Project

Università di Prelmo

An Optimization Package for Electrical Distribution Network Reconfiguration

Motivations and Goals

This work describes the design and the development of a software package capable of optimizing the reconfiguration procedures that can be adopted when a fault occurs in a distribution electrical network.
The proposed optimization algorithm will allow to quickly select an optimal solution in the wide set of possible network configurations.

Project Goals:

- Individuating the most appropriate network model;
- Selecting the optimization algorithm allowing an efficient exploration of the space of possible network configurations, in order to individuate those configurations capable of supporting service sustainability at the same cost;
- Determining the trade-off between computing power and computational complexity in order to achieve faster-than-real-time solutions

Project Evolution

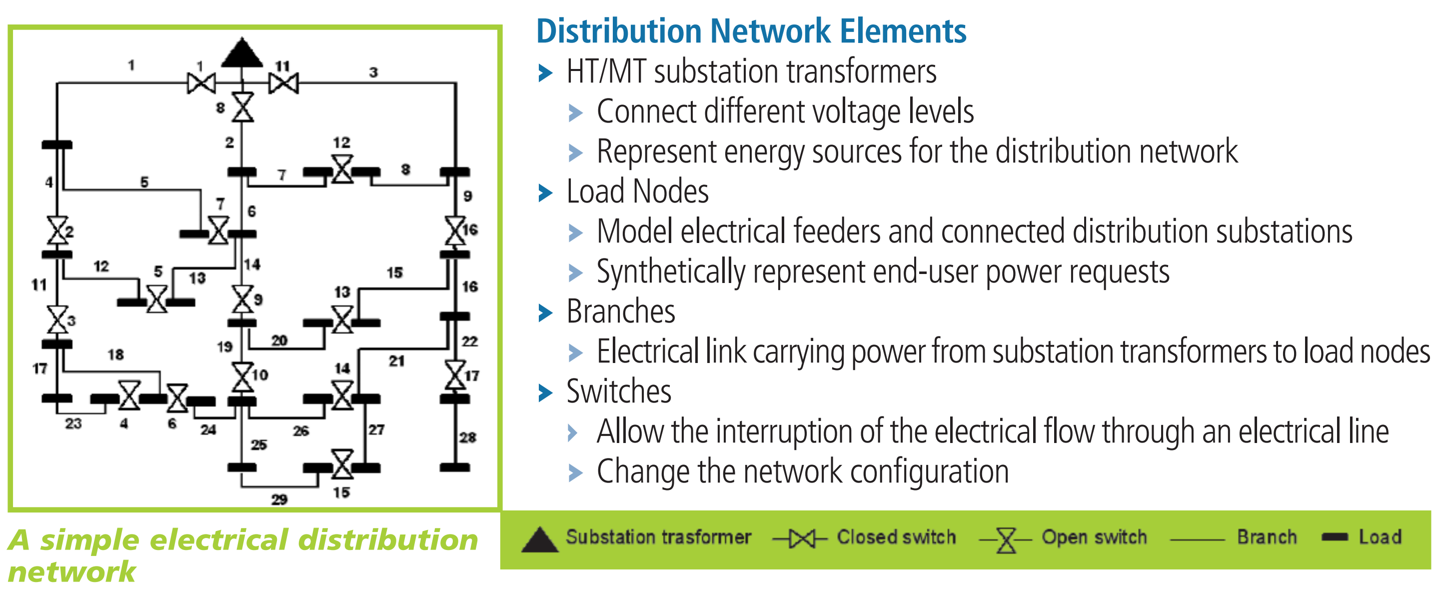
The Project was split in two distinct phases, the former devoted to the dominion analysis and problem definition, and the latter related to the software development and the experimental evaluation.

First Phase:

- Problem Domain Analysis: identification of features and components of electrical distribution networks, definition of the reconfiguration goals;
- Network Model Formulation: definition of faults, of static and variable elements, and of network structural constraints;
- Optimization Algorithm Design: definition of the solution space, design of the searching procedure.

Problem Domain Analysis and Network Model Formulation

Electrical distribution networks are collocated the penultimate level in the whole chain of the electricity delivery to the end users, representing the critical link connecting energy sources and customers.
To guarantee a high level quality of service in electricity distribution is the most important goal for the distribution system management. The quality level is measurable from customer satisfaction and is a direct consequence of the service interruption frequency and interruption duration.
Restoration main goal: performing the service restoration faster than in real-time, supplying the greatest number of loads.



A simple electrical distribution network

Distribution Network Elements

- HT/MT substation transformers
  - Connect different voltage levels
  - Represent energy sources for the distribution network
- Load Nodes
  - Model electrical feeders and connected distribution substations
  - Synthetically represent end-user power requests
- Branches
  - Electrical link carrying power from substation transformers to load nodes
- Switches
  - Allow the interruption of the electrical flow through an electrical line
  - Change the network configuration

Distribution Network Configurations

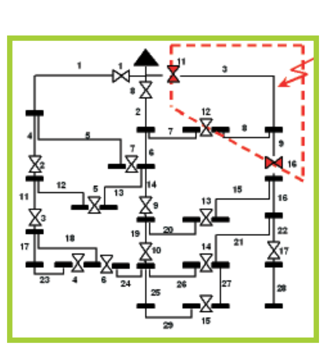
All the network configurations can be attained by operating the switches. The number of configurations grows exponentially with respect to the number of controllable switches, but the number of admissible configurations is much lower than the number of all switch status configurations. This is due to the constraints that an admissible network configuration has to respect:

- Kirchhoff laws;
- Voltage Constraints;
- Power Constraints;
- Radial Configuration:
  - Commonly adopted in real distribution systems;
  - Particularly suitable for fault detection and isolation;
  - Derived from the original meshed configuration by operating on an opportune set of switches;
  - Allows to represent a network configuration as a tree forest.

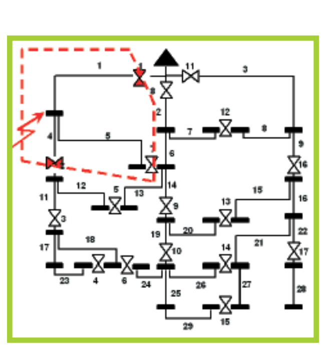
> A radial distribution network can be represented as a tree forest and the problem of finding an optimal network configuration is very similar to Steiner Tree Problem in Network, which is concerned with finding the minimum cost network (the network of minimum length) connecting a set of points. In service restoration the goal is to find the network configuration which allows feed of a set of loads with the minimum cost

In order to specify objectives and constraints for the service restoration problem, it is essential understanding which kind of objectives and constraints characterize the optimal exercise in regular conditions. Classic objectives for the usual management of distribution networks are:

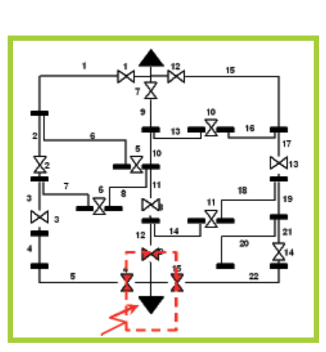
- Minimization of losses of active power;
- Regularization of voltage level for each bus,
- Balance of loads among AT/MT substations,
- Maintenance of line currents within limits established by line capacity.



Branch Interruption



Load Node Fault



Source Node Fault

Faults Definition

Unexpected interruptions can take place externally or internally in the distribution network. In the former case, for instance, a fault in the transmission network affects the distribution network as a loss of supply at the HV/MV transformers, and it is perceived as a malfunctioning in a source node. In the latter case, faults take place inside the distribution network, affecting some components, such as the unavailability of a load node and the interruption of a branch.

Problem Definition

The optimization problem is to find the switch status configuration that maximizes a given goal function while respecting the problem constraints.
The status of a switch can be represented as a binary values, then a network configuration can be represented as the binary string made up of all binary values associated to network switch status.
In our formulation we consider the following constraints:

- Load flow admissibility: expressing all Kirchhoff laws;
- Radial network constraint: to generate admissible solutions;
- Power constraints for source nodes;
- Voltage constraints for each bus;
- Strategic-load feeding.

As optimization goals are considered:

- The maximization of the number of loads supplied;
- The minimization of active power losses due to the Joule effect.

The Optimization Algorithm

We propose an optimization algorithm based on the Genetic Algorithm, opportunely modified to cope with the dominion of electrical distribution network.

Features of the Basic Genetic Algorithm

- Each solution is represented as a sequences of variables, called chromosome and is a single point in the search solution space;
- The GA procedure operates on a set of strings, called population, selecting individuals and applying on them string operators, in order to obtain new solutions;
- The execution of the GA algorithm causes the extinction of the worst solutions and drives toward better ones;
- The evaluation function is correlated to the "fitness function" that expresses the individual resistance to the evolutionary process.

Features of the Proposed Optimization Algorithm

- A solution, i.e. a network configuration, is represented as the binary string of switch status;
- A single mutation operator is used over strings population, in order to maintain solutions diversity keeping their feasibility;
- The evolution process is very elitist, as it strongly favors the survival of best individuals;
- The fitness function is multi-objective, mixing the power losses factor with the load feeding factor.

The optimization algorithm in details

Initialization:

- Creation of random paths starting from leaf nodes => High solution variance but also high computational costs;
- Creation of the tree starting from sources nodes => Low solution variance but also low computational costs;
- **Distributed creation of the tree starting from intermediate nodes** => The best trade-off.

Evolutionary Loop:

For each generation:

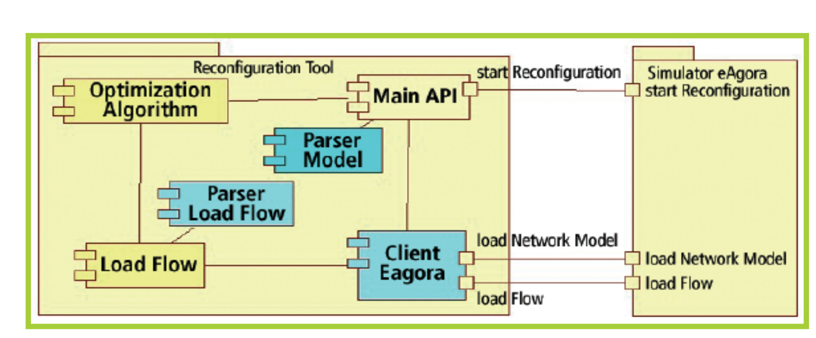
- Selection of the best solutions as parents for the next generation;
- Generation of the off-spring solutions by the application of the single mutation operator to each selected parent. The mutation operator consists of the following steps:
  - A branch exchange that changes the tree internal structure;
  - A load exchange that changes the load connection status;
  - The connection of residual loads.
- Fitness ranking of all solutions (both parents and children);
- Selection of the best solutions for the next generation.

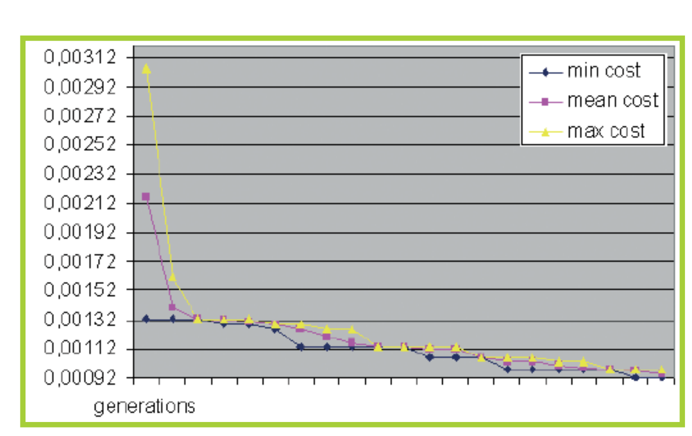
Termination:

The evolutionary loop terminates when a limit generation number is reached or when the fitness value converges, namely when the population fitness variance is lower than a given threshold.

Interaction with eAgora Simulator

The proposed optimization package adopts the eAgora simulator for electrical network to perform load flow computation. This task is performed for evaluating the feasibility of a network configuration according to Kirchhoff laws, and for computing power losses due to the Joule effect.





Preliminary Experimental Evaluation

Experimental Settings:

- The electrical distribution network of the ENEA Casaccia site, modeled through the eAgora interface;
- The Optimization package has been prototyped as a sequential java program, and preliminarily tested on a single grid node.

Experimental Results:

After few generations the algorithm quickly converges to a cost value lower than the starting mean cost.

Conclusions and on-going work

TThis project proposes the design and implementation of an optimization package for the electrical distribution network reconfiguration, which has to be carried out after some fault occurrence.
The following step of the project is the parallel implementation of the optimization package in order to exploit the CRESCO-GRID computing power. The high-performance platform, will allow the evaluation of the package real time performance.

Some References: 1. A. Chella, A. De Paola, G. Lo Re, "Progetto CRESCO: DINFO Technical Report 1", June 2006; 2. E. Riva Sanseverino, "Tecniche di Soft Computing per la gestione di reti di distribuzione automatizzate", Ph. Thesis in Electrical Engineering, University of Palermo, Italy, 1999; 3. S. Toune, H. Fudo, T. Genji, Y. Fukuyama, Y. Nakanishi, "Comparative Study of Modern Heuristic Algorithms to Service Restoration in Distribution Systems", IEEE Transactions on Power Delivery, vol. 17 n° 1, January 2002.

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