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Contingencies Ranking for Voltage Stability Analysis using Continuation Power Flow Method

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Introduction

Voltage instability is mainly associated with reactive power imbalance. The loadability of a bus in the power system depends on the reactive power support that the bus can receive from the system, as the system approaches the Maximum Loading Point (MLP) or voltage collapse point, both real and reactive power losses increase rapidly. Therefore, the reactive power supports have to be local and adequate [1].

Based on bifurcation theory, two basic tools have been developed and applied to the computation of the collapse point, direct and continuation methods. Of these two techniques continuation power flow method is used for voltage analysis. These techniques involve the identification of the system equilibrium points or voltage collapse points where the related power flow Jacobian becomes singular. Voltage instability is the cause of system voltage collapse, which makes the system voltage decay to a level from which they are unable to recover. The voltage collapse occurs when a system is loaded beyond its maximum loadability point.

The consequence of voltage collapse may lead to a partial or full power interruption in the system [2]. For an ideal condition, when system does not experience an event and all components work correctly in system, system can provide maximum loading point and so its corresponding maximum mega watt margin. So to analyze how much power system is utilized safe, it needs to simulate possible contingencies for power system and network performance to be considered for each event. Surveying contingencies to analysis static voltage collapse, contingencies ranking are among necessary aspects of voltage safety.

Ranking all possible contingencies based on their impact on the system voltage profile will help the operators in choosing the most suitable remedial actions before the system moves toward voltage collapse [3]. In [4], surveying possible contingencies with ranking according to line FVSI indicator is carried out. The method of ranking the possible contingency based on right eigenvector and branch parameter especially in [5] is given. Appearing the artificial intelligence, possible contingency ranking is done based on neural networks [6]-[8], fuzzy logic [9], [10] and genetic algorithm [11]. In this paper applying continuation power flow (CPF) that is based on reformulation of load flow equations applying a continuum parameter, calculating MLP and its corresponding mega watt margin decrease percent in each contingency, we set to ranking of possible contingencies based on the severity of their effect on static voltage collapse.

Procedure of CPF Method

In this discussion, to seek for transmission line (TL), the power flow equations on the buses associated with the loading increments were reformulated to contain a parameter λ. If the functional vector F (θ, V, Q_c, λ) is used to denote the whole set of equations, the problem can be expressed by:

$$F(\theta, V, Q_c, \lambda) = 0 \,,\ \lambda \geq 0 \,, \qquad (1)$$

where vectors θ and V consist of system buses phase angles and load buses voltage magnitude; Q_c denotes the reactive powers provided by the installed compensator. If each PQ bus is installed with a compensator, the dimension of **F**(.) would be $n_g + 3n_d + 1$, n_g and n_d being the numbers of the PV and PQ buses, and the number of total system buses $N = n_g + n_d + 1$.

Given λ = 0, a base case state (θ_o, V_o) can be obtained first using a conventional power flow, and then λ will be sought along the loading increment path by applying the CPF process. During the process, when λ can no more be increased, namely λ reaches $\lambda_{critical}$, eventually the TL (= $\lambda_{critical} \sum_{i \in \pi_L} \Delta P_{li}$) is derived.

The procedure of CPF uses a predictor-corrector scheme along the loading increment path to find subsequent values for λ [12].

Predictor

After a base case state was obtained, a prediction of the next solution can be made by taking an appropriately sized step in a direction tangent to the solution path (loading increment path). Thus, the first task in the predictor process is to calculate the tangent vector. This tangent calculation is derived by first making derivative to both sides of (1) as follows:

$$\begin{bmatrix} F_\theta & F_V & F_\lambda \end{bmatrix} \begin{bmatrix} d\theta \\ dV \\ d\lambda \end{bmatrix} = \begin{bmatrix} 0_V \\ 0_\theta \end{bmatrix}. \quad (2)$$

In the left side of (2) is a partial derivative matrix multiplied by a differential vector. The matrix is the conventional load flow Jacobian augmented by the column vector F_λ that is directly associated with the base loading increment. In order to find a unique solution, an important barrier must be overcome. This problem arises when variable λ was inserted into the power flow equations but the number of equations remains unchanged.

Thus, one more equation is required. This problem can be solved by choosing a non-zero magnitude, say 1, from one of the components in the tangent vector. Since the equations in (2) are linear, let dλ be equal to 1 to simply denote the tangent vector and suppose λ would increase in each step until $\lambda_{critical}$ being reached. Equation (2) is then augmented and becomes:

$$\begin{bmatrix} F_\theta & F_V & F_\lambda \\ & e_k & \end{bmatrix} \begin{bmatrix} d\theta \\ dV \\ d\lambda \end{bmatrix} = \begin{bmatrix} 0_V \\ 0_\theta \\ \pm 1 \end{bmatrix}, \quad (3)$$

where e_λ – an appropriately dimensioned row vector with all elements equal to zero except the $(n_g + 2n_d + 1)^{th}$, which is equal to 1 associated with the unit change of λ.

Once the tangent vector is obtained by solving (3), the predication can be made by:

$$\begin{bmatrix} \theta^* \\ V^* \\ \lambda^* \end{bmatrix} = \begin{bmatrix} \theta \\ V \\ \lambda \end{bmatrix} \pm \delta \begin{bmatrix} d\theta \\ dV \\ d\lambda \end{bmatrix}, \quad (4)$$

where "*" denotes the predicted solution for a subsequent value of λ and the scaling factor δ should be appropriately chosen during each predication so that the solution can be within the convergence radius of the corrector.

Corrector

The corrector process is used to modify the predicted solution onto the solution path with one of the state variables being ascertained into an additive equation, say. Then, the new set of equations would be:

$$\begin{bmatrix} F(x, \lambda) \\ x_k - x_k^* \end{bmatrix} = [0]. \quad (5)$$

One of the voltage magnitudes on the PQ buses will be denoted as x_k*, assuming on bus k, which has the most negative value in the prediction. With an additive equation and a variable λ, the augmented equations can be solved by a slightly modified Newton-Raphson power flow method [13].

For dealing with the saddle-node bifurcation point on the loading increment path, the Psat program developed in [14] is employed to execute the CPF process.

Contingencies Ranking with CPF Method

Processing to contingencies ranking, first we calculate the variables of power system using an analytical method for each event and then the severity of effect in each event are calculated based on a performance indicator that is function of these variables. At first, appearing each contingency (like line outages and/or generation unit outages), the MLP and its corresponding MWM decrease percent would be calculated by continuation power flow method.

The MWM of the system is the distance measured in MW from the initial operating point, the nose of the P-V curve with or without applying contingencies to the system. To Arranging MLP as ascending and it's corresponding MWM decrease percent as descending, contingencies with lower MLP and higher MWM decrease percent set in higher ranks. MMWM and MWM calculate for system as:

$$\text{MMWM} = P_{i\max} - P_{base}, \quad (6)$$

$$\text{MWM} = P_{i+1\max} - P_{base}, \quad (7)$$

where $P_{\max}$ – maximum load active power corresponding with MLP; and P_{base} – base load active power. The MWM decrease percent is also calculated based on this:

$$\text{MWM decrease percent} = 100 \times [1-(\frac{MWM}{MMWM})]. \quad (8)$$

In power systems, the numbers of contingencies is dependent the number the elements exposed to failure in the system.

For event numbers of L level with NC_L: L=0,1,2,…,N we have [3]:

$$NC_L = \frac{N!}{L!(N-L)!}. \quad (9)$$

The zero level contingency NC_0 means no element in the system is subject to failure. Contingency of first level, NC_1 is equal with unique element numbers exposed to failure In power system the total number of all possible contingencies is extensive, so usually the first level or sometimes the second level contingencies are considered The total number of zero, first and second level contingencies, $NC_{0,2}$ is given in (10).

$$NC_{o,2} = \sum_{L=0}^{2} NC_L = 1 + N + \frac{1}{2}(N)(N-1). \quad (10)$$

In this paper contingencies of zero level and first level are considered so we have:

$$NC_{0,1} = \sum_{L=0}^{1} NC_L = 1 + \text{N}. \qquad (11)$$

Simulation Results

In the test, a modified IEEE 14 buses system was used to validate the proposed method. The test system consists of five generators and eleven PQ bus (or load bus). The simulations use PSAT simulation software. PSAT is power system analysis software, which has many features including power flow and continuation power flow.

The simulation was run by conventional P-V curve calculation to find the load margin for all possible first level contingencies. The continuation power flow for normal system manner is done that all generation units and lines are in the network and in fact no contingencies has occurred in system. Maximum Loading Point is $\lambda_{max} = 2.77\,p.u.$

Also load active powers are in base and maximum cases are $p_{base} = 3.626\,p.u.$ and $p_{\max} = 10.044\,p.u.$ respectively. The weakest bus also is identified bus 5 with voltage 0.676 *p.u.* The results of calculation of MWM for contingencies of generation unit outages in one level are shown in Table 1. Attention to (11); there are 5 contingencies in zero and first levels. In the first in contingency zero level that all system components are utilized correctly, MWM is 6.418 *p.u.* Contingencies ranking of first level based on their effects in continuum of generation unit outages in first level, we calculate system MWM in each manner.

Table 1. Contingencys Ranking of First Level in Single Generation Unit Outages

Rank	Generation unit outage	λ_{max} (p.u.)	P_{max} (p.u.)	P_{base} (p.u.)	MWM (p.u.)	MWM decrease (%)
1	Bus 6	1.730	6.274	3.626	2.648	58.74%
2	Bus 2	1.984	7.195	3.626	3.569	44.39%
3	Bus 3	2.062	7.478	3.626	3.852	39.98%
4	Bus 8	2.388	8.640	3.626	5.014	21.87%

In generation unit outage connected to bus 6, MWM and its percent are 2.6481 *p.u.* and 41.26% respectively that is lower than other generation unit outages. Contingencies with lowest MLP and highest MWM decrease percent are in higher rank in table. Attention to table 1, the generation unit outage connected to bus 6 with $\lambda_{\max}$=1.7303 *p.u.* and MWM decrease percent 58.74% are identified as the most critical contingency between contingencies of other generation unit outages. So in table put in higher rank. As so contingencies of generation unit outage connected to buses 2, 3 and 8 are in lower ranks in table.

The results of calculated MWM for contingencies of line outages in zero and first levels are shown in Table 2. Attention to (11); there are 21 contingencies in zero and first levels. We set the calculation of MWM with the line outages in first level. Exiting line11, MWM and its percent calculate 1.6978 *p.u.* and 26.45 % respectively that decrease more than to other line outages.

Table 2. Contingencies Ranking of First Level in Lines Outages

Rank	line Outage	λ_{max} (p.u.)	P_{max} (p.u.)	P_{base} (p.u.)	MWM (p.u.)	MWM decrease (%)
1	Line 11	1.1854	5.3238	3.626	1.6978	73.55%
2	Line 12	1.5731	5.704	3.626	2.078	67.62%
3	Line 18	1.5943	5.7424	3.626	2.1164	67.02%
4	Line 10	1.9814	7.0322	3.626	3.4062	46.93%
5	Line 16	2.2612	8.199	3.626	4.573	28.75%
6	Line 4	2.2635	8.2306	3.626	4.6046	28.26%
7	Line 9	2.2702	8.2318	3.626	4.6058	28.24%
8	Line 1	2.3564	8.5359	3.626	4.91	23.5%
9	Line 20	2.3937	8.5808	3.626	4.9548	22.8%
10	Line 19	2.4417	8.8536	3.626	5.2276	18.55%
11	Line 5	2.4502	8.8839	3.626	5.2579	18.08%
12	Line 14	2.5191	9.1223	3.626	5.4963	14.36%
13	Line 6	2.5848	9.3726	3.626	5.7466	10.46%
14	Line 8	2.6441	9.5863	3.626	5.9603	7.13%
15	Line 13	2.6728	9.6916	3.626	6.0656	5.49%
16	Line 17	2.7015	9.7951	3.626	6.1691	3.88%
17	Line 15	2.7056	9.8103	3.626	6.1843	3.64%
18	Line 2	2.7327	9.9087	3.626	6.2827	2.11%
19	Line 7	2.7414	9.9403	3.626	6.3143	1.62%
20	Line 3	2.7635	10.0205	3.626	6.3945	0.37%

Table 2 shows contingencies ranking of first level in line outages. Attention to table, outages of lines 11, 12, 18 and 10 are considered as critical lines and are in higher ranks in table. The outage of Line 11 with $\lambda_{\max} = 1.1854\,p.u.$ and MWM decrease percent 73.55% is identified as the most critical lines between other line outages. This line because of connection to slack bus (bus 1) and generation unit bus (bus 2) is under high loading, so its outage results in sudden voltage drop and more approximating the system to voltage collapse. Lines 3, 7, 2, 15, 17, 13 and 8 with higher loading point and lower MWM decrease percent are in lower ranks in table. The outage of line 3 with MWM decrease percent 0.37% is considered as contingency that has not too much effect on static voltage instability.

Conclusions

The loading margin to the point of voltage collapse is a fundamental index of relative voltage stability and system security. This paper has demonstrated that computing the MW margin sensitivities from the nose of the P-V curve can do effective contingency analysis for voltage collapse studies. It is shown that sensitivity of the MW margin to voltage collapse studies with respect to first level contingencies could be computed efficiently and quickly. In this paper to analyze static voltage collapse, we set to surveying contingencies of power system based on ranking these contingencies with continuation power flow method based on MLP and MWM decrease percent. The results show that the occurrence of contingencies in power system result in increasing of voltage drop in some of buses, the possibility of change in the weakest bus position, decrease of MLP and so its corresponding decrease of MWM. The contingencies with lower loading point and higher MWM decrease percent dedicates itself higher ranks. So with identifying these critical contingencies, we can do works to create preventive and reforming strategies to avoid system static voltage collapse.

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A screening method and continuation power flow program to analyze contingencies and their impact on static voltage stability in power systems is proposed. The proposed method for contingency analysis and voltage stability studies and is based on the impact of the contingency on the load, the Mega Watt Margin (MWM) and maximum loading point. The Method provides initially a ranking scheme for first level contingencies by comparing their loadability with the maximum loadability of the system. It then makes a short list of important contingencies for detailed analysis. The proposed method is tested by the IEEE 14-bus Test System. Bibl. 14 (in English; summaries in English, Russian and Lithuanian).

М. А. Камарпошти, Г. Лесани. Рейтинг непредвиденных случаев в анализе стабильности напряжения используя метод непрерывного потока мощности // Электроника и электротехника. – Каунас: Технология, 2010. – № 3(99). – С. 73–76.

Предложен метод скрининга и программа на основе метода непрерывного потока мощности для анализа непредвиденных случаев и их влияния на стабильность статического напряжения в энергетических системах. Предложен метод анализа чрезвычайных ситуаций и исследование стабильности напряжения основаны на воздействии помех на нагрузку, MWM и точке максимума нагрузки. Первоначально метод обеспечивает способ ранжирования для непредвиденных случаев первого уровня путем сравнения их нагружаемости с максимальной нагружаемостью системы. Предложен метод протестирован на „ IEEE 14-bus“ системе тестирования. Библ. 14 (на английском языке; рефераты на английском, русском и литовском яз.).

M. A. Kamarposhti, H. Lesani. Nenumatytų atvejų reitingavimas analizuojant įtampos stabilumą nepertraukiamo galios srauto metodu // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2010. – Nr. 3(99). – P. 73–76.

Nenumatytiems atvejams ir jų įtakai statinės įtampos stabilumui galios sistemose analizuoti pasiūlytas atrankos metodas ir programa, sukurta taikant nepertraukiamo galios srauto metodą. Metodas ir įtampos stabilumo tyrimas remiasi trukdžio įtakos apkrovai, MWM ir maksimalios apkrovos taško analize. Metodas užtikrina pradinį pirmojo lygmens nenumatytų atvejų reitingavimą lyginant esamą apkrovimą su maksimaliu sistemos apkrovimu. Pasiūlytas metodas testuotas naudojant „IEEE 14-bus“ testavimo sistemą. Bibl. 14 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).