Multilevel Adaptive Prefilter for MW Contingency Selection

ANTONIO F. GUERRA, CARLOS A. CASTRO
Power Systems Department
State University of Campinas
DSEE/FEEC/UNICAMP, C.P. 6101, 13081-970, Campinas, SP
BRAZIL
afguerra@dsee.fee.unicamp.br, ccastro@ieee.org, http://www.dsee.fee.unicamp.br

Abstract: - This paper focuses on the MW contingency selection problem. It is assumed a real time operation environment. A multilevel prefilter is proposed, so as to discard the contingencies that are certainly harmless to the system operation from the standpoint of MW power overflows. The prefilter is also adaptive, since information from one operation cycle can be used in the next operation cycle, provided that the change in the system operating conditions is small, which is often the case. Simulation results show that the proposed prefilter is accurate and results in significant computational time savings.

Key-Words: - Security analysis; contingency selection; MW overflow; prefilter; real time operation.

1 Introduction

Security analysis is one of the most important and computationally demanding functions that are performed at modern control centers [1]. As systems tend to operate closer to their operational limits, contingency analysis plays an increasingly important role as far as power systems security is concerned. It is crucial to identify the contingencies that would lead the system to abnormal or close to critical operating conditions. Contingency analysis consists of obtaining the post-contingency operating conditions for the most probable contingencies by performing load flow calculations. Preventive and/or corrective control action strategies may be developed for cases where post-contingency operating conditions are considered inadequate according to some criterion. For instance, operation with overloaded equipment (MW violations) or out of limit voltages (voltage violations) are considered inadequate conditions.

For realistic, large systems, the number of probable contingencies is very large, so a detailed analysis for all of them becomes impratical, especially for time constrained environments such as in real time operation. A well known and widely accepted procedure has been to perform a *contingency selection* prior to the contingency analysis itself. Contingency selection consists of computing approximate post-contingency operating conditions for a list of predefined contingencies and ranking them according to some criterion. Only the most severe ones (that appear at the top of the ranking list) undergo contingency analysis. For example, approximate operating conditions can be obtained by performing one iteration of the fast decoupled load flow [2]. The ranking is based on the so-called performance indices, which are computed for each contingency and reflect the severity of violations. Usually, only the single contingencies (outage of one equipment) are considered for contingency selection. Fig. 1 shows several cycles of real time operation and the most relevant analysis functions.

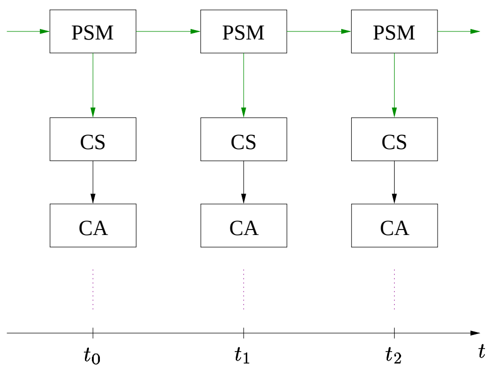

Figure 1: Real time operation of power systems.

At time t_0 a power system model (PSM) is obtained from the available data (both from a database and data acquisition system). Contingency selection (CS) is performed and contingencies are ranked. The top most severe contingencies undergo contingency analysis (CA). These functions are carried out periodically, say each 15 to 30 minutes, at times t_1, t_2 and so on.

Given this scenario, the following two points are addressed in this paper.

(a) The contingency selection function can itself be split up into several levels. In a first selection level a very simple analysis method can be used to discard those contingencies that are certainly harmless to the system operation. The remaining (potentially harmful) cases are inputs to a second selection level. Now a more elaborated model is used. Again, a number of contingencies are discarded and a smaller set of contingnecy cases are passed to a third level, and so on. In this paper, a two level contingency selection process is proposed. Each level will be described in detail.

(b) The real time operation and control of power systems consists of performing analysis functions in a cyclic fashion, as shown in Fig. 1. Contingency selection and analysis are performed every 15 to 30 minutes. Usually the system operating conditions do not change significantly in this time period. Therefore, it seems reasonable that many computations carried out in one cycle are still valid and do not need to be repeated in the next cycle. A procedure for passing information from one cycle to the next is shown in this paper.

By taking into account the two points discussed before, the contingency selection scheme shown in Fig. 2 is presented in this paper. It would replace block CS of Fig. 1.

Once the power system model is available for time t_i, the contingency selection function starts with a *prefilter* (PF). Through a very simple analysis of the system operating conditions, harmless contingencies are discarded. PF uses information from the system at time t_i only.

The outputs of PF are the inputs to the *adaptive block*. An evaluation of the changes that have occurred in the system from previous cycles is done. In case these changes are significantly *large*, a contingency selection is performed in the same way shown in Fig. 1, that is, by computing one iteration of the fast decoupled load flow for each contingency and ranking them according to a predefined performance index (CS/LF). In addition, a set of relevant information about the contingencies (basically a set of sensitivity factors) is stored

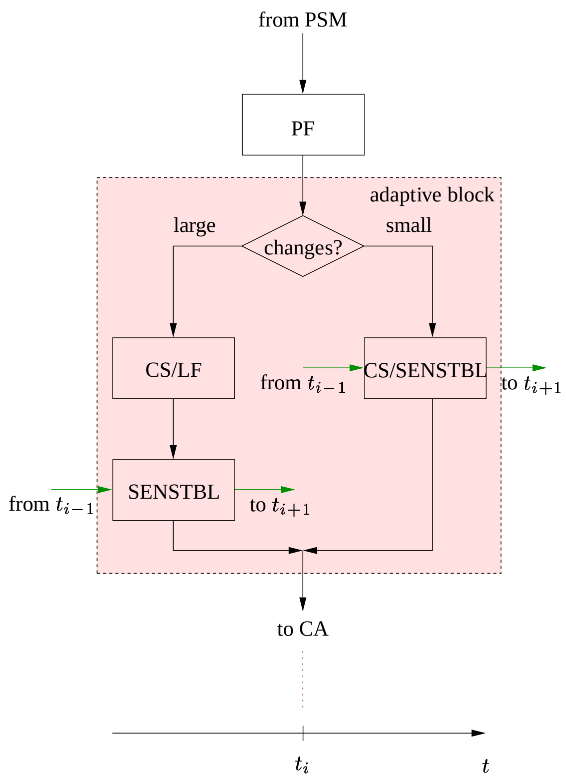

Figure 2: Proposed scheme for real time operation of power systems.

in a table (SENSTBL). Ocasionally this table can be updated rather than completely rebuilt, depending on the kind of changes that have occured from t_{i-1} to t_i. In case the changes are *small*, the ranking of contingencies is done based on the table of sensitivities only (CS/SENSTBL). The contingencies that are considered as potentially harmful (the top ranked ones) are inputs to the conventional contingency analysis function.

In the following sections the prefilter as well as the adaptive block are described in detail. Results of simulations are shown in order to provide an evaluation of the proposed process.

2 Prefilter (PF)

The prefilter (PF) processes information from the system operating conditions at time t_i only, that is, information from previous cycles are not used. The idea is to filter out those contingencies that are obviously harmless to the system operation. This has to be done using a very simple analysis method. PF is based on rules defined in [3], with the help some ideas that appeared in [4].

Consider a system with nbr branches. Let the base case real power flows through the branches be $P_i, i = 1 \ldots nbr$. Let also their respective maximum power flow limits be $P_i^{max}, i = 1 \ldots nbr$. Therefore, their spare capacities are $\Delta P_i = P_i^{max} - P_i, i = 1 \ldots nbr$. The minimum spare capacity is $\Delta P^{min} = \min \Delta P_i, i = 1 \ldots nbr$. For the outage of a branch ℓ:

(a) If $P_\ell \leq \Delta P^{min}$, contingency ℓ is harmless to the system operation and can be filtered out. Otherwise, continue.

(b) Initialize a *working region* with branch ℓ and its terminal buses k and m.

(c) Expand the working region tier by tier up until a *return path* is found. Fig. 3 shows a return path for an example power system. The return path is defined as a branch that connects the k-side to the m-side of the system. In the example the return path has been found in the first tier.

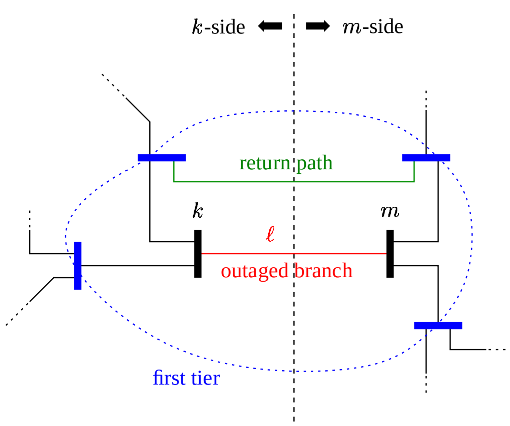

Figure 3: Return path for an example power system.

For each branch α that is added to the working region, compare P_ℓ to ΔP_α. If $P_\ell > \Delta P_\alpha$ stop the process and consider the outage of branch ℓ as potentially harmful. Otherwise continue.

(d) Expand the working region even further for nt tiers. For each branch α that is added to the working region, compare P_ℓ to ΔP_α. If $P_\ell > \Delta P_\alpha$ stop the process and consider the outage of branch ℓ as potentially harmful. Otherwise continue.

(e) In case the working region has been totally expanded (nt tier beyond the return path) and P_ℓ was found to be less than the spare capacity of all branches within the region, the outage of branch ℓ is considered harmless to the system operation and can be filtered out.

The prefilter has been set up considering that the effects of an outage are more noticeable in a region close to the outage itself. A branch with a small spare capacity is very unlikely to experience post-contingency overflow problems in case it is located far away from the outage. By adjusting the value of nt it is possible to be more or less conservative as far as accepting the risk of filtering out a potentially harmfull contingency. The simulations carried out in this research work have shown that $nt = 2$ provided very good results for realistic, large systems.

3 Adaptive block

Once a list of contingencies is sent to the adaptive block, two paths can be followed, depending on the events that took place in the system from previous cycles (Fig. 2). Each path consists of blocks that will be described in the next sections. Also, the interaction among the blocks is also discussed.

3.1 Block CS/LF

Block CS/LF (Contingency Selection through Load Flow calculations) of Fig. 2 is the same as block CS of Fig. 1. One full iteration of the fast decoupled load flow is performed. Though unnecessary, the reactive power/voltage magnitude iteration is also performed in this case because the contingency selection for voltage magnitude violations will be added to the process in a near future. The post-contingency MW power flows are computed as well as the performance indices. In this paper the performance index for the outage of branch ℓ was defined as

$$\mathrm{PI}_\ell = \sum_{i=1}^{nbr} \left(\frac{P_i}{P_i^{max}} \right)^{20} . \qquad (1)$$

3.2 Block SENSTBL

Block SENSTBL (SENSitivities TaBLe) consists basically of building/updating a table of sensitivities. It follows a description of such sensitivities [5, 6].

Consider that the contingency selection is to be carried out at time instant t_0. Consider also the outage of branch ℓ. Let the array of post-contingency voltage phase angles be $\boldsymbol{\theta}^\ell$. The phase angle variation with respect to base case is

$$\boldsymbol{\Delta\theta}^\ell = \boldsymbol{\theta}^\ell - \boldsymbol{\theta}^{bc},$$

where $\boldsymbol{\theta}^{bc}$ is the array of base case voltage phase angles. The sensitivities of bus voltage phase angles with respect to outage ℓ can be approximated by

$$\boldsymbol{\alpha}^{\ell} = \frac{\boldsymbol{\Delta\theta}^{\ell}}{P_{\ell}^{bc}},$$

where P_{ℓ}^{bc} is the base case MW power flow through branch ℓ. Vectors $\boldsymbol{\alpha}$ for all contingencies are stored.

3.3 Block CS/SENSTBL

Block CS/SENSTBL consists of performing a contingency selection using the sensitivity table built as described in Sec. 3.2. This is expected to result in significant computational savings if compared to computing one iteration of the fast decoupled load flow. Assume that the sensitivity table has been built and stored at time instant t_0. Consider now that the table is to be used at time t_1 for contingency ranking and selection. For a contingency ℓ, the approximate post-contingency bus voltage phase angles are computed by

$$\boldsymbol{\theta}^{\ell} = \boldsymbol{\theta}^{bc} + \boldsymbol{\alpha}^{\ell} \cdot P_{\ell}^{bc}. \tag{2}$$

It must be noted that $\boldsymbol{\theta}^{bc}$ and P_{ℓ}^{bc} are respectively the array of base case bus voltage phase angles and the base case MW power flow through branch ℓ at time t_1, while $\boldsymbol{\alpha}^{\ell}$ is the array of sensitivities computed at t_0. Equation (2) provide very good estimates for the post-contingency angles provided that the system changes from t_0 to t_1 are sufficiently small.

After computing the angles, the MW power flows and performance indices are computed and the contingencies are ranked.

3.4 Checking and updating SENSTBL

Updating or even rebuilding the sensitivity table may be necessary depending on the changes that occur between cycles. Usually the table is rebuilt after major load changes or topology changes (such as an equipment outage, even if it is for maintainance reasons). In case of small changes, such as a local load change or a minor topology change, only portions of the table should be updated. Nonetheless, simulation results have shown that consistent results can be obtained with the sensitivity table even after significant system changes. These results will be shown later.

4 Simulation results

The idea of this section is to ilustrate the performance of the prefilter, the adaptive block and the overall contingency selection process. As far as the prefilter, the important information refers to the number of harmless (noncritical) contingencies picked. It will be shown that the prefilter can be set to be more or less conservative. Regarding the adaptive block, it will be shown that the use of $\boldsymbol{\alpha}$ results in very good rankings. The quality of these rankings are quantified by a *capture ratio*. The performance of the adaptive block was assessed as follows.

Time t_0

- Perform one full iteration of the fast decoupled load flow for each contingency of the list and compute the respective vector $\boldsymbol{\alpha}$.

Time t_1

- Define changes in the system that have occurred in the meantime. Simulated changes were: load change in one bus, load change in all buses, load change in all buses followed by proportional changes in generation, outage of a branch, and outage of a generator.
- Determine the potentially critical contingencies according to the prefilter.
- For each contingency of the list that was considered as potentially critical by the prefilter, compute the postcontingency bus angles by (2). Compute power flows and rank the contingencies according to (1). This contingency list will be referred to as *list 1*.
- Compute the capture ratio.

The capture ratio mentioned above is a measure of the ability of the adaptive block to identify the most critical contingencies. Basically the ranked list obtained with the procedure just described is compared with a ranked list obtained by solving one full iteration of the fast decoupled load flow for each contingency. The m top contingencies of the later list (hereafter called *list 2*) are taken as a reference. Then the following procedure is carried out for computing the capture ratio:

- Define the number n of the top contingencies in *list 1*.
- Determine k, which is the number of contingencies that appear simultaneously in both *list 1* and *list 2*.
- The capture ratio is defined as $(k/n) \cdot 100\%$.

4.1 IEEE 14 bus, 20 branch system [7]

Fig. 4 shows the system's one line diagram.

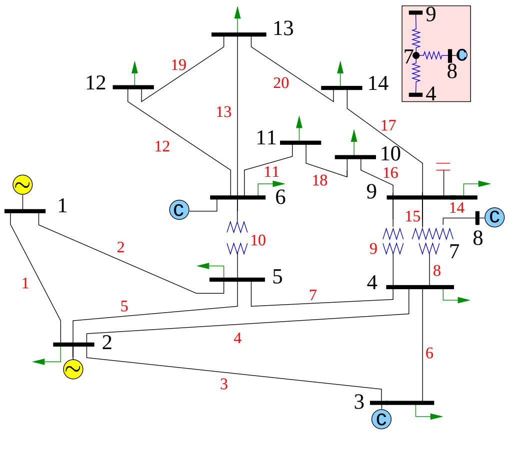

Figure 4: 14 bus, 20 branch system.

The following MW limits were used in the simulations: {210, 99, 99, 60, 54, 36, 82, 38, 48, 72, 24, 20, 26, 28, 38, 15, 15, 25, 15, 20}. A contingency list was built including 18 out of the 20 branches. The outage of branch (1-2) resulted in divergence, while the outage of branch (7-8) resulted in islanding.

The results provided by the prefilter PF depend on the value of nt, that is, the number of tiers that are expanded after the return path has been found. Branches (10-11) and (12-13) were declared harmless (noncritical) at step **(a)** of the procedure shown in Sec. 2, since the base case MW power flows through these branches were smaller than the system's minimum spare capacity. Also, for $nt < 2$, branch (6-12) was also declared noncritical. However, it was declared potentially critical for $nt \geq 2$. Actually, branch (6-12) is noncritical, that is, its outage does not result in MW overloads. This result shows that the larger nt is, the more conservative the prefilter becomes. Table 1 shows the effectiveness of PF for different system conditions. In particular, a load increase at bus 13 only was considered at time t_1.

Table 1: Performance of PF.

load increase [%]	contingency list	noncritical
0	18	3
10	18	1
70	18	0
150	16	0

A load increase results in a smaller number of noncritical contingencies picked by PF. Moreover, for a load increase of 150% another 2 contingencies resulted in load flow divergence, and were taken out of the list.

Regarding the adaptive block and the use of $\boldsymbol{\alpha}$, m was set to 5, that is, the top 5 most critical contingencies were considered as a reference. The block CS/SENSTBL of Fig. 2 performed as shown in Table 2. The number of contingencies of the list appear between parenthesis just after the load increase percentage.

Table 2: Performance of CS/SENSTBL for a load increase at bus 13.

0% (18)		10% (18)	
n	capture ratio [%]	n	capture ratio [%]
5	80	5	80
10	100	10	100
70% (18)		**150% (16)**	
n	capture ratio [%]	n	capture ratio [%]
5	80	5	100
10	100		

Table 3 shows the performance of CS/SENSTBL now considering that at time t_1 a generalized load increase, followed by a proportional generation increase has occurred.

Table 3: Performance of CS/SENSTBL for a generalized load and generation increase.

0% (18)		10% (17)	
n	capture ratio [%]	n	capture ratio [%]
5	80	5	80
10	100	10	100
20% (17)		**35% (13)**	
n	capture ratio [%]	n	capture ratio [%]
5	80	5	60
10	100	10	100

4.2 904 bus, 1283 branch system

This system corresponds to a reduced version of the Southwestern USA power system. The contingency list contained 956 branches, since the outage of the other 327 branches resulted in either load flow divergence or islanding. Table 4 shows the performance of PF.

Through step **(a)** of the PF procedure 4 contingencies were immediately discarded. In case the working re-

Table 4: Performance of PF.

nt	0	1	2	3
Step (**a**)	4	4	4	4
Full PF	259	156	112	83

gion is expanded one tier after the return path is found ($nt = 1$), another 152 contingencies were discarded, resulting in a total of 156 noncritical contingencies that were taken out of the contingency list at a very small computational cost. However, one out of the 152 contingencies filtered out by PF is indeed critical, that is, its outage results in MW power flow violation. Worse yet, for $nt = 0$ four critical contingencies were filtered out. For $nt \geq 2$ no critical contingencies were mistakenly filtered out. On one hand, a small working region may result in misclassification of critical contingencies. On the other hand, a large working region may result in too many false alarms (noncritical contingencies are considered as potentially critical). The simulation results showed that a good compromise occurs for $nt = 2$. Also, nt can be reset for a same system depending on the load conditions. For instance, different values of nt can be set during peak hours and light load hours. Table 5 shows the results of contingency selection using CS/SENSTBL.

Table 5: Performance of CS/SENSTBL for a generalized load and generation increase.

0% (956)		10% (934)	
n	capture ratio [%]	n	capture ratio [%]
5	80	5	80
10	100	10	100
20% (911)		**30% (891)**	
n	capture ratio [%]	n	capture ratio [%]
5	80	5	80
10	100	10	100

Again the capture ratios were very good, indicating that the overall contingency selection can correctly identify the most critical contingencies. Table 6 shows some computational times, indicating that the savings in computational times are expressive. Since the computational times depend on the hardware and software implementations, the most important information taken from Table 6 is that PF takes negligible time, and can discard a considerable number of contingencies, especially for light loading conditions. CS/SENSTBL takes just a small fraction of the time required by CS/LF (less than 15% in this particular case).

Table 6: Computational times.

Procedure	Time [sec]
PF ($nt = 2$)	0.41
CS/LF for 956 contingencies	352.47
CS/SENSTBL for 956 contingencies	47.43

5 Conclusion

In this paper a multilevel, adaptive contingency selection method has been proposed. The method showed to be accurate and robust, being able to correctly identify the most severe contingencies as far as MW power flow violations are concerned. Further studies are under way to improve the overall efficiency of the method, by storing the least number of sensitivity factors as possible. Also, the voltage magnitude violation problem will be added, preferably by following a similar multilevel, adaptive procedure.

6 Acknowledgements

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