ELECTRICITY CONSUMPTION ANALYSIS & ENERGY EFFICIENCY

INSTITUTO POLITÉCNICO DO PORTO

Knowledge Engineering and Decision Support Research Center

Radial Distribution Networks Planning

by

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Outline

- Introduction
- Methodology for radial distribution networks planning to improve the reliability
- Case study
- Conclusions

Introduction

Electric power distribution systems

Highest individual unavailability contribution for the customer's supply

Major portion of power losses occur at the distribution level

Reliability and optimization

Two important components for overall predictive performances studies for distribution networks

In the past more importance was given to reliability studies in generation and transmission

Introduction

Distribution networks

Looped in design but radial operated

Many customers can be affected by a failure of a single component

The adequacy of distribution networks can be assessed by reliability indices

- Failure rate – λ
- Average outage duration – r
- Annual outage duration – U

→ Load point indices

Introduction

Average outage duration and average failure rate

Can be reduced by adequate choices concerning:

- Network reconfiguration
- Substation location
- Feeder length
- Preventive and corrective maintenance measures

↓

Modifying failure rate and repair time

Introduction

Repair time and failure rate modifications may require additional efforts which are associated with aditional expenditures

Incentives to the crew involved in preventive maintenence and corrective repair process

Introduction

Distribution system reliability is an important issue in system planning

SAIDI - System Average Interruption Duration Index

SAIFI - System Average Interruption Frequency Index

CAIDI - Customer Average Interruption Duration Index

NSE - Non-Supplied Energy

Used to evaluate the reliability

Problem

None of published works have proposed a method for reliability evaluation considering investments actions, in order to reduce the repair time and failure rates of the distribution network components and all the technical network constraints.

Solution

A methodology for reliability evaluation of radial distribution networks through the **identification of new investments** in radial distribution network components, while **minimizing the costs of that investments**, **maximizing the reliability** by minimizing the **Non-Supplied Energy (NSE) cost**, the **power losses cost** and the **cost of the optimal capacitor location and size** (multi-objective problem).

Solution

The investments aim to reduce

- Repair time and the failure rate

Repair time reduction can be obtained by

- Increasing the operation personnel
- Upgrading the automation system
- Improving the communication system, etc

The failure rate reduction can be achieved by

- Reinforcing lines
- Placing a new line in parallel with an existing one
- Moving a line to another location, etc

Methodology

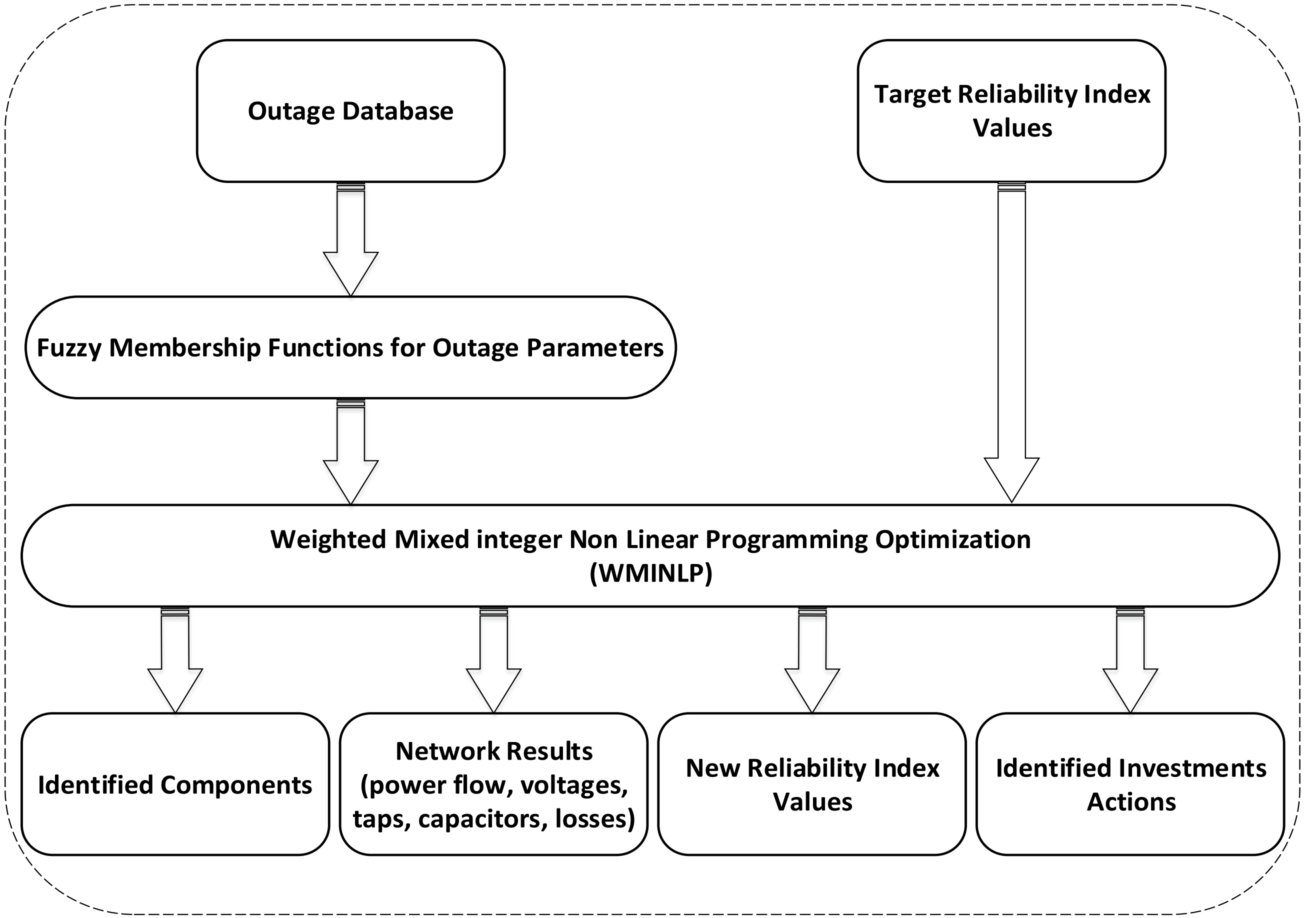
Proposed methodology

- Weighted AC optimization
- Mixed Integer Non-Linear Programming
- Pareto front technique
- Fuzzy set approach to estimate the outage parameters

- Minimize investment cost
- Minimize non-supplied energy cost
- Minimize power losses cost
- Minimize optimal capacitor location and size cost

Methodology

Proposed methodology diagram



Methodology

- System Average Interruption Duration Index - SAIDI

$$SAIDI = \frac{\sum_{i=1 \in L} U_i \cdot N_i}{\sum_{i=1 \in L} N_i}$$

- System Average Interruption Frequency Index - SAIFI

$$SAIFI = \frac{\sum_{i=1 \in L} \lambda_i \cdot N_i}{\sum_{i=1 \in L} N_i}$$

Methodology

- Customer Average Interruption Duration Index - CAIDI

$$CAIDI = \frac{\sum_{i=1 \in L} U_i \cdot N_i}{\sum_{i=1 \in L} \lambda_i \cdot N_i}$$

- Non Supplied Energy - NSE

$$NSE = \sum_{ij=1}^{NE} \lambda_{ij} \cdot r_{ij} \cdot S_{ij}$$

Methodology

Objective function

$$Z_1 = \left(\sum_{ij=1}^{NE} \sum_{m=1}^{Nm} C^{r}_{ij,m} \cdot X_{ij,m} + \sum_{ij=1}^{NE} \sum_{m=1}^{Nm} C^{\lambda}_{ij,m} \cdot Y_{ij,m} \right) + \frac{(1+dr)^t - 1}{dr \cdot (1+dr)^t} \cdot \left(\sum_{ij=1}^{NE} \sum_{m=1}^{Nm} Cy^{r}_{ij,m} \cdot X_{ij,m} + \sum_{ij=1}^{NE} \sum_{m=1}^{Nm} Cy^{\lambda}_{ij,m} \cdot Y_{ij,m} \right)$$

$$Z_2 = \frac{(1+dr)^t - 1}{dr \cdot (1+dr)^t} \cdot \left(\sum_{ij=1}^{NE} C^{NSE}_{ij} \cdot F\lambda_{ij} \cdot Fr_{ij} \cdot S_{ij} \right)$$

$$Z_3 = \frac{(1+dr)^t - 1}{dr \cdot (1+dr)^t} \cdot \left(\sum_{ij=1}^{NE} C^{loss}_{ij} \cdot loss_{ij} \cdot \left(T_e - F\lambda_{ij} \cdot Fr_{ij} \right) \right)$$

$$Z_4 = \sum_{i=1}^{NN} \sum_{a=1}^{Na} \left(C^{cap}_{a} + \frac{(1+dr)^t - 1}{dr \cdot (1+dr)^t} \cdot CostA \cdot Qcap_i \right) \cdot W_{i,a}$$

Methodology

Constraints

- Active and reactive power flow equations

$$\sum_{ij=1}^{NE}\left(P_{ij}-P_{ji}\right)+Pgen_i-Lp_i-Ploss_{ij}=0$$

$$\sum_{ij=1}^{NE}\left(Q_{ij}-Q_{ji}\right)+Qgen_i+Qcapv_j\cdot W\left(j,a\right)-Lq_i-Qloss_{ij}=0$$

$$P_{ij}=G_{ij}\cdot V_i\cdot V_j\cdot\cos\left(\delta_i-\delta_j\right)+B_{ij}\cdot V_i\cdot V_j\cdot\sin\left(\delta_i-\delta_j\right)-G_{ij}\cdot V_i^2$$

$$Q_{ij}=G_{ij}\cdot V_i\cdot V_j\cdot\sin\left(\delta_i-\delta_j\right)-B_{ij}\cdot V_i\cdot V_j\cdot\cos\left(\delta_i-\delta_j\right)+B_{ij}\cdot V_i^2-\frac{1}{2}\cdot Cp_{ij}\cdot V_i^2$$

- Losses

$$loss_{ij}=\sqrt{Ploss_{ij}^2+Qloss_{ij}^2}$$

Methodology

- Selection of a unique value in each capacitor bank

$$\sum_{a=1}^{d} W\left(j,a\right) \le 1$$

- Reactive power output by shunt capacitors

$$Qcapv_j = B_{j,a} \cdot W\left(j,a\right) \cdot V_j^2$$

- Capacitors capacity cannot exceed the total reactive load

$$\sum_{j=1}^{Nc} Qcapv_j \le Q_j^{\max}$$

Methodology

- Upper and lower power output limits (active and reactive power) of the substation and distributed generator units

$$Pgen_i^{\min} \le Pgen_i \le Pgen_i^{\max}$$

$$Qgen_i^{\min} \le Qgen_i \le Qgen_i^{\max}$$

- Bus voltage magnitude limits

$$V_i^{\min} \le V_i \le V_i^{\max}$$

- Bus angle limits

$$-\pi \le \delta_i \le \pi$$

- Capacity limits of distribution lines/cables

$$\sqrt{P_k^2 + Q_k^2} \le S_k^{\max}$$

Methodology

- Transformer taps limits

$$tap_i^{\min} \leq tap_i \leq tap_i^{\max}$$

- Final repair time

$$Fr_{ij} = r_{ij} - \left(\Delta r_{ij} \cdot X_{ij,m}\right)$$

- Final failure rate

$$F\lambda_{ij} = \lambda_{ij} - \left(\Delta\lambda_{ij} \cdot Y_{ij,m}\right)$$

- System Average Interruption Duration Index

$$SAIDI^{Final} \leq SAIDI^{Max}$$

- System Average Interruption Frequency Index

$$SAIFI^{Final} \leq SAIFI^{Max}$$

Methodology

- Customer Average Interruption Duration Index

$$CAIDI^{Final} \leq CAIDI^{Max}$$

- Non-Supplied Energy

$$NSE^{Final} \leq NSE^{Max}$$

- Only one investment option (action) can be chosen for repair time

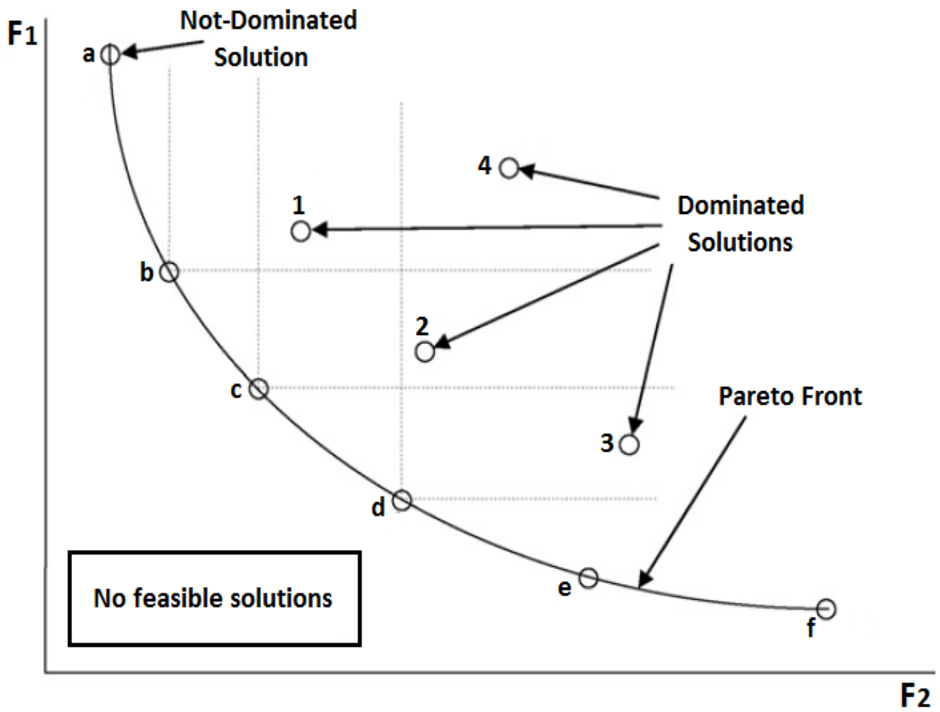
$$\sum_{ij=1}^{NE} \sum_{m=1}^{Nm} X_{ij,m} \leq 1$$

- Only one investment option (action) can be chosen for failure rate

$$\sum_{ij=1}^{NE} \sum_{m=1}^{Nm} Y_{ij,m} \leq 1$$

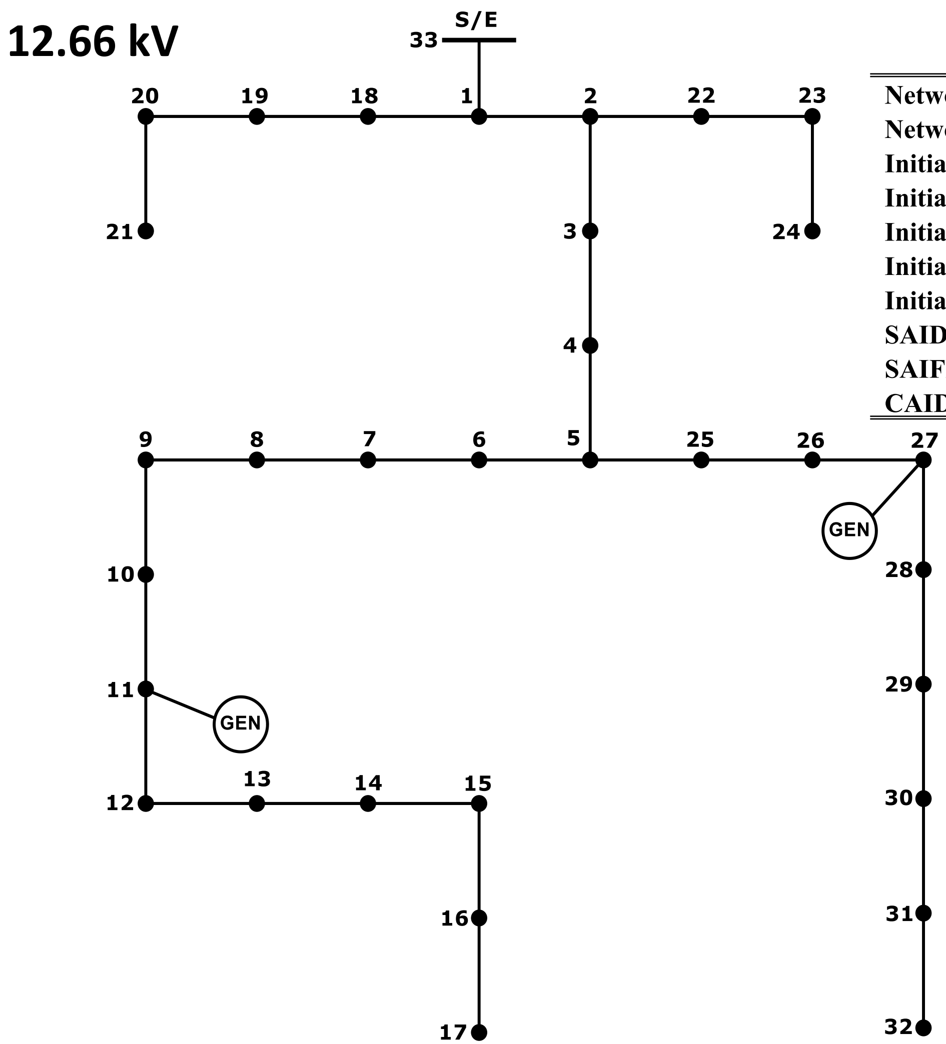
Methodology

Pareto Front



For instance, solution *"1"* is dominated by *"b"* an *"c"*, solution *"4"* is dominated by *"b"*, *"c"*, *"d"* and *"1"* and *"2"*.

Distribution network 33 buses



Network Active Load (kW)	3,715.000
Network Reactive Load (kVAr)	2,300.000
Initial Active Losses (kW)	91.570
Initial Reactive Losses (kVAr)	63.650
Initial Non-Supplied Energy (kVAh/year)	545,060.000
Initial Non-Supplied Energy Cost (m.u./year)	1,090,121.000
Initial Losses Cost (m.u./year)	508,750.000
SAIDI (hour/customer)	167.800
SAIFI (interruption/customer)	10.200
CAIDI (hour/customer interruption)	16.500

Results

Results

Plan	Investment Cost (m.u.)	Non-Supplied Energy Cost (m.u.)	Capacitors Cost (m.u.)	Losses Cost (m.u.)	Total Cost (m.u.)
50	9,523,140	3,752,758	15,223	197,734	13,488,854

Plan	Non-Supplied Energy Income (m.u.)	Losses Income (m.u.)
50	6,167,346	4,431,891

Bus	Size (kVAr)
8	300
17	150
21	150
22	150
23	150
24	450
29	750
31	150

Results

Results

Plan	Total Investment (m.u.)	Total Income (m.u.)	Final Benefit (m.u.)	Annual Net Cash Flow (m.u.)	Payback (years)	Internal Rate of Return (%)
50	9,538,363	10,599,237	1,060,874	1,164,751	8.200	11.120

	Initial Values	Threshold Values	Obtained Values
SAIDI (hour/customer)	167.800	120.000	87.801
SAIFI (interruption/customer)	10.200	8.000	7.998
CAIDI (hour/customer interruption)	16.500	11.000	10.977
NSE (kVAh/year)	545,060.000	250,000.000	206,200.000

Conclusions

- A new methodology that allows assessing the reliability in a radial distribution network by identifying new investments in order to reduce the repair time and failure rate in network components was presented

- This leads to a reduction of the forced outage rate and, consequently, to an increase of reliability

- As a key contribution, a multi objective AC optimization model based on mixed integer non-linear programming was developed considering the Pareto front technique (weighted method)

- This method identifies the components in which the system operator should invest at minimum cost, and the actions to be taken

- The method proved to be adequate to support the distribution network operator for planning future network investment actions

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Thank you!