A Network Reference Model for Distribution Regulation and Planning: the Spanish Case

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Network Reference Models: two types

- **From Scratch**: to design the whole distribution network that connects customers of electricity to the transmission substations without taking into account the actual network, but considering the same technical constraints and planning principles.

- **Expansion Planning**: to design the distribution network expansion in order to supply both an horizontal and vertical demand increase optimally, given the actual network as well as considering the same technical constraints and planning principles.
Main features of Network Reference Models

Main Features

- Large scale ( > 1 million customers)
- Both urban & rural areas
- Detailed Geographical Features:
  - Settlements identification
  - Automatic street map building
  - Forbidden ways through
  - Aerial/underground areas
- Voltage, capacity & reliability constraints
- Detailed standardized equipment and parameter library
- Detailed reliability assessment
Network Reference Models (NRM): scope

**Network Structure**

Types and number of facilities

- **Transmission substations**
  - Number: > 15
  - HV network: (36, 220) kV

- **HV/MV substations**
  - Number: > 150
  - HV network: (36, 220) kV

- **MV/LV transformers**
  - Number: > 15000
  - MV network: (1, 36) kV

- **LV customers**
  - Number: > 10^6
  - LV network: < 1kV

**Input Data:** HV, MV and LV customers, and transmission substations

**Results of the model:** LV, MV & HV network, HV/MV and MV/LV substations
Regulatory applications of NRM

Revenue Cap: Remuneration Formula

\[ R_{n+1}^i = R_n^i \cdot \left[ 1 + CPI_{n+1} - X \right] + Y_{n+1}^i + Q_n^i \pm D_{n,n-1}^i \]

- To set the initial remuneration: Reference Network Model (from scratch)
- To set the remuneration according to an activity increase: Reference Network Model (expansion planning)
- To determine the objective network losses and quality of service indexes
- To determine a set of efficient distribution tariffs
The Desired Characteristics of a NRM

1. The service areas are modelled as accurately as possible, and

2. If the model considers optimal planning principles, a “sound” standardized equipment library, and the same technical constraints as in actual networks,

Then

1. Both rural and urban areas are optimized even-handedly
2. It is useful for assessing utility’s network technical efficiency
3. The reference network is useful as a benchmark of actual networks
Input Data

- Customers and transmission substation georeferenced data
  - Coordinates x,y,z
  - Contracted power and billed energy.

- Standardized equipment
  - Substations, transformers, lines, cables, capacitors...
  - Maintenance crews, protective devices...

- Set of technical and economic parameters
  - Rate of return, demand increase rate, loss factor, power factor, simultaneity coefficients...

- Geographic data and constraints
The modelling of Service Areas

1. To identify and to model settlements
   - To identify groups of customers meeting some criteria
   - To build street maps within settlements

2. To classify areas according to the quality of service
   - Urban, semi-urban, rural
   - Reliability indexes constraints

3. To set aerial and underground rates of networks
   (according to the service areas considered)

4. To process geographical features
   - Orography, forests, forbidden paths though...
Identification of Settlements

A distribution area comprising more than 1 million customers.
The outline of settlements (automatically identified) are depicted in red.
The model builds street maps automatically

- To identify the outline of settlements
- To build the street map using the GPS coordinates of customers

Note that line routes cannot cross wide streets a lot of times, and that line routes can cross neither blocks nor parks…
Global Approach to the Planning Problem

OPTIMIZATION

Considering simultaneously:

- Geographical features of the service areas
- A global approach to network optimization
- The quality of service

These are key issues to optimize rural and urban areas even-handedly.
Global Approach to the Planning Problem

\[ \text{Min } z = \text{NPV}(\text{investment} + \text{losses} + O \& M) \]

Subject to:
Capacity, voltage drop and geographical constraints.

Present Value:
investment + losses + O&M

Network must be feasible at the end of stage 1. Several types and sizes of conductors, substations, transformers may be used to meet this sizing criteria.
Geographical features: approach

Planning Modules

- Transmission substations
  - HV network
- HV/MV substations
  - MV network
- MV/LV transformers
  - LV network
- LV customers

GIS

- Location costs
- Path Optimization

A Substations & transformers coordinates
B Lines & cables ends
The quality of service

- Deterministic Methods. A constant failure rate for each asset.

- Two possibilities:
  
  A) Minimization of: Investment + Network losses + Non-supplied Energy
  
  B) Minimization of: Investment + Network losses. Subject to reliability constraints.

- The goal: to obtain the optimum equilibrium between investment and quality
Case study: An urban MV network

Street map built by the model. Note the crossings in the large avenues
Case Study: rural MV network & orography

Small rural area in the middle of the mountains. Note the impact that the orography has on the line paths. Overall costs and losses increase roughly 7%
Case Study: investment to improve reliability of MV network

Large area: 50,000 km$^2$, 4000MW peak demand. Input data: HV/MV substations, a radial MV network whose cost is 16 million €, MV/LV transformers and MV customers. Output: investment in reclosers, manual sectionalizers, fault indicators, maintenance teams, alternative supplies and network reinforcements.
Case Study: reliability & HV/MV substations

Large area: 50,000 km². HV/MV planning from scratch and MV network considering two QoS scenarios. Input data: transmission substations and MV/LV transformers and MV customers.
Case study: An urban/rural MV network

HV/MV substation

Alternative feeder supply
Reliability & HV/MV substations: ENS=0.6€/kWh
Reliability & HV/MV substations: ENS=1.8€/kWh
Reliability & HV/MV substations: comparison

<table>
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<tr>
<th>TIEPI</th>
<th>0.6 €/kWh</th>
<th>1.8 €/kWh</th>
<th>TIEPI</th>
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<tr>
<td>13.0 hours</td>
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<td>Zone B</td>
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<td>4.8</td>
<td>Zone C</td>
<td>Zone C</td>
<td>2.2 hours</td>
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Conclusions

- Network Reference Models are very flexible tools and can be used for achieving different goals. (Locations of HV/MV substations and/or MV/LV transformers may be planned from scratch or may be fixed beforehand)

- Distribution network investment, quality of supply and losses are closely linked. Different networks can be obtained according to losses and/or QoS targets imposed to the model.
Conclusions

• The Regulator should set beforehand: the network sizing criteria, the quality of service targets, the standardized equipment library, economic & technical parameters…, in order to run the model and obtain a “reference network”. Its final use by the Regulator depends on these criteria to a large extent.

• The differences between actual and reference networks are closely linked to the aforementioned criteria, but the results usually match.

• Significant differences between reference and actual network should trigger the signal that something “weird” is happening: (i) actual network over/under investment or QoS deficiencies, (ii) inappropriate standarized equipment used by the model…
Conclusions

• A Network Reference Model is a definitive tool for assisting Regulators.

• It decreases the asymmetry of information significantly.

• It is a useful tool to assess network costs, DG’s impact, losses and reliability, and therefore the distribution utility’s networks technical efficiency.

• Currently, the Spanish Regulatory Commission is using a NRM developed by IIT. A similar model, developed also by IIT, has been used in Chile and Argentina in previous tariff revisions.
Conclusions

- Graphical User Interface to introduce input data: customers, parameters, standard equipment...

- A conventional GIS may be used to display and query the results (shape files) of the model and actual networks
Projects

- Assessing the impact of installing photovoltaic energy cells on the distribution network

- Chilean Tariff Revision 2000, for Chillectra S.A. (Chile)

- Gran Buenos Aires Tariff Revision 2000, for ENRE (Argentina)

- Chilean Tariff Revision 2004, for Chillectra S.A. (Chile)

- Chilean Tariff Revision 2004, for SYNEX-CNE (Chile)

- Spanish Tariff Revision 2004-2006, for CNE (Spain)