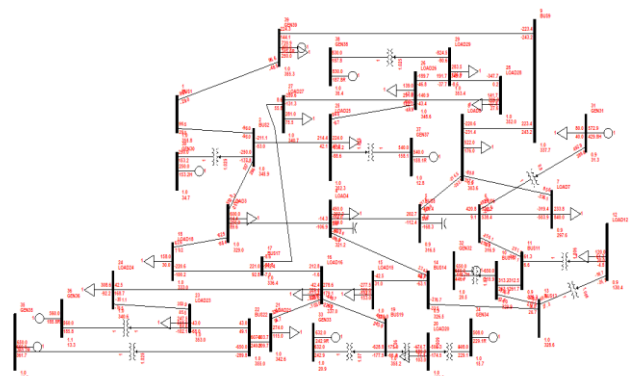


Figure-1: Single line Diagram of IEEE 39 bus system

The Contingency ranking methodology adopted is based on an offline simulation of IEEE 39 bus base case using PSS/E. The Newton Raphson iterative algorithm is used for load flow solution. Three approaches are devised to rank down the severity of contingencies i.e., Power Flow violations, voltage range violations and voltage deviation violations.

A. Power Flow Violation Approach

The Power flow violation approach adopted in this research work is based on the active power monitoring after a contingency occurred. In this approach, for each contingency the simulations are performed and the power flow on each of the lines and transformer is monitored. In case the power flow exceeds the maximum limit or capacity of that specific element i.e. Line or transformer, it is noted down as violation. In such manner all violation for each contingency is recorded and the same process is repeated for all contingencies in the network.

The Power flow violations recorded are listed down in descending order and accordingly, contingencies are ranked down. The Power flow violation approach is helpful for Transmission system planning and this approach provided an overview to the system expert about the operational constraints in the system.

B. Voltage Range Violation

The Grid code of any utility clearly mention the minimum and maximum voltage limits for each voltage level. In this research work, these limits are considered $\pm 5\%$ of rated voltage level in line with the Grid code approved by National Electric Power Regulatory Authority (NEPRA). So, for each contingency the voltages of all buses are monitored and if the limits are exceeded, the violations are listed down and accordingly contingencies are ranked down.

C. Voltage Deviation Violation

Sudden and abnormal voltage variation may be a great concern equally for both the power system control engineer and consumer as well. Therefore, the third approach used for ranking down the contingencies is voltage deviation. So, for each contingency the voltages of all buses are monitored and if the deviation limits (3% drop and 6% rise) are exceeded, the violations are listed down and accordingly contingencies are ranked down.

IV. THE PROCESS FLOW OF PROPOSED CONTINGENCY ANALYSIS

The process flow of proposed contingency analysis in this paper is summarized below;

The parameters of the base case are checked and any suspects if found are removed. Then to check the healthiness of the base case, the base case is solved for power flow. Single line (N-1) contingency is simulated and results obtained are analyzed for Power flow violations, Voltage Limits and Deviation violations. The contingency is ranked based on above mentioned approaches individually as well as overall. The process is repeated for all line outages and all the contingencies are ranked based on the overall ranking.

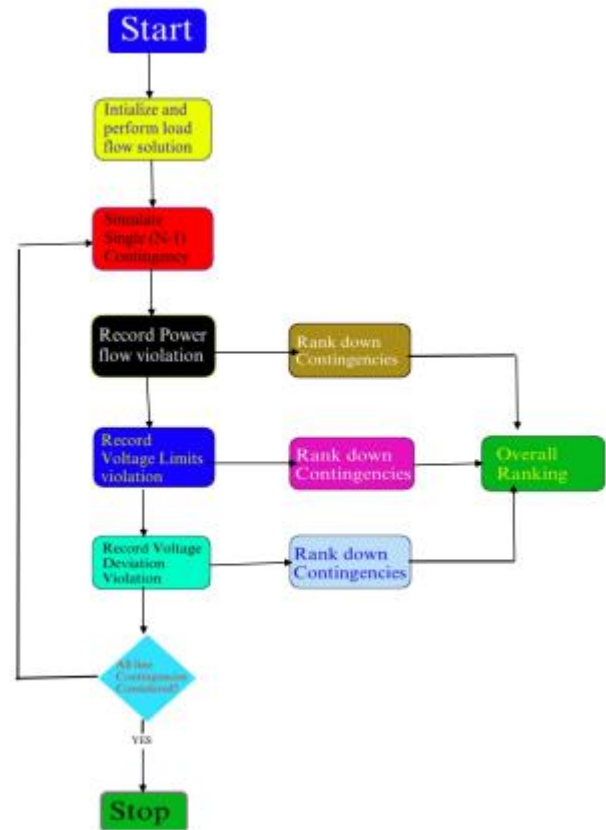


Figure-2: Flow Chart of Contingency Analysis

V. TEST CASE AND RESULTS

The proposed approach is tested for voltage contingency analysis and ranking on base case of IEEE 39- bus system shown in Fig. 1. This test system consists of 46 transmission lines, 12 transformers, 19 loads and it has 10 generators [23]. Simulations were performed for single (N-1) contingency and results obtained were investigated for three different approaches proposed in previous section.

The Base case is initially solved without any contingency and the results obtained showed very

few power flow violations and Voltage ranged/limits violations, however, there were no voltage deviations violations in base case as shown in Fig. 3.

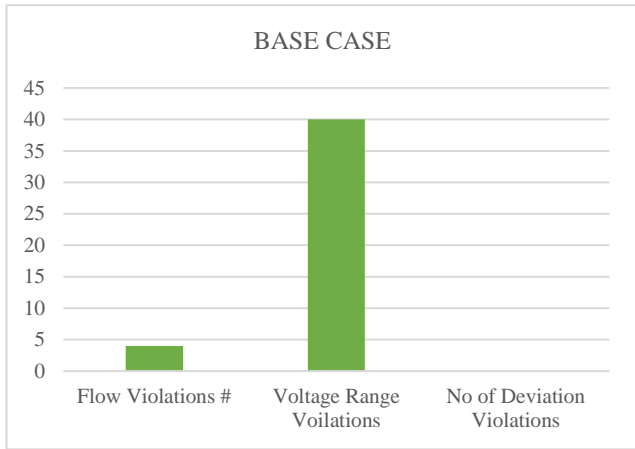


Figure-3 Deviation statistics in base case

The IEEE 39 bus base case was then solved for N-1 contingency using Newton Raphson technique and the results obtained were analyzed in context of power flow violation, voltages range violations and voltage deviations. The simulation converged for all contingencies except six numbers of contingencies where the simulation either blown up or met maximum number of iterations before reaching the solution. The contingencies where the system either blown up or could not met convergence are the worst contingencies and the network would not be able to remain stable with these contingencies. These contingencies are listed in table 1.

Table 1. List of contingencies where simulations could not converge

S. No	Contingency type	From No	Bus	To No	Bus
1	N-1	2		3	
2	-do-	6		31	
3	-do-	8		9	
4	-do-	9		39	
5	-do-	15		16	
6	-do-	29		38	

A. Power Flow Violation Approach

The results obtained after the IEEE 39 bus base case solved for N-1 contingency are analyzed for power flow violation and a total of 571 power flow violations were recorded. The N-1 contingency that

has the worst impact on the network in term of power flow violation is single contingency between Bus#10 and Bus#32 as shown in Fig. 4.a. The power flow violation recorded in this contingency was 662%. Power flow violations ranking is shown in Fig. 4.b

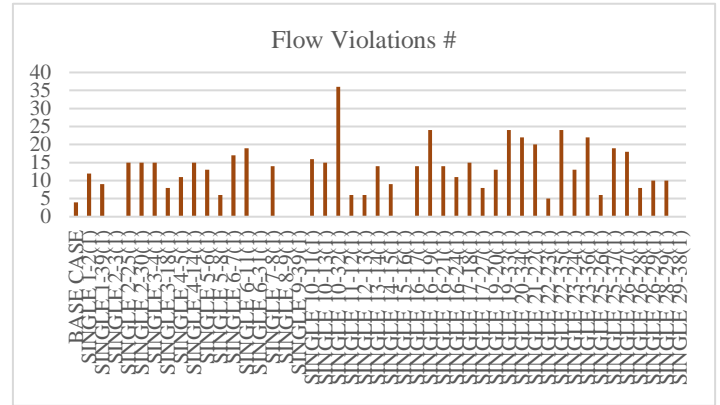


Figure-4a Top ten contingencies with maximum power flow violations

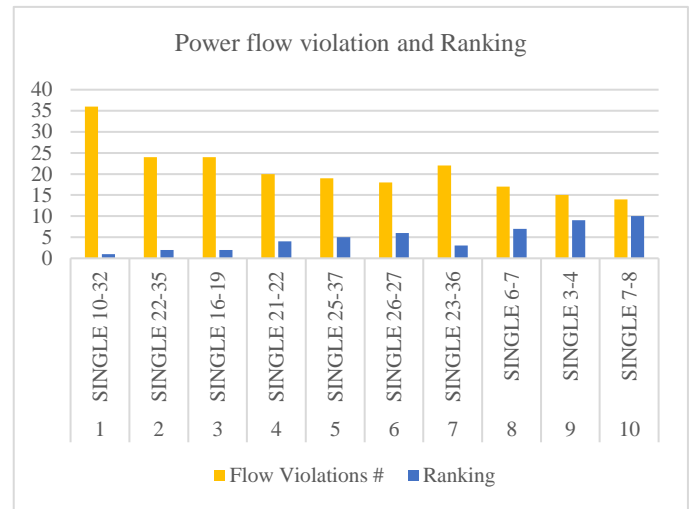


Figure-4b Power flow violations and Ranking for N-1 contingencies

The ten worst contingencies amongst these are shortlisted as given in table 2 below to devise the remedial action plan or better operational planning could be performed as interim arrangement till the long-term planning required for permanent solution is pending.

Table 2. Top ten contingencies with maximum power flow violations

Seq #	Contingencies	Flow Violations	Ranking
1	SINGLE 10-32	36	1
2	SINGLE 22-35	24	2

3	SINGLE 16-19	24	2
4	SINGLE 21-22	20	4
5	SINGLE 25-37	19	5
6	SINGLE 26-27	18	6
7	SINGLE 23-36	22	3
8	SINGLE 6-7	17	7
9	SINGLE 3-4	15	9
10	SINGLE 7-8	14	10

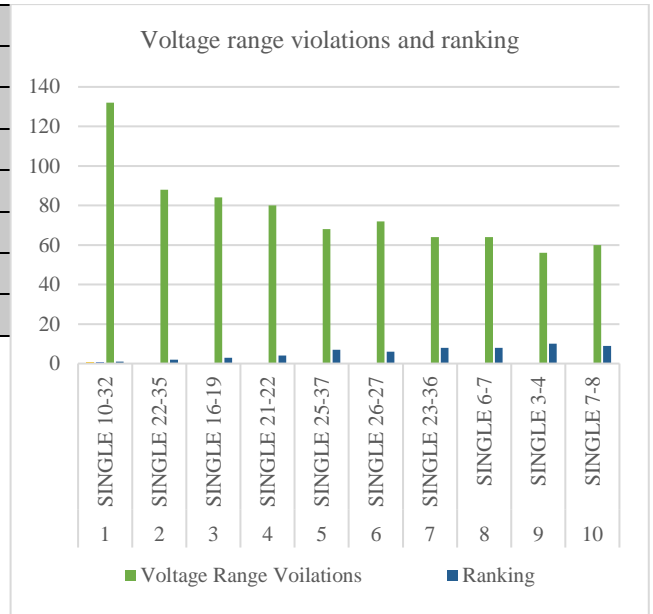


Figure-5b Voltage Range Violation and Ranking

B. Voltage Range Violation Approach

The results obtained after the IEEE 39 bus base case solved for N-1 contingency are analyzed for Voltage range violation and a total of 2324 voltage range violations were recorded. The N-1 contingency that has the worst impact on the network in term of voltage range violation is single contingency between Bus#10 and Bus#32. The voltage range violations recorded in this contingency were 132 i.e., the maximum number of violations for the solved contingencies as shown in Fig. 5.

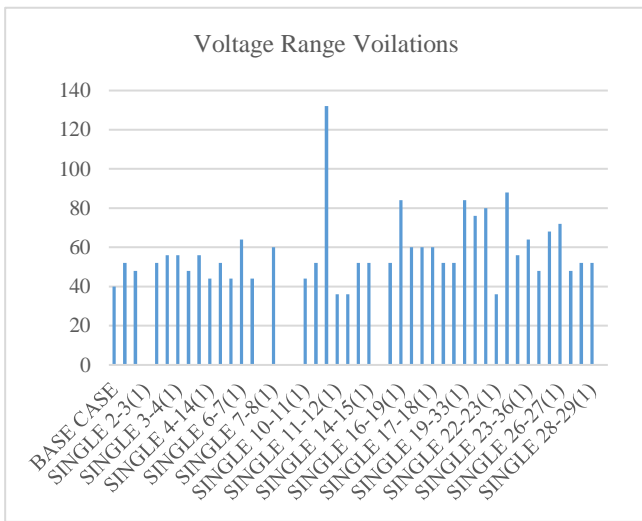


Figure-5a Voltage range violations for N-1 contingencies

The ten worst contingencies amongst these are shortlisted as given in table 3 below to devise the remedial action plan or better operational planning could be performed as interim arrangement till the long-term planning required for permanent solution is pending.

Table: 3 Top ten worst Contingencies on the basis of Voltage Range violation

Seq #	Contingencies	Voltage Range Violations	Ranking
1	SINGLE 10-32	132	1
2	SINGLE 22-35	88	2
3	SINGLE 16-19	84	2
4	SINGLE 21-22	80	4
5	SINGLE 25-37	68	5
6	SINGLE 26-27	72	6
7	SINGLE 23-36	64	3
8	SINGLE 6-7	64	7
9	SINGLE 3-4	56	9
10	SINGLE 7-8	60	10

C. Voltage Deviation Violation

The results obtained after the IEEE 39 bus base case solved for N-1 contingency are analyzed for Voltage deviations violation and a total of 1168 voltage deviation violations were recorded. The N-1 contingency that has the worst impact on the network in term of voltage deviations is single contingency between Bus#10 and Bus#32. The

number of violations recorded in this contingency were 140 i.e., the maximum number of violations for the solved contingencies as shown in Fig. 6.

The ten worst contingencies amongst these are shortlisted as given in table 4 below.

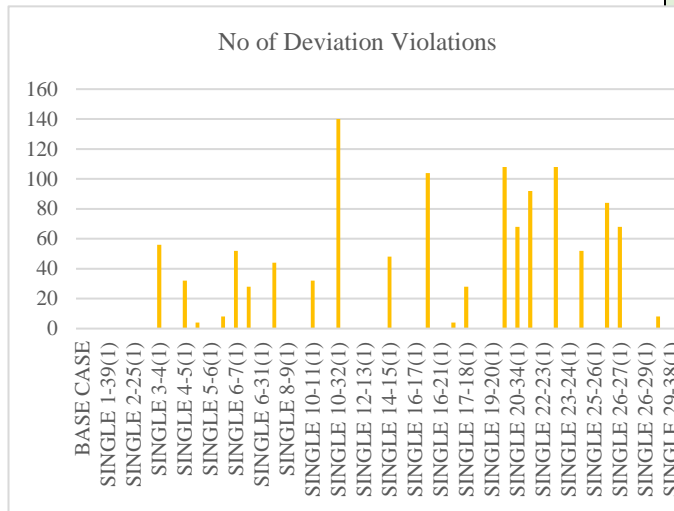


Figure-6a Number of Voltage Deviation violations for N-1 contingencies

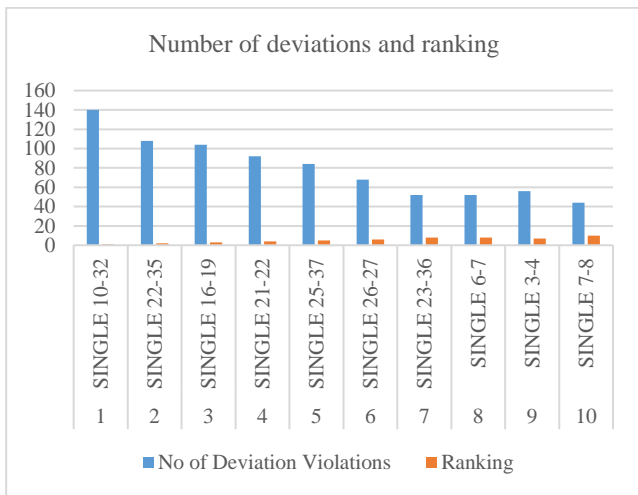


Figure-6b Number of Deviation and it's Ranking Voltage

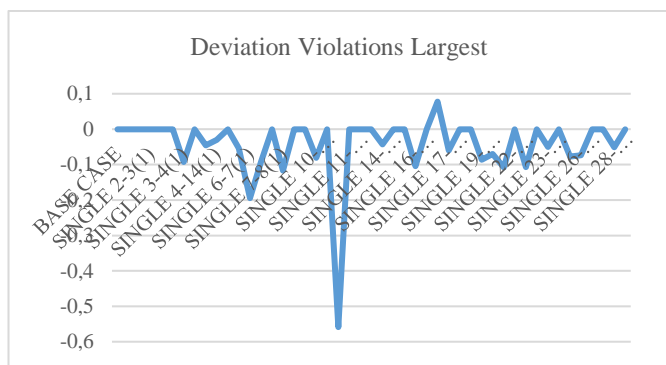


Figure-6c Largest Deviation violations for N-1 contingencies

Seq	Contingencies	Flow Violations	Ranking
1	SINGLE 10-32	36	1
2	SINGLE 22-35	24	2
3	SINGLE 16-19	24	2
4	SINGLE 21-22	20	4
5	SINGLE 25-37	19	5
6	SINGLE 26-27	18	6
7	SINGLE 23-36	22	3
8	SINGLE 6-7	17	7
9	SINGLE 3-4	15	9
10	SINGLE 7-8	14	10

VI. OVERALL RANKING OF CONTINGENCIES

The power system control engineer is required to be given a list of contingencies which are important from system stability, reliability and operational point of view along with Remedial Action Plan to avoid any cascaded tripping's. Therefore, the results obtained for each individual approach discussed previously are consolidated and overall, ten worst contingencies are shortlisted given in table 5.

Table-5 Top ten most sever Contingencies on basis of Overall Ranking

Seq #	Contingencies	No of Flow Violations	No of Voltage Range Violations	No of Deviation Violation	Overall Ranking
1	SINGLE 10-32	36	132	140	1

2	SINGLE 22-35	24	88	108	2
3	SINGLE 16-19	24	84	104	3
4	SINGLE 21-22	20	80	92	4
5	SINGLE 25-37	19	68	84	5
6	SINGLE 26-27	18	72	68	6
7	SINGLE 23-36	22	64	52	7
8	SINGLE 6-7	17	64	52	8
9	SINGLE 3-4	15	56	56	9
10	SINGLE 7-8	14	60	44	10

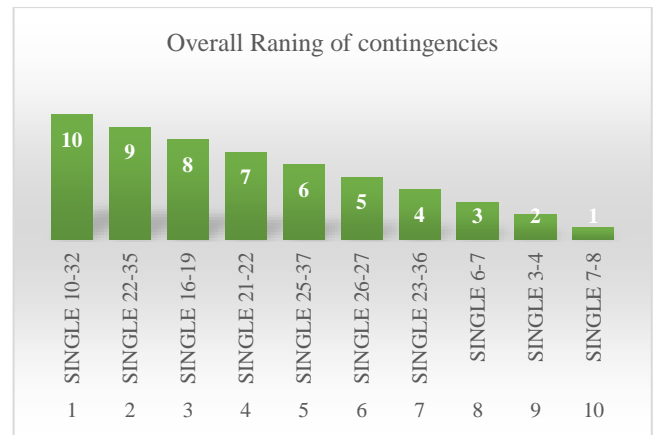


Figure-7 Overall Ranking of Contingencies

The overall ranking of contingencies are shown in Fig. 7 which show the same list of contingencies as shortlisted for power flow, voltage range and voltage deviation violations. The N-1 contingency between Bus#10 and Bus#32 is the worst amongst all contingencies and the N-1 contingency between Bus#7 and Bus#8 is the least bad amongst top ten contingencies.

VII. CONCLUSION

In In this paper an effort has been made to analyze single (N-1) contingencies of IEEE-39 bus standard system using Newton Raphson load flow method. To carry out the proposed analysis three different approaches were proposed and using these approaches the first ten most sever contingencies were ranked down in decreasing order of severity. The highest rank corresponds to the most severe contingency which involved power flow violation, voltage violations and voltage deviation range violation also which high lead to the violation of voltage limits.

It is observed during the analysis that the N-1 contingency between Bus# 2 and Bus#3 Bus#8 and Bus#9 has severe overloading impact on the remaining system and the simulations failed to converge in the given iteration limit. Moreover, the N-1 contingencies between Bus# 6 to 31, Bus# 9 to 39, Bus# 15 to 16 and Bus# 29 to 38 caused the simulation blown up and could not converged.

It is concluded that the system could bear any of the N-1 contingency mentioned above and augmentation to the system is required to avoid system cascaded trippings in these contingencies. Apart from the list of contingencies mentioned in previous section, with all others N-1 contingencies, the system remain safe and system stabilities is intact. However, the short-term operational

planning and long term Transmissional planning [13] required for these contingencies to avoid the power flow, voltage range and voltage deviations violation in these contingencies. [14]
 Future work may be investigating the contingency analysis by some new approaches and the remedial action plan to avoid the sever effects of these contingencies on the test case. [15]

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