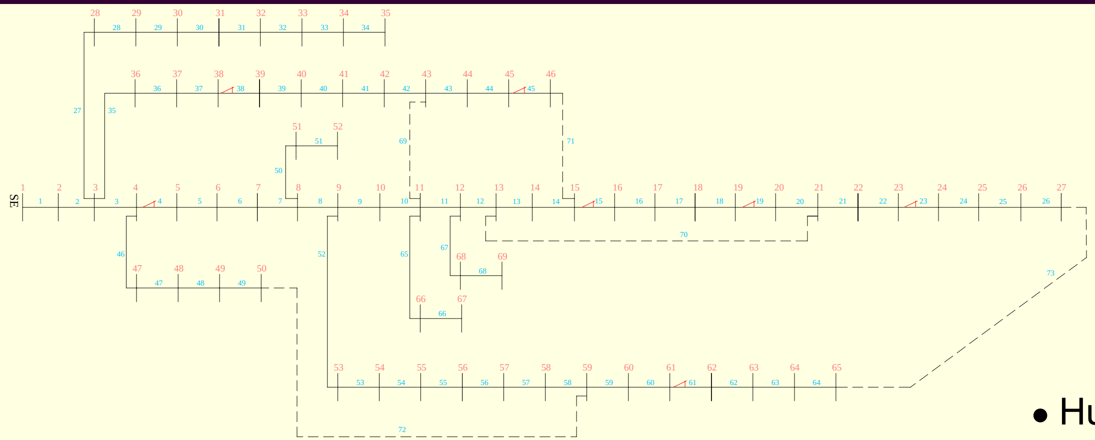
Network Reconfiguration to Improve Reliability and Efficiency in Distribution Systems



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Introduction

- Proposal of a new method to improve reliability and also efficiency (minimization of active power losses) in radial distribution systems through a process of network reconfiguration;

- To evaluate reliability is used the Monte Carlo simulation (*MC*) and an historical data of the network (level of reliability and the severity of potential contingencies in each branch);

- Two Perspectives of optimization:

  • **1st** (no investment) – using only the switches presented in the network;

  • **2nd** (with investment) – possibility to place a limited number of tie-switches (only in certain branches), defined by a decision agent.

Genetic Algorithm Approach (IGA)

– *Main Features of the IGA (Improved Genetic Algorithm)*

- List of non-admissible solutions (reveals loads not energized; transformers capacity and heat capacity of all the branches not satisfied; bus voltage limits violation);
- Two-termination criterion (Number of generations and a convergence threshold);
- Adaptive *Crossover* and *Mutation* probabilities according to the genetic diversity in the population;
- Suitable coding and decoding technique (obtains a small chromosome length and can assure the radiality of the network);
- Elitist selection (the best individual at the early generation (k) is maintained in the next generation (k+1)).

Distribution System Reliability

– Branch Reliability

- A fundamental element of the network to assure continuity of service. To define the reliability level of each network branch it was considered the following:

Level	*Failure*
1	Very unlikely
2	Unlikely
3	Likely
4	Very likely

↔ Historical information about component failures

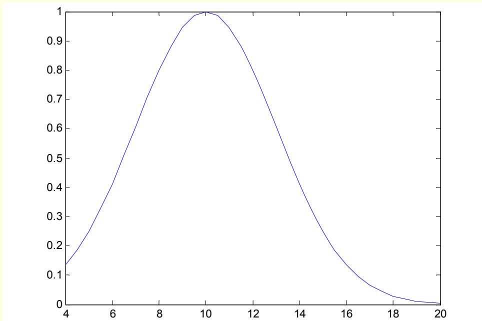
- To better characterize the possible contingencies, were defined degrees of severity (based on historical data) each with different average interruption durations ("D_{av}");

Distribution System Reliability

– *Monte Carlo Simulation method*

- The method considered ***N*** trials and, in each trial, an annual number of contingencies, in locations according to the reliability level of each branch;
- The interruption duration of each contingency is variable and follows a normal density curve with a standard deviation (σ) and average (μ).

$$f(x;\mu,\sigma) = e^{\frac{-(x-\mu)^2}{2\sigma^2}}$$



- Estimation of the annual reliability indexes in the considered network configuration. In this study, the total energy not distributed (***TEND***) is used as the reliability index to minimize.

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Evaluation of the solutions

– *Multi-objective fitness assignment*

- A fitness function we want to minimize is used to evaluate the performance of the solutions and considers two objectives:

$$fitness = (\alpha_1 W_{Loss} + \alpha_2 TEND) \times 100$$

- *1st part* – represents the annual active energy loss (W_{Loss});
- *2nd part* – represents the annual total energy not distributed (***TEND***), obtained through the MC simulation.
- Due to the difference between the values of W_{Loss} and *TEND* it was used a normalization method (parameters α_1 and α_2) also capable to reflect the importance of both objectives to the decision agent.

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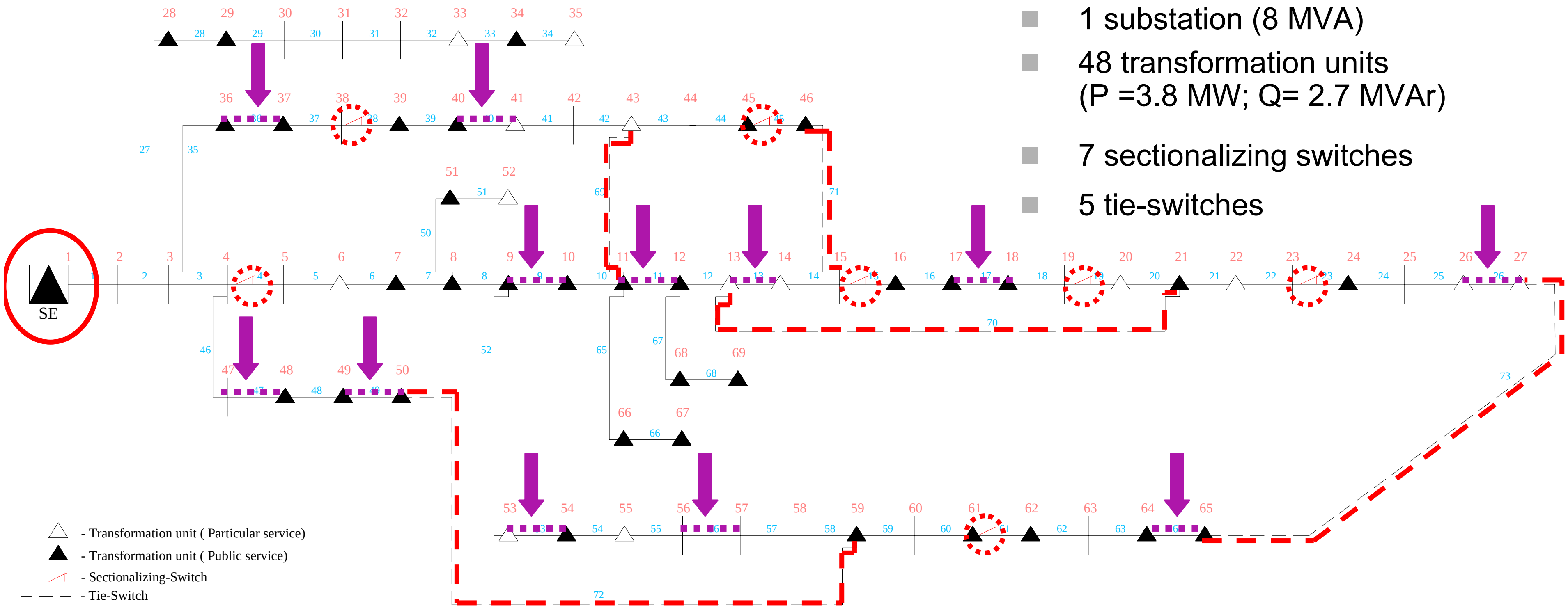
Case Study – MV network (12.66 kV)

- Restricted number of branches for tie-switch placement !

Characteristics:

- 69 nodes
- 73 branches
- 1 substation (8 MVA)
- 48 transformation units (P =3.8 MW; Q= 2.7 MVAr)
- 7 sectionalizing switches
- 5 tie-switches



Test Results – 1st Solution

– 1st perspective: Optimization without investment

- Same weight to efficiency and reliability (**w_1** = 0.5; **w_2** = 0.5);

	Base network	1st Solution
Open Branches	[69-70-71-72-73]	[19-61-69-71-72]
W_{Loss} (MWh)	3157.5	2953.1
***TEND* (MWh)**	4.2924	4.1801
Fitness value	100	95.45

- Annual Energy Loss reduction (W_{Loss}) of **6.5 %** and Total ENergy not Distributed (*TEND*) reduction of **2.6 %**.

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Test Results – 2nd Solution

– 2nd perspective: Optimization with investment (1 new tie-switch)

- Same weight to efficiency and reliability (w_1 = 0.5; w_2 = 0.5);

	Base network	2nd Solution
Open Branches	[69-70-71-72-73]	[15-56-61-69-71]
W_{Loss} **(MWh)**	3157.5	2613.19
TEND **(MWh)**	4.2924	3.0706
Fitness value	100	77.15

- **2nd Solution:**
  W_{Loss} reduction of **17.2 %** and TEND reduction of **28.5 %**.
- **1st Solution** (Without investment and same weight)**:**
  W_{Loss} reduction of **6.5 %** and TEND reduction of **2.6 %**.

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Test Results – 3rd Solution

– 2nd perspective: Optimization with investment (1 new tie-switch)

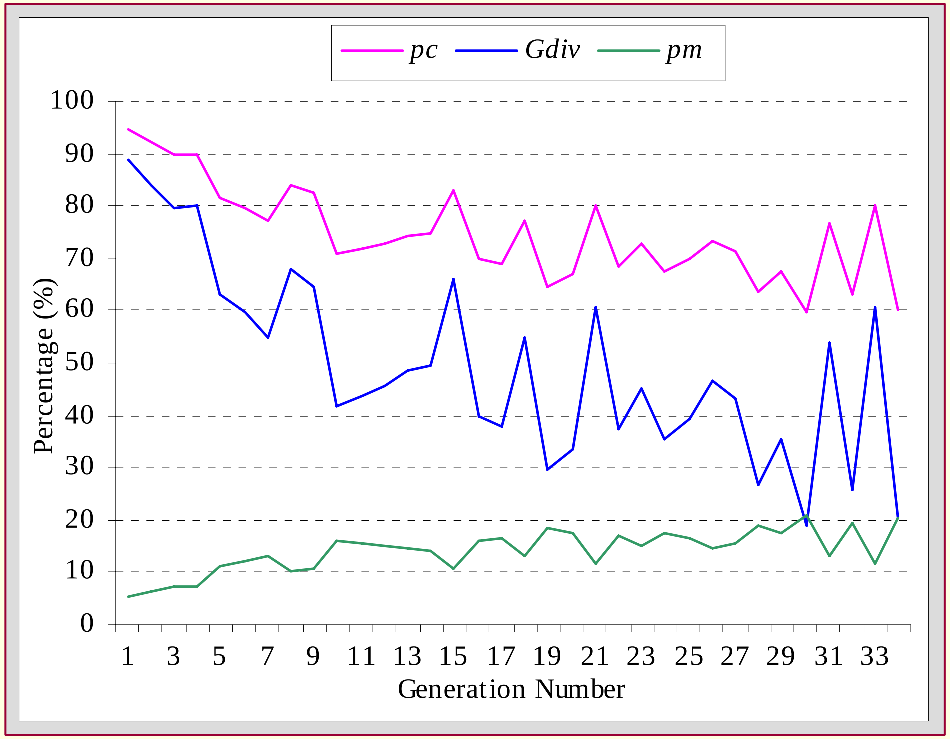
- Different weight to efficiency and reliability (w_1 = 0.3; w_2 = 0.7);

	Base network	3rd Solution
Open Branches	[69-70-71-72-73]	[19-45-56-69-73]
W_{Loss} **(MWh)**	3157.5	2898.69
TEND **(MWh)**	4.2924	2.6758
Fitness value	100	71.17

- **3rd Solution (reliability with higher importance):**
  W_{Loss} reduction of **8.2 %** and TEND reduction of **37.3 %**.
- **2nd Solution** (With investment and same weight)**:**
  W_{Loss} reduction of **17.2 %** and TEND reduction of **28.5 %**.

Test Results

– Dynamic Adjustment of genetic operator probabilities



- Learning of crossover (*pc*) and mutation (*pm*) probabilities is dependent on the genetic diversity (G_{div})
- Maintains the Genetic Diversity
- Prevents premature convergence to local optimum

Conclusions

- Possibility of obtaining network solutions that allow the simultaneous optimization of losses and reliability considering different weights;
- Good performance of IGA (convergence speed and stability increased) due to the introduction of new features (dynamic “pc” and “pm”, …);
- Two-perspective approach was used, giving to the decision agent the possibility to compare the benefits achieved with both solutions (with and without investment);
- Through network reconfiguration it is possible to make the distribution system more efficient (in terms of load balancing and voltage stability) considering only the reduction of the electrical losses.

Perspectives of future developments

- Inclusion of new objectives in the field of reliability (minimization of number and duration of the interruptions (NI,DI) according to the geographic zone of each consumer);
- Annual energy loss estimation considering the daily load diagram of each consumer (LV or MV);
- Consider different network configurations throughout the year (Winter, Summer and Half-Season);
- Use of Multi-objective optimization techniques (MOO) allowing to capture multiple solutions of the Pareto front ("*Decision Maker*" will decide after search).