OPTIMAL POWER DISTRIBUTION SYSTEMS CONFIGURATION AND SWITCHING SEQUENCE PROCEDURE DETERMINATION

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ABSTRACT

This paper presents a methodology and a computational tool for power distribution systems planning based on load spatial analyses and providing an optimal system configuration, with regard to substation load balancing, and an effective switching operation sequence allowing the improvement of system reliability and power quality. The proposed optimization algorithm is a two-stage procedure. The first procedure determines the optimal distribution system configurations and the second procedure determines the sequence of switching operations required to convert the original system configuration into the optimal system configuration obtained previously. It is proposed two different approaches for the optimal distribution system configuration determination. A distribution system comprising several substations is selected for the simulation and the efficiency of the proposed method is verified.

INTRODUCTION

Power distribution systems are becoming larger and more complex due to the society high dependency on electric power supply, and then higher network reliability and power quality are required [1]. The problem of optimal distribution system configuration determination and the sequence of switching device operations are complexes decision-making and control problems for power system operators.

Most of the systems reconfiguration methodologies provide only the final configuration, i.e., the initial and final switches state, suppressing the switching operations sequence between each configuration [2].

Therefore, a research and development (R&D) project, in association with Sulgipe, a northeast Brazilian electric utility, was conducted to develop a methodology and computational tool to determine the optimal distribution system configuration along with its switching operations sequence procedure, taking into account the minimization of both the number of consumers without supply and the number of switching operations, respecting the electrical system constraints [3]: current and voltage ratings of the lines, transformers and other equipment must not be exceeded and preserve the radial structure of the distribution system.

METHODOLOGY

To accomplish the concerns presented, the following approach proposed in this work is divided into two procedures, applied consecutively.

Optimal Distribution System Configuration

The optimal system configuration is determined based on the substations load spatial analyses which, through the supply regions screening process (divided into smaller sectors), indicates the areas where management actions can be executed in order to serve the load demand optimally. The management action applied transfers load sections (set of load in between switches) between feeders using sectionalizing and tie switches (network reconfiguration) along with expansion plans proposed automatically, when and where necessary, such as line expansions and switches installations.

Two different methods were developed and the results can be compared by the system planner.

Penalized Short Linear Distance

The procedure searches for the shortest linear distance between each sector and the substations, penalized when the substation capacity is overloaded [4]. The algorithm 1 describes this method:

Algorithm 1:

i. Assume all substations with unlimited capacity;
ii. For each sector:
    a. Determine the linear distance from each substation;
    b. Link with the closest substation;
iii. Check the substations capacity;
iv. For each overloaded substation:
    a. Raise the virtual substation height (virtual Z-Axis);

b. Link each sectors with the closest substation;
c. Repeat step (iii) until all substations reach permissible loading levels;

Weighted Short Network Path

The procedure searches for the shortest network path (electric distance) which supplies each sector by the closest substation, weighted by the conductors' resistance. The algorithm 2 describes this method:

Algorithm 2:

i. Switch off the switches devices;
ii. Determine the feeders inside each sectors;
iii. For each sector:
    a. Determine each weighted distance from each substation through the network topology;
    b. Link with the closest substation;

Both methods optimise the substation supply area (closest distance to the load centres') and the system configuration (considering losses magnitude, node voltage and feeder capacity constraints).

Switching Sequence Procedure

The switching sequence operation, which brings the system into the previously obtained target, is established by a branch-and-bound algorithm [5], which generates a sequence of solutions (systems configurations), originated by an embedded heuristic, taking into account the constraints:

i. System: Ensures the system operation within its equipment-allowable limits. Capacity constraints are concerned with setting upper limit on the power dispatched from each transformer station. Voltage constraints are set such that voltage drop does not exceed specific allowable limits and preventing the substations from supplying far areas.
ii. Consumers: Minimises the number of consumers without supply and prevents distinguished consumers, such as hospitals for instance, to be cutted off.
iii. Switching: Minimises the number of switching operations.

The branch-and-bound algorithm developed works moving from solution to solution (system configutations) in the space of candidate solutions (combinations of the switches state) by applying local changes (changing the switches state), until a solution satisfying the restrictions is found or a time bound is elapsed.

It is not required to find the global optimal sequence of switching operations, but only the one that converts the original system configutation to the optimal system configuration determined previously.

Each local change (change of one switche state) requires the evaluation of the total of consumers without supply and the identification of distinguished consumers. In cases which distinguished consumers are cutted off, the soluton is rejected, the search path is abandoned and the search is restarted via backtraking procedure.

In order to guarantee the electrical system constraints, the final configuration is evaluated by the load flow analysis, called Forward/Backward Power Flow [6], since each section of a radial distribution feeder is connected radially. The algorithm 3 describes this method:

Algorithm 3:

i. Identify the differences between the original and the optimal system configuration (sections transferred);
ii. Determine the set of switches (sectionalizing and tie switches) which connect the sections to be transferred from the original feeder to the optimal feeder;
iii. Start time counter;
iv. Choose randomly a switch from the set of switches:
    a. Change the switch state;
    b. Evaluate the total of consumers without supply;
    c. Remove the switch from the set of switches;
    d. Add operation to the sequence of operations;
    e. Search for distinguished consumers cutted off. If found, return the switch state to the original and remove operation from the sequence of operations;
    f. Repeat step (iii) until the set of switches is empty;
v. Verify the system configuration obtained:
    If all sections transfer where carried out, is executed the load flow analysis, finished execution and shown result;
    Else, identify the sections not transferred, expand the set of switches (add switches from the section neighbourhood) and return to step (iii);
vi. If time bound is elapsed or all switches where tested, finish execution and show result;

The Figure 1 exemplifies the algorithm 3 execution.

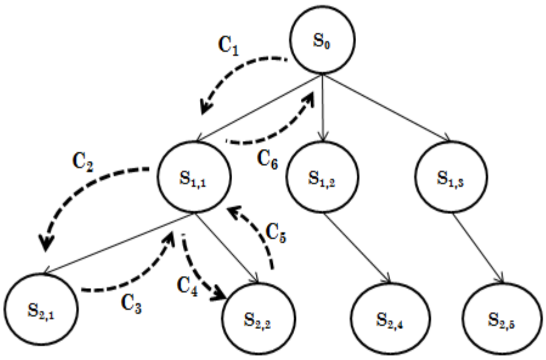


Figure 1: Branch-and-bound algorithm execution

Taking S_0 as the original system configuration, one switch is chosen randomly from the set of switches. Its state is changed resulting the $S_{1,1}$ system configuration. Another switch is chosen randomly from the set of switches and has its state changed, resulting the $S_{2,1}$ system configuration, which has cutted off a distinguished consumer. So the backtrack procedure return to the $S_{1,1}$ system configuration and the execution continues.

RESULTS

The computational tool developed, which encloses the procedures proposed, is shown in Figure 2.

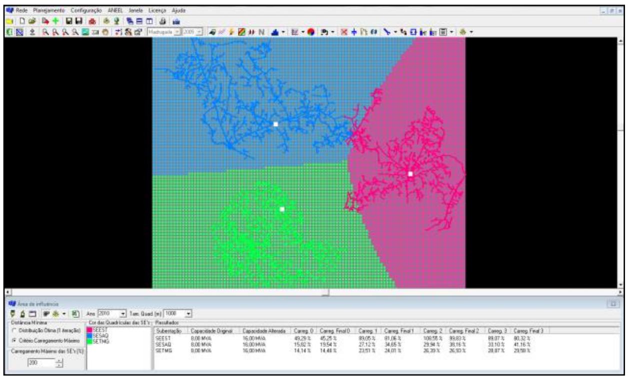


Figure 2: Computational tool

Simulation

In order to evaluate the proposed methodology, simulations were carried out on 6 substations (total of 25 feeders) from Sulgipe supply region.

Figure 3 shows the result of the Penalized Short Linear Distance procedure.

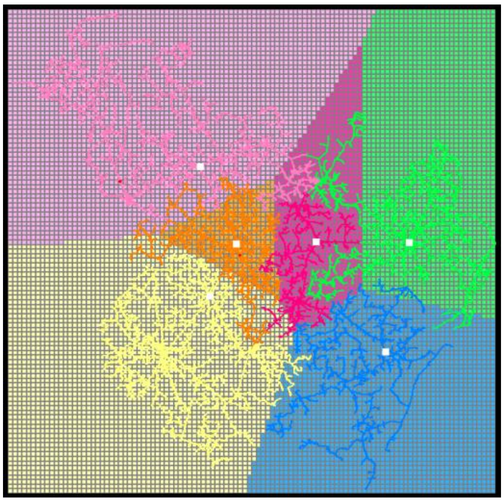


Figure 3: Penalized Short Linear Distance result

Figure 4 shows the result of the Weighted Short Network Path procedure.

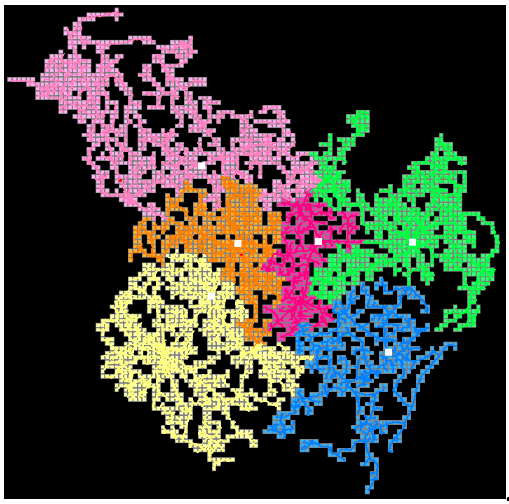
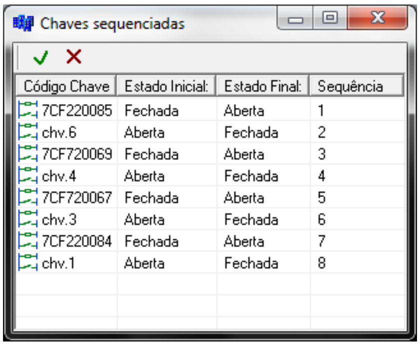


Figure 4: Weighted Short Network Path result

Once obtained the optimal system configuration, using any of the methods and applying the expansion plans required, and executed the switching sequence procedure the final system configuration is evaluated by the load flow analysis, resulting in two possibilities:

i. The switching sequence is feasible, so the sequence of operations is presented, as shows the Figure 9;
ii. The switching sequence is unfeasible.


Chaves sequenciadas

Código Chave	Estado Inicial:	Estado Final:	Sequência
7CF220085	Fechada	Aberta	1
chv.6	Aberta	Fechada	2
7CF720069	Fechada	Aberta	3
chv.4	Aberta	Fechada	4
7CF720067	Fechada	Aberta	5
chv.3	Aberta	Fechada	6
7CF220084	Fechada	Aberta	7
chv.1	Aberta	Fechada	8

Figure 5: Switching sequence operations obtained

The causes of switching sequence unfeasibility are listed, reported and graphically explicit, as shown in Figure 6, exemplifying a case of line current and voltage ratings violation (red color).

The knowledge of these causes helps the planner identify and apply reinforcement strategies or expansion plans in order to solve the problems allowing the establishment of a feasible switching sequence operations.

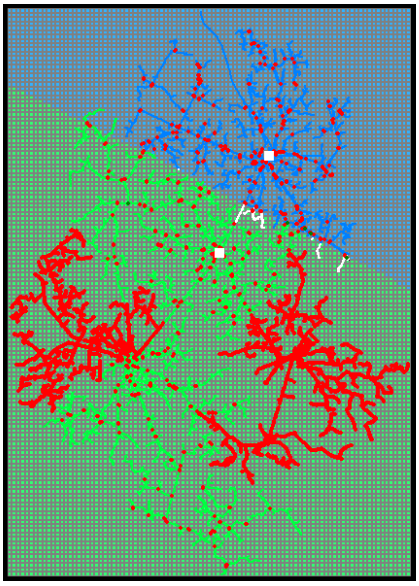


Figure 6:Result of unfeasible switching sequence

CONCLUSIONS

This paper provides an approach for power distribution systems reconfiguration and determination of switing sequence operations.

The proposed methodoloy properly handles the system, consumers and switching constraints and the software is shown as a flexible and powerful tool for the distribution system planning engineers. The system developed shows great results and has proved to be a useful tool for distribution network planners.

The software can yield several suitable system reconfiguration plans and assists the planners in reaching an switching sequence operations by providing valuable information.

Ultimately, the proposed methodoloy has the potential to be suitable for real-time implementation and to handle realistic operating constraints if applied for restoration of loads during a fault or a maintenance.

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