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EVALUATION OF N-1 CONTINGENCY RANKING FOR SECURITY ANALYSIS IN MODERN POWER SYSTEM

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ABSTRACT

The modern power system is becoming wide and complex day by day due to increased loading and exploitation. In such situation, outage of single transmission line may lead to overload other transmission lines and sudden system voltage deviation (drop or rise) which may further cause successive outage of other lines if system constraints (line loading, bus voltage etc.) violate. To address this crucial issue, contingency analysis is attracting more and more attention of the power system engineers, researchers and planners. This paper presents a simple and reliable algorithm based on overall severity index (OSI) by computing severity index based on active power flow (SIP) and severity index based on voltage deviation (SIV) for all line outage. Thereafter, ranking of the contingencies for all line outage has been developed which will help the power system operator to take necessary control actions for maintaining power system, reliability and security. The effectiveness and viability of the proposed approach has been tested on standard IEEE 5, 14, 30, 57, and 118 bus systems in MATLAB environment.

KEYWORDS

contingency, power system, active power flow, voltage deviation.

1. INTRODUCTION

Contingency analysis basically refers to the investigation of the different contingency situation which arises due to outage of any element of the power system. The elements may be the generator, transformers, transmission lines, breaker tripping etc. It is worth noting that outage of any of these elements results into the abnormal situation of the power system. Furthermore, if the system parameters goes beyond the normal operating limit, the stable operation of the system is not possible. Therefore, the contingency analysis is an essential requirement for maintaining the reliable and stable operation of the power network.

A plenty of research works have been conducted for contingency analysis of the power system. The modern power system is facing a number of challenges like:

- System load demand increasing exponentially
- Power system is gradually overloaded and becoming stressed
- Unpredictability and uncertainty of fault occurrence
- Voltage stability, transient stability
- Introduction of various power electronics based non-linear devices, FACTS devices has made the power system more and more complex
- Increasing penetration of distributed generation lead to increased system complexity
- Reliability, security and quality of power

All of the above factors combinedly gave an impetus to the academicians, researchers and power system planners to find out an efficient way to increase the power system reliability and security so that quality power can be made available. One of the important aspect for improvement of

power system security and reliability is contingency analysis.

Nomenclature

PSCA	power system contingency analysis
SIV	severity index based on voltage deviation
SIP	severity index based on power flow
OSI	overall severity index
L	number of lines
N	number of buses
P_{il}	active power flow through i^{th} line with l^{th} line outage
P_{imax}	maximum power flow through i^{th} line
V_j	voltage at j^{th} bus
V_j	voltage at j^{th} bus
X_{ij}	line reactance between i^{th} and j^{th} bus
V_{isp}	specified voltage at i^{th} bus
V_{imax}, V_{imin}	maximum and minimum voltage limit at i^{th} bus respectively

Therefore, the power system contingency analysis (PSCA) is one of the major attracted area of research in today's modern power systems. A study presented the post contingency security assessment for prediction of bus voltages and power flows (Wood and Wollenberg, 1996). The different challenges associated with the execution of the algorithm are also highlighted. (Lee and Chen, 1992) utilized the distribution factors (Singh and Srivastava, 1987) to calculate the line flow changes following the outage of generator or transmission line. Brandwin and Lauby, 1989 adopted bounding method to reduce the line flow computation. Alam et al., 2018 authors described the variation of the voltage magnitude and

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phasors angle due to contingency arising from line outage. The PV curve method has been adopted to show the impact of each contingency on the static voltage stability and the degradation of the voltage profile of the buses is observed due to contingency. Zaborzky et al., 1980 presented the concentric relaxation method for PSCA and the mentioned approach advantageous due to the consideration of limited area. Ejebe and Wollenberg, 1979 proposed the performance index (PI) for ranking the different contingencies according to the severity. Kamwa et al., 2001 discussed the dynamic security assessment of power system utilizing the value of bus voltages and angles captured through phasor measurement unit (PMU) installed in the network. Fathehi et al., 2007 suggested voltage stability criteria index for contingency ranking and the reactive power margin has been used as a criterion to identify the most severe contingency. (Fathehi et al., 2007) suggested a new index based on reactive power and the scheme is applied on modified IEEE 39 bus network. The concept of Q-V curve is adopted for the execution of the methodology. Jia and Jeyasurya, 2000 presented the voltage stability assessment following contingency is presented by adopting generalized curve fit method and the voltage stability margin is also calculated.

In this study, we have developed a list of contingencies and rank them according to the severity. The most severe contingency is determined based on the rank. The severity of the contingencies is determined using two parameters i.e., voltage deviation and power flow deviation.

2. MATHEMATICAL MODEL

The contingency may arise due to the outage of any elements (generators, lines, transformers etc.) of the power network. However, in this work, we only consider the contingency arising from line outage. It is well known that normal operating voltage level of the power system is 0.95 p.u-1.05 p.u. Higher voltage level is not desirable from insulation view point and lower voltage level is not also acceptable due to performance degradation or stability point of view. In this context, a bus is said to have low voltage if the operating voltage is below 0.95 p.u. similarly, a bus is said to have high voltage if the operating voltage is above 1.05 p.u. Both situations are not desirable and system operators must maintain the voltage level within this limit. On the other hand, each line of the transmission network is characterized with power flow limit i.e., each line is having a prescribed power flow constraint. If the power flow through the lines goes beyond the limit then the corresponding line will be tripped. The power flow limit of the transmission line is specified by the MVA limit. Generally, the transmission lines are designed in such a manner that they are capable to withstand 125% of the rated MVA limit. However, when excessive power flows through line, the line loss increases with the square of the line currents and the temperature also increases. The active power loss is basically responsible for the temperature rise. From this view point, two severity indices are proposed for determining the severity of lines in case of contingency. These two severity indices are:

- Severity index based on power flow (SIP)
- Severity index based on voltage deviation(SIV)

Now, the violation of the active power flow w.r.t maximum power flow is represented by

$$SIP = \sum_{i=1}^L \left(\frac{P_{ii}}{P_{imax}} \right) \quad (1)$$

Where, L represents the total number of lines, P_{ii} represents the active power flow through i^{th} line with i^{th} line outage, P_{imax} is the maximum power flow through i^{th} line. The maximum power flow through each line can be computed using

$$P_{imax} = \frac{V_i V_j}{X_{ij}} \quad (2)$$

Here, V_i and V_j are the voltage at i^{th} and j^{th} bus respectively after load flow study. X_{ij} is the line reactance between i^{th} and j^{th} bus. Another severity index associated with the bus voltage magnitude violations is formulated as

$$SIV = \sum_{i=1}^N 2 \left(\frac{V_i - V_{ispl}}{V_{imax} - V_{imin}} \right)^2 \quad (3)$$

Here, V_i represents the voltage at i^{th} bus after load flow study. V_{ispl} is the specified voltage at i^{th} bus. V_{imax} is the maximum voltage limit (taken as 1.05 p.u) at i^{th} bus. V_{imin} is the minimum voltage limit (taken as 0.95 p.u) at i^{th} bus. If the bus voltages are within the limit, then SIV will be small and vice versa. This fact clearly illustrates that the deviation of the voltage profile results into the severity. However, combining the effect of both factors i.e., power flow violation and voltage level violation, the overall severity can be determined.

The overall severity index (OSI) due to line outage will be the summation of both severity index and can be written as

$$OSI = SIP + SIV \quad (4)$$

2.1 Implementation of the methodology

The ranking of the contingencies is very much vital for taking proper corrective actions. The corrective actions will be taken according to the severity of the contingency. Therefore, the offline analysis is used in this study to prepare a list of contingencies and ranking of the contingencies is done according to the severity. The Fast Decoupled Load Flow (FDLF) method has been used due to its faster convergence. The post-contingency voltages and power flows are found using FDLF method and the OSI is calculated for different contingencies.

Stepwise implementation procedure of the proposed PSCA algorithm is described below:

STEP 1: Read line data and bus data

STEP 2: Conduct the load flow study and obtain the base case results

STEP 3: Assume single line outage and again simulate the load flow

STEP 4: Calculate active power flow based severity index using (1) and (2)

STEP 5: Calculate voltage deviation based severity index according to (3)

STEP 6: Compute overall severity index (OSI) for this particular line outage as per equation (4)

STEP 7: Consider next line outage (contingency) and repeat steps 4,5,6 for each subsequent outage

STEP 8: Prepare ranking of contingencies based on overall severity index (OSI) and take control actions accordingly

3. SIMULATION RESULTS AND DISCUSSIONS

The simulation studies have been conducted on standard IEEE systems in MATLAB platform. The logical program was run with MATLAB version 7.10.0 (R2010a) loaded in a PC having in Intel core-i3 processor and 4 GB RAM. The load flow simulation is conducted considering base loading of the system.

3.1 IEEE 5,14,57 and 118 bus case studies

The IEEE 5 bus system consists of seven lines and hence seven contingency cases have been studied by considering one line outage at a time. The severity indices for various contingency cases and their ranking are also provided in Table 1. Among the seven contingencies, the contingency due to line outage 1 is ranked first as it is associated with the highest value of OSI. IEEE 14 bus system has 20 lines.

Therefore, 20 contingency cases are simulated one by one and the OSI is calculated. The severity indices for various contingencies and their ranking are presented in Table 2.

We can see that highest value of OSI has been found for contingency 10. On the other hand, lowest value of OSI has been found for contingency 13. From results, it can be concluded that the most severe contingency should be given first priority and stringent actions to be taken to avoid this contingency. It is worth noting that for line outage no. 14, the OSI could not be computed as load flow was not converged. In this case, severity index and ranking has been denoted by UD (undefined).

In case of IEEE 30 bus network, total 41 number of contingency cases have been investigated by taking single line outage at a time. The severity indices and OSI for all the contingency cases are presented in Table 3. Among all the cases, contingency due to line outage no. 36 is the most severe case as the OSI value is highest (30.0156).

Table 1: Contingency ranking of IEEE 5 bus system

Line outage no.	SIV	SIP	OSI	Ranking
1	23.517	0.3999	23.9169	1
2	0.4512	0.2833	0.7345	7
3	1.0646	0.2892	1.3538	5
4	0.9934	0.2929	1.2863	6
5	4.8499	0.4927	5.3426	2
6	1.2489	0.285	1.5339	3
7	1.208	0.289	1.497	4

Table 2: Contingency ranking of IEEE 14 bus system

Line outage no.	SIV	SIP	OSI	Ranking
1	6.4693	1.1952	7.6645	16
2	7.4239	0.9545	8.3784	12
3	7.4173	1.1177	8.535	11
4	7.0884	0.972	8.0604	13
5	7.6474	0.9525	8.5999	9
6	8.5163	0.9355	9.4518	2
7	6.8848	0.9627	7.8475	14
8	8.0935	1.0367	9.1302	5
9	7.7999	0.9476	8.7475	7
10	10.2056	1.1809	11.3865	1
11	6.1715	0.9811	7.1526	17
12	6.8006	0.9747	7.7753	15
13	4.9334	1.02	5.9534	19
14	UD	UD	UD	UD
15	5.6791	1.038	6.7171	18
16	7.6919	0.9785	8.6704	8
17	8.2328	0.9785	9.2113	4
18	7.9469	0.971	8.9179	6
19	8.2623	0.9691	9.2314	3
20	7.571	0.9729	8.5439	10

Table 3: Contingency ranking of IEEE 30 bus system

Line outage no.	SIV	SIP	OSI	Ranking
1	5.0194	1.521	6.5404	37
2	7.0586	1.2766	8.3352	33
3	7.4044	1.2578	8.6622	30
4	8.5557	1.2747	9.8304	17
5	7.1534	1.4787	8.6321	31
6	7.1953	1.279	8.4743	32
7	7.5311	1.2889	8.82	27
8	5.5421	1.2555	6.7976	36
9	9.7998	1.2676	11.0674	4
10	8.6858	1.3479	10.0337	14
11	8.9761	1.3552	10.3313	6
12	8.1983	1.2652	9.4635	24
13	UD	UD	UD	UD
14	4.5375	1.3587	5.8962	38
15	5.6143	1.5117	7.126	34
16	2.9045	1.2235	4.128	39
17	7.4866	1.2854	8.772	28
18	5.6387	1.3344	6.9731	35
19	7.3693	1.2952	8.6645	29
20	8.7782	1.2796	10.0578	12
21	8.6829	1.2832	9.9661	15
22	8.0572	1.2945	9.3517	25
23	8.7532	1.2851	10.0383	13
24	8.578	1.287	9.865	16
25	7.8237	1.2945	9.1182	26
26	8.3266	1.2865	9.6131	22
27	8.3782	1.3051	9.6833	19
28	8.8654	1.2822	10.1476	10
29	8.8654	1.2822	10.1476	11
30	8.364	1.2976	9.6616	20
31	8.871	1.2955	10.1665	8
32	8.8823	1.2828	10.1651	9
33	9.3305	1.2816	10.6121	5
34	UD	UD	UD	UD
35	8.2734	1.298	9.5714	23
36	28.584	1.4316	30.0156	1
37	10.4736	1.2941	11.7677	2
38	10.377	1.3081	11.6851	3
39	9.0459	1.2759	10.3218	7
40	8.4815	1.2831	9.7646	18
41	8.341	1.3159	9.6569	21

In case of IEEE 57 bus network, total eighty number of contingency cases have been studied by taking single line outage at a time. Severity indices (SIV and SIP) for all the contingency cases are presented in Fig.1. Among all the cases, contingency due to line outage no. 50 is the most critical case

as the OSI value is highest (302.9867) in this case (Fig. 2). The value of severity index has been assumed zero in case of load flow divergence to make the plot easily and for simplicity in calculation.

Figure 1: Severity index for IEEE 57 bus system

Figure 2: OSI for IEEE 57 bus system

As IEEE 118 bus system consists of 179 lines, so total 179 contingency cases have been analysed. Both the severity indices (SIV and SIP) for all the contingency cases depicted in Fig. 3. From Fig. 4, it is clear that the outage of line no. 107 is the most severe case as the OSI value is highest (44.23) in this case and thus failure of this line will cause the system more vulnerable compared to other cases.

Figure 3: Severity index for IEEE 118 bus system

Figure 4: OSI for IEEE 118 bus system

Although we have studied the ranking of the contingencies by taking single line outage but in some cases of single line outage the power flow solution diverges. For illustration, in case of outage of branch 14 (IEEE 14 bus), branch 13 and branch 34 (IEEE 30 bus system), the power flow solution diverges. Similarly for outage of branch 45,48 (IEEE 57 bus system) and outage of branch 15,19,110,120,144 (for IEEE 118 bus system) load flow does not converge. For these cases, the system becomes islanded and MATLAB generates output "NaN". In view of this, the OSI could not be computed for these cases which can be treated as special cases. As the SIV and SIP could not be computed for these cases, the OSI is represented by assuming the value zero for simplicity purpose.

Although a considerable research has been carried out for contingency analysis of power system and prediction of line outage, still several shortcomings exist and those are yet to be addressed. The following points can be helpful to the researchers and power system planners for improvement in the contingency analysis

- Perform the contingency analysis considering outage of multiple lines
- Enhancement of accuracy level in determining contingency
- Development of new faster algorithm to determine the contingency
- Contingency ranking evaluation through advanced algorithm via soft computing techniques like fuzzy logic, ANN (Artificial Neural Network) etc.
- Contingency study considering multiple equipment failure like generator, transformer etc.
- Consideration of the aspect of load variation during contingency analysis
- Incorporation of the FACTS or DG for congestion management due to contingency and find the suitable locations of these devices

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