AN OPTIMIZATION ALGORITHM TO IMPROVE SECURITY OF ELECTRICAL ENERGY SYSTEMS

An hybrid approach based on Linear Programming and Load Flow Calculations

José V. Canto dos Santos, Arthur T. Gómez, Antônio G. Rodriguez
PIPCA – UNISINOS
P O Box 275, 93022-000 – São Leopoldo – RS, Brazil

Keywords: Security Analysis, Power System Restoration, Linear Programming.

Abstract: Power system restoration is one of the main problems in the electrical engineering area, due to the improving dependency of electricity of the modern industrial society. The restoration of large electrical power systems after the occurrence of serious blackouts is a complex problem where the basic goal is to obtain the system configuration in order to supply loads with different priorities. The restoration is done through stages and in each stage the service is restored to a predetermined set of loads. A method to solve the basic problem in a real power system restoration process is presented in this work. The solution takes into account the nonlinear electric network model (AC model) as well as its constraints and operational limits. The fictitious network concept is extended to the reactive model. Linear programming, a new model for the linearized power flow and conventional load flow calculation are also used. Results obtained with a test system and with a large realistic system are presented.

1 INTRODUCTION

The occurrence of blackouts involving large sections of electric energy systems is a real possibility, however the remarkable investments for the improvement of its security made by utilities. The damages caused to industrial societies by these blackouts are significant. With the continuous growth of the complexity of the systems and the demand for electric energy, it is necessary that the treatment of systems after the occurrence of blackouts become a part of operation procedures. In this context, the power systems restoration (PSR) has received special attention in the last years. It is easy to see in the literature that the general solution to the problem was still not found. The use of Artificial Intelligence techniques to deal with the restoration is widespread, with prominence for the development of expert systems to support the operators of systems. Some examples are the articles of Kirschen and Volkman (1991) and Matsumoto et al. (1992). In this approach, a basic point is the use of the experience of operators about the electric network in the construction of rules used in expert systems, so it is natural that a certain degree of dependence between the modelled electrical network and the developed expert system is maintained. Another approach to the problem is based on optimization techniques, considered in a minor number of works, whose distinguished examples are Wu and Monticelli (1988) and of Huang et al. (1995). According to Wu and Monticelli (1988) the problem is non linear with restrictions, combinatorial and multistage. The authors ponder that if the restoration procedure will be determined after the blackout, a basic restriction is the period in which the system is without energy supply, so the adopted model must allow the fastest solution to the problem. There are other publications that focus important details of the problem, like Adibi et al. (1992).

In this work a method is presented regarding one of the basic problems in restoration procedures: the determination, in each stage of the process, of a system configuration that accounts for the priority load attendance. The method considers, in the static point of view, the active and reactive aspects of the systems and its main operative limits. The obtained solutions can be used either for the determination of restoration procedures during blackouts (on line use) as well as in the planning of such procedures (off line use). The presented method improves the PSR processes; therefore it also improves the security of operation of the electrical energy systems.

V. Canto dos Santos J., T. Gómez A. and G. Rodriguez A. (2006).
AN OPTIMIZATION ALGORITHM TO IMPROVE SECURITY OF ELECTRICAL ENERGY SYSTEMS - An hybrid approach based on Linear Programming and Load Flow Calculations.
In *Proceedings of the Third International Conference on Informatics in Control, Automation and Robotics*, pages 119-123
DOI: 10.5220/0001212101190123

2 PROBLEM FORMULATION

Restore a power system means to determine the best form to guide the system from a state where its integrity is harmed, after serious contingencies, to another where priority loads are supplied and operative limits are respected. This problem is multistage, being the objective in each stage the reestablishment of the service to a group of priority loads. The main constraint is the time gap where consumers are without energy. The restoration process is complex, even in its static aspect, because the high number of involved factors. In these factors we can list the identification and scheduling of the available resources of power generation, the available equipment to be reconnected and the operative limits of all the equipments installed in a system.

In this work, the presented method starts in the point where the electric system (or part of it) is in blackout. Events that had carried the system for the restorative state are not analyzed. In each stage of the process, the priority loads and the equipment in conditions to be used for the restoration are known.

2.1 Treatment of Disconnected Systems

In the course of a blackout, the separation of the system in diverse subsystems (islands) is frequent due to loss of interconnections. To treat disconnected systems in this work a fictitious (dummy) network is used, in a procedure described previously for electric transmission expansion planning - Monticelli et al. (1982). In this procedure, each out of operation branch of the system is substituted by a fictitious branch with artificially high impedance. The analyzed network is therefore always connected (not having singulars matrices in the solutions of type Ax = b) allowing the verification of pathways with power flow need.

2.2 Alternative Model of Linearized Power Flow (DCLF*)

In the PSR, an early problem is to determine which generator (or generators) will be used to supply the priority loads. The problem is more critical in the beginning of the process, when diverse generators may need to attend a few loads. To prevent a large optimization problem (generation scheduling) in this stage, a new model of linearized power flow was developed. This model automatically determines the generators near to loads and assigns the requested power to each generator. As it will be seen ahead, possible operation limits breakings are treated after.

The detailed electrical description of this model is out of the scope of this work, but basically, the joint use of the new model of linearized power flow with fictitious network allow the work with disconnected systems and also the verification of the power flows in the fictitious branches. Thus, we can decide on the necessity of the reconnection of an equipment, like it will be seen forward.

3 PROPOSED APPROACH

The solution for each problem stage is obtained through two main phases. The equipments that can be returned to operation and loads to be restored are defined in each stage. Each phase is described in a summarized way below.

Phase I – DC Problem

It determines which branches have to be reconnected to consider the active aspect of the problem. This Phase is composed of 2 steps.

I.1. Determine branches to be reconnected using the fictitious network and the alternative model of power flow described in the previous section. A DCLF* is performed after and the more loaded fictitious branch is reconnected (when a branch is reconnected the fictitious parameters are substituted by the real ones) until there is no more considerable flow in the fictitious network - see Figure 1.

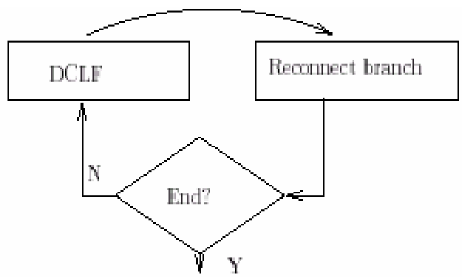

Figure 1: Simplified vision of the step I.1.

I.2. If there are limit violations in the injections of the generators or in the branches flows after the *I.1* step is finished, a Linear Programming model (LPM) is performed and, if necessary, new branches are reconnected. The load cut is not allowed in this phase, aiming at the integral supply of priority loads, so the LPM calculation may not be possible. In this case, the most loaded branch in the last solution of DCLF* is successively relocated and a new LPM is executed. When the LPM presents a solution, the linearized power flow model is the conventional. The LPM determines how much active power is needed from each generator assuring that their limits will be respected. Aiming at maintain the solution next to the obtained in the *I.1* step, the LPM model looks for a solution where the limits are respected with a minimum deviation from the current point. The problem is described as follows.

$$Min C'\Delta P_I + C'\Delta P_{II} \quad (1)$$

subject to:

$$\sum_{i=1}^{nb} \Delta P_I - \sum_{i=1}^{nb} \Delta P_{II} = 0 \quad (2)$$

$$0. \le \Delta P_I \le P^{\max} - P^0 \quad (3)$$

$$0. \le \Delta P_{II} \le P^0 \quad (4)$$

$$P_{km}^{\min} - P_{km}^0 \le \Delta P_{km} \le P_{km}^{\max} - P_{km}^0 \quad (5)$$

where: *nb* - number of buses of the system, *C* - costs, ΔP_I, and ΔP_{II} - increments of increase and reduction in the injections P^0. P^0 *e* P^{max}.- initial active powers and maximum limits for injections. P_{km}^0, $P_{km}^{\min}$, $P_{km}^{\max}$ and ΔP_{km} - flows of active power in the initial solution, limits and increments for flows. In the end of this phase we have a composed network with branches, generators and loads with all its limits respected.

Phase II - AC Problem

In this stage the network obtained in Phase I is tested and, if necessary, modified to comprise the reactive part of the system. Equipment that is not reconnected is still represented for fictitious parameters. This phase is executed in three steps, as seen below.

II.1. A reactive dispatch for the network is performed having as objective function the use of reactive sources associated costs. In this dispatch, the limits for voltage are relaxed in buses not reconnected that possess non static sources of reactive power, allowing the algorithm to allocate reactive power if necessary. The limits for reactive injections in priority buses are such that the attendance of these injections is guaranteed. CRIC Model (Carpentier, 1986) is used in sensitivity between reactive power and magnitudes of voltage, providing that the reactive power and the active problem are managed in a nearly independent form.

II.2 The reconnection necessity of reactive sources in the network buses configured in Phase I is verified after step *II.1*. Later, it is verified if the constructed network is in operation condition. This is made using a non linear power flow calculation with data collected in previous stages. If the solution is available, end of the stage and beginning of the next one solution. In contrary, phase *II.3* must be carried through.

II.3 It is verified in this stage the need of reactive sources situated in buses that had not been reconnected in Phase *I*. The bus is incorporated in the system during this process by the reconnection of the branches with bigger reactive flow until a bus already ‘energized’ is reached. The power flow for the new configured network is then calculated. If this calculation has solution, end of the stage and beginning of the next one. In contrary, stage *II.1* must be carried through again, with new data.

4 TESTS

Dual Linear Programming and software MINOS was used in the implementation. The fast decoupled load flow (Monticelli et al., 1990), version BX, was used for the non linear case.

4.1 IEEE-14 Test System

The IEEE-14 test system (Freris and Sasson, 1968) is small, hence is adequate for the obtained results description. For this system, it was considered an occurrence of a general blackout and that the generators of buses 1 and 2 and all the 20 branches were available for the restoration of the net. Two stages had been defined, first with priority loads in the buses 4 and 12, and the second with the supply of all system load objective.

In the first stage solution was obtained a network with 5 buses and 4 branches. After, the network was expanded for 13 buses and 15 branches in the second stage. In both stages, the objective of supply priority loads respecting the existing limits was reached. In first stage solution, stages I.2 and II.3 have not been needed. This fact has been observed in diverse tests with different systems. Solution details are supplied in Tables 1 and 2 and configured network topology is shown in Figure 2.

Table 1: Tests with IEEE-14 test system.

First stage solution	
Reconnected buses - step I.1	2 4 5 6 12
Reconnected branches - step I.1	2-5, 4-5, 5-6, 6-12
Reconnected equipments – Phase II	-
Load flow calculations – Phase II	1

Table 2: Tests with IEEE-14 test system.

Second stage solution	
Reconnected buses - step I.1	3 7 9 10 11 13 14
Reconnected branches - step I.1	3-4, 4-7, 7-9, 6-13, 9-10, 9-14, 10-11
Reconnected buses - step I.2	1
Reconnected branches - step I.2	1-2, 2-3, 1-5, 2-4
Equipments reconnected – Phase II	-
Load flow calculations – Phase II	1

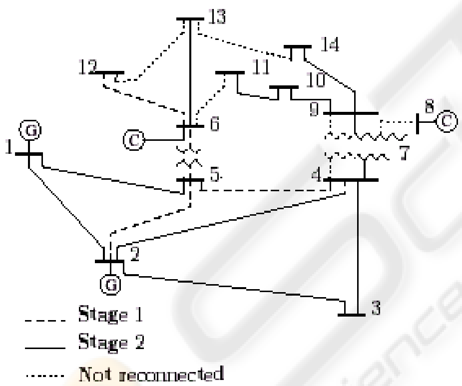

Figure 2: Solution for IEEE-14 test system.

4.2 Large Realistic System

In this test we used a large realistic system configuration with 810 buses and 1340 branches. The test presented here considers the occurrence of a system blackout and that all its components were available to be reconnected for operation. Two stages of restoration has been proceeded. In the first stage the objective was to supply only two important loads totalizing 1027 MW. In second and the last stage the objective was the supply of all the system loads, of about 40000 MW. In the first stage solution, the system configuration consisted of 2 sub-nets (assigned as A and B) in independent operation and it was obtained without necessity of steps I.2 and II.3. Tables 3 - 4 show the solution for this test.

Table 3: Tests with a large realistic system.

First stage solution	
Number of reconnected buses - step I.1	13
Number of reconnected branches - step I.1	11
Reconnected equipments– Phase II	1
Load flow calculations – Phase II	1
Generators in activity	4

Table 4: Tests with a large realistic system.

Second stage solution	
Number of reconnected buses - step I.1	747
Number of reconnected branches - step I.1	1198
Number of reconnected buses - step I.2	0
Number of reconnected branches - step I.2	14
Equipments reconnected – Phase II	6
Load flow calculations – Phase II	1
Generators in activity	82
Number of reconnected buses	760
Number of reconnected branches	1223

5 CONCLUSION

In this work a method was presented to assist processes of power systems restoration, solving one of the basic problems in such procedures: the determination of the system configuration adjusted for the priority load supply in each stage of the process. Beyond linear programming, the method uses a new model of linearized power flow and an expansion of the fictitious net concept. These two developments can be applied in other areas of electric energy systems analysis. The developed approach, simple but robust, is an analytical method that can be applied to any electric system whose restoration after a blackout is necessary. Also, it allows for an easy modeling of typical circumstances of a system in the restorative state. In the performed simulations the obtained results had been fully satisfactory and the necessary computational efficiency for execution in real time was reached. Results revealed that, in each stage of the restoration process, depending on the definition of the set priority loads, the necessary equipment number for system recompose the can be smaller than the system total. This fact was expected since most often the systems operate with a safety margin.

Research in progress points to the necessity of inclusion in the developed methodology of other problem aspects still not focused, like an application of combinatorial optimization procedures.

REFERENCES

Adibi, M. et al. (1992). Special Considerations in Power System Restoration. *IEEE Transactions on* PWRS, EUA, 7(4): 1419-1427.

Carpentier, J. (1986). CRIC, a New Active Reactive Decupling Process in Load Flows, Optimal Power Flow and System Control. *Proceedings IFAC Conference on Power Systems and Power Plan Control*, China, p.65-70.

Freris, L., Sasson, A. (1968). Investigation of the Load Flow Problem. *Proceedings of IEE,* Inglaterra, 115(10):1459-1470.

Huang, J. et al. (1995). A Systematic Method for Power System Restoration Planning. *IEEE Transactions on PWRS,* EUA, 10(2): 869-875.

Kirschen, D., Volkman, T. (1991). Guiding a Power System Restoration With an Expert System, *IEEE Transactions on PWRS*, EUA, 6(2): 558-566.

Matsumoto, K. et al. (1992). Knowledge-Based Systems as Operational Aids in Power Systems Restoration. *Proceedings of the IEEE*, EUA, 80(5): 689-697.

Monticelli, A. et al. (1982). Interactive Transmission Network Planning Using a Least-Effort Criterion. *IEEE Transactions on PAS*, EUA, 101(10): 3919-3925.

Monticelli, A. et al. (1990). Fast Decupled Load Flow: Hypothesis, Derivations and Testing. *IEEE Transactions on PWRS*, EUA, 5(4):1425-1431.

Wu, F., Monticelli, A. (1988). Analytical Tools for Power System Restoration - Conceptual Design. *IEEE Transactions.*