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Comparison of Different Methods of Contingency Analysis in Power System

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Abstract— *For power system security purpose Contingency analysis is necessary. When increasing loading of transmission lines, contingency analysis is required to predict outages. If proper analysis of contingencies is not done then it can lead to voltage instability. It also helps in finding optimal location of FACTS devices. Different methods of contingency analysis (Performance index method, Exact ranking method and Precise ranking method) are compared in this paper.*

1. INTRODUCTION

Following several major outages related to voltage collapses, voltage instability has become a serious concern to electric power utilities. This phenomenon is not new, however, because today's power system environment has forced systems to operate ever closer to voltage stability limits. Accordingly systems should be operated with care to prevent the collapse. There are several factors which contribute to voltage collapse such as increased loading on transmission lines, reactive power constraints, on-load tap changer (OLTC) dynamics and load characteristics.

Contingency analysis technique is being widely used to predict the effect of outages like failures of equipment, transmission line etc, and to take necessary actions to keep the power system secure and reliable[1]. The off line analysis to predict the effect of individual contingency is a tedious task as a power system contains large number of components. Practically, only selected contingencies will lead to severe conditions in power system. The process of identifying these severe contingencies is referred as contingency selection.

Contingency analysis being very important and sensitive part of power system security, demands maximum possible accuracy. The number of contingencies in a large power system can be in more than thousands, however the time slot available for power system operator to analyze so many contingencies and take appropriate action to avoid any post contingency violation is quite limited. The constraint of time boundation necessitates screening and ranking of only potential contingencies followed by detailed analysis and proper control actions for credible contingencies. All constrains including flowgate limits need to be respected following any credible contingency. Various algorithms have been proposed in literature for efficient screening and ranking of credible contingencies. One of the earlier and still widely used method of contingency analysis employs line outage distribution factors (LODFs) and generation shift factors [1,2]. A serious s drawback of LODFs and generation shift factors which are calculated from dc power flow is no information on voltages and reactive power is provided. In this paper three methods of contingency ranking are compared - Performance index method, Exact ranking method and Precise ranking method. 10 bus two area system is used for analysis[3]. Area1 supplies the power to Area2 (load side) across transmission system of five 500KV parallel transmission lines. Area1 consists of two generating units. Area2 consists of one generating unit and two load buses. The data for all the generators is taken from [4]

2. PERFORMANCE INDEX METHOD

One of the earliest used methods for contingency ranking is Performance Index (PI) method [5]. In this method for the initial operating state, we consider one of the lines is under contingency and the resultant loading level is calculated using PI method. To identify the severity level of any line outage contingency in the network, the PI value is determined by using (1).

$$PI = \Sigma_l (f_l/f_{lmax})^{\wedge 2x} \quad (1)$$

where l is the number of transmission lines, f_l is the absolute flow of line l and f_{lmax} is its MVA rating.

The higher value of PI for any operating state of the system indicates overloading of one or more transmission lines in the network. The contingencies which are having less PI values are considered as normal or minor contingencies. However the main thrust in these PI based ranking methodologies is on voltage security without giving due concern to line overloading

Table 1: PI and actual number of violation based contingency ranking

S. No	Outage	PI	PI based Ranking	Ranking based on actual no. of violations.
1	Gen-1	251.12	9	6
2	Gen-2	7.34	11	4
3	Gen-3	985.97	8	1
4	Line (bus4-bus5)	251.06	10	6
5	Line (bus5-bus6)	3.58	12	6
6	Line (bus7-bus8)	32313065.9	2	2
7	Trafo (bus1-bus4)	18987177.3	5	5
8	Trafo (bus2-bus5)	17265383.4	6	3
9	Trafo (bus3-bus6)	27120890.8	3	1
10	Trafo (bus6-bus7)	57655269.2	1	4
11	Trafo (bus8-bus9)	15636009.1	7	2
12	Trafo (bus6-bus10)	24813219.2	4	6

3. EXACT RANKING METHOD

This method aims at finding the exact number of possible violations following a contingency in power system[6]. The logic behind this is to have contribution of '1' by violated line/bus and '0' by non-violated line/bus to ranking index named as exact ranking index(ERI) as given in eqn.(2).

$$E_{RI} = \Sigma_{\text{all branches(l)}}(RI_S)+\Sigma_{\text{all buses(i)}}(RI_V) \qquad (2)$$

where

RIS : Ranking index for apparent power flow Sl of line

$$RI_S = \begin{cases} 1; \text{ for } S_l > P_l^{\max} \\ 0; \text{ for } S_l < P_l^{\max} \end{cases}$$

RI_V: Ranking index for voltage of bus

$$RI_V = \begin{cases} 1; \text{ for } \left|E_{nom} - E_i\right| > \Delta E_i^{\max} \\ 0; \text{ for } \left|E_{nom} - E_i\right| < \Delta E_i^{\max} \end{cases}$$

Where E_{nom} is nominal voltage of bus

ERI is calculated for all lines and buses for each outage and the contingency with largest value of ERI is placed at the top of list. This method was implemented on 10 bus benchmark system. All the steps are shown through a flow chart. The results are shown in Table 2. The results clearly show that ERI based ranking exactly matches with actual number of violation based ranking. These results also show that outages having same number of violation have same ranking. However, power system operator may like to know relative degree of severity among equally ranked outages like near limit operation of lines or buses in post contingency case for a particular outage. This is kept in consideration in the next method.

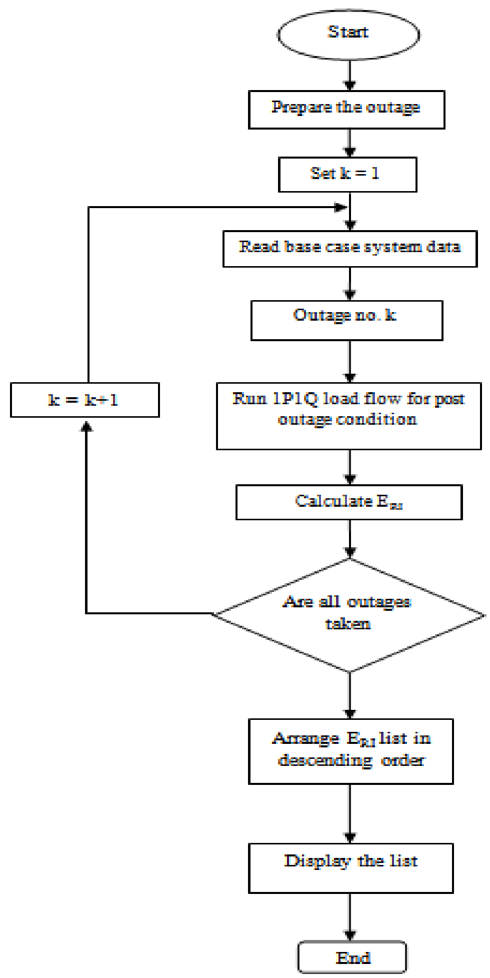

Fig. 1: Flow chart for exact contingency ranking

Table 2: E_{RI} based ranking

S. No	Outage	ERI	ERI based Ranking	Ranking based on actual no. of violations.
1	Gen-1	1	6	6
2	Gen-2	3	4	4

3	Gen-3	7	1	1
4	Line (bus4-bus5)	1	6	6
5	Line (bus5-bus6)	1	6	6
6	Line (bus7-bus8)	6	2	2
7	Trafo (bus1-bus4)	2	5	5
8	Trafo (bus2-bus5)	4	3	3
9	Trafo (bus3-bus6)	7	1	1
10	Trafo (bus6-bus7)	3	4	4
11	Trafo (bus8-bus9)	6	2	2
12	Trafo (bus6-bus10)	1	6	6

4. PRECISE RANKING TECHNIQUE

Exact ranking methodology discussed in section II(B) has presented fairly acceptable and correct results, however it doesn't differentiate between the outages resulting in same number of violations and hence label them with same ranking. This technique hereafter called precise ranking technique addresses the concern of identical ranking for outages resulting in same number of violations and takes into account in case there is any line or bus reaching near to its limit following a particular contingency. This ranking is based on new index hereafter called as precise ranking index (P_{RI}) given in eqn.(3).

$$P_{RI}=\Sigma_{allbranches(l)}(RI_S)+\Sigma_{allbuses(i)}(RI_V) \quad (3)$$

where

RIs: Ranking index for apparent power flow S_l of line

$$RI_S=\begin{cases} 1; & \text{for } S_l > P_l^{\max} \\ \left(\dfrac{P_{flowl}}{P_l^{\max}}\right)^{2n}; & \text{for } S_l < P_l^{\max} \end{cases}$$

RIv: Ranking index for voltage of a bus

$$RI_V=\begin{cases} 1; \text{ for } \left|E_{nom}-E_i\right| > \Delta E_i^{\max} \\ \left(\dfrac{\left|E_{nom}-E_i\right|}{\Delta E^{\max}}\right)^{2m}; \text{ for } \left|E_{nom}-E_i\right| < \Delta E_i^{\max} \end{cases}$$

Where Enom is nominal voltage of bus

In order to avoid drawback of PI based ranking upper limit is put on both load and voltage ratios which ensures all over loadings and over/under voltages beyond certain limit are given equal weightage irrespective of percentage of limit violation which is the case in practical life. The procedure for this technique remains same as shown in Fig. 2 except the ranking index ERI is replaced by PRI. The outage with largest PRI is placed at the top of list. Algorithm for this technique was implemented on 10 bus benchmark system. The results obtained are presented in Table 3.

The results of precise ranking technique presented in Table 3 differentiates the credibility of outages resulting in same number of violations as can be clearly observed violations and placed at the same place in ranking list by precise technique shows that, in addition to same number of violations all other lines and buses are pushed to their limits in exactly same extent e,g; outage of generator-1 and transformer(bus1-bus4) result in single violation and all other remaining line loadings and bus voltages are pushed to same value in both contingencies. It can be seen from comparison of results that precise technique based ranking follows actual number of violation based ranking with additional clear demarcation of severity between outages resulting in same number of post contingency violations, thus providing more information to the operator for better and effective control strategy.

Table 3: P_{RI} based ranking

S. No	Outage	PRI	PRI based Ranking	Ranking based on actual no. of violations.
1	Gen-1	2.35	8	6
2	Gen-2	4	4	4
3	Gen-3	9.6	1	1
4	Line (bus4-bus5)	2.35	8	6
5	Line (bus5-bus6)	3.29	7	6
6	Line (bus7-bus8)	6.53	2	2
7	Trafo (bus1-bus4)	3.35	6	5
8	Trafo (bus2-bus5)	4.88	3	3
9	Trafo (bus3-bus6)	9.6	1	1
10	Trafo (bus6-bus7)	3.85	5	4
11	Trafo (bus8-bus9)	6.53	2	2
12	Trafo (bus6-bus10)	2.11	9	6

Table 4: Comparison of ranking methods

Outage	PI based Ranking	ERI based Ranking	PRI based Ranking	Ranking based on actual no. of violations.
Gen-1	9	6	8	6
Gen-2	11	4	4	4
Gen-3	8	1	1	1
Line (bus4-bus5)	10	6	8	6
Line (bus5-bus6)	12	6	7	6
Line (bus7-bus8)	2	2	2	2
Trafo (bus1-bus4)	5	5	6	5
Trafo (bus2-bus5)	6	3	3	3
Trafo (bus3-bus6)	3	1	1	1
Trafo (bus6-bus7)	1	4	5	4
Trafo (bus8-bus9)	7	2	2	2
Trafo (bus6-bus10)	4	6	9	6

5. CONCLUSION

Contingency analysis is necessary for power system operation and control. There are several methods available for ranking contingencies. Three methods were compared in this paper. The result of each method was compared with actual number of post contingency violations. From the results it is concluded that Precise ranking method has some advantage over other two methods (PI based ranking and Exact ranking method) since it differentiates severity between outages resulting in same number of post contingency violations. Precise method gives better ranking in such cases giving more information to the operator for better and effective control strategy.

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