RE-POWER A DISTRIBUTION NETWORK WITH A RAPIDLY CHANGING LEVEL OF DEMAND THROUGH SIMULATION TECHNOLOGY

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ABSTRACT
This paper addresses the planning of distribution networks with an accelerated growing demand and illustrates the impact of simulation technologies on the design of strategies to repower such networks. The paper specifically presents methods to study a real network – the HV and MV distribution network of EDEL, in Luanda, Angola, that is being studied jointly by EDP and EDEL. Luanda’s network was designed for a population of 800 thousand and now has a population of 5 million. The paper describes the technologies and methodologies used (1) to survey the existing network and converting multiple support information into a unique georeferenced database, (2) to assess the existing network operational status, strengths and shortcomings, and (3) to develop strategies to overcome the problems found, reduce losses, improve reliability and security. The paper also presents the network designs employed to mitigate high-probability low-risk events and low-probability high-risk extreme events.

1. INTRODUCTION
A very high demand growth in distribution, related to emergent social-economical development, requires high quality planning. Planning approaches that rely upon archaic information representations and out-of-the-shelf analysis tools cannot respond appropriately to rapidly changing environments. Network data updating and analysis processes would be too time-consuming to be effective. To respond adequately, planners must be one step ahead of distribution network needs, which requires the use of flexible and agile data management and simulation technologies.

In the past, EDEL’s planning relied upon human expertise only, supported by general purpose software applications. This had consequences to the distribution network performance, which has deteriorated due to the lack of response capacity.

This paper aims at presenting the main results of our experience in planning EDEL’s network of Luanda, in Angola, and how that has been achieved by migrating network information into modern data management and simulation technologies. The paper will describe the methodology used (1) to survey the existing network and convert the multiple physical support information into a unique georeferenced digital database, (2) to assess the existing network operational configuration, evaluate its strengths and shortcomings, and (3) to develop strategies to overcome the problems found, reduce losses, improve reliability and security. The implementation of the three phase methodology has been supported by the same simulation platform – DPlan, from which proposal solutions could be obtained using network optimization [1]. Figure 1 schematically illustrates that.

2. SURVEY AND DATA INTEGRATION
In the survey phase we needed to build up a solid and trustfully digital georeferenced database upon which the simulation will run. Three sets of data are required: (1) the main assets individual characterization and their geographic location (transformers, cables and lines), (2) the loads’ historic data, and (3) the energy consumption forecast. While the first and second data sets are necessary to build up the network simulation environment as it is presently, the second and the third are necessary to extend such environment to the future in order to be one step ahead of the network needs. The integration of all data sets into a single platform is very important to identify anomalies before going into the next phase.
2.1 Characterization of main assets
This task is highly dependent on what has been already done for each asset. Some assets may be already registered in digital georeferenced databases, e.g. in CAD software, others may be registered in physical maps or schematic drawings, and some may be not registered at all.

If information is somehow georeferenced, either in CAD or as physical maps, the conversion to the simulation environment is straightforward. If information is in CAD, loading it into the simulation platform is just an application interface problem; if information is in maps, digitalization of the existing physical maps is necessary before loading the network. If information is not georeferenced at all, field work is necessary to find the assets location. This used to be a time-consuming task some years ago but not today. Today, with the vulgarization of orthophotos and GPS systems, this task can be enabled fast and precisely.

2.2 Loads’ historical data
Having an electrically connected infrastructure, the next step will be load assignment. A load profile of the present situation could be assigned based on metering. But when metering is neither regular nor automatic, and the data has not been stored in databases, then its use to assign loads directly into the simulation platform becomes complex.

Even indirectly, the use of metering information introduces severe bias associated with lack of synchronism and errors introduced by human reading and hand writing.

However, the errors can be reduced by undertaking coherency tests between the metering and the infrastructure characteristics; network configuration, area load density, transformer installed capacity, etc. These tests should be carried out within the simulation platform as simulation can be very effective in detecting incoherencies between load assignment and assets characterization.

2.3 Energy consumption forecast
Historics on loads could be used to forecast load growth in existing consolidated network areas, but historics do not exist for the new network areas.

For the new areas, additional information is necessary about client profiles and client types: commercial, industrial or domestic.

Usually, this information be hard to get, since, in most cases, it will be spread by multiple state departments.

3. OPERATIONAL ASSESSMENT
With a valid network model obtained in the survey phase, the operational assessment will require (1) the definition of parameters that will set the limits between an acceptable operational state, under both normal and permanent failure conditions, and a non-acceptable one, (2) the definition of the network reconfiguration security level required under permanent failure conditions and (3) an assessment methodology to be incorporated by the simulation platform that, by integrating the previous requirements, uses power flow and service quality algorithms to point out the operational violations found, as exposed in Figure 3.

Table 1. Operational limits

<table>
<thead>
<tr>
<th>Asset type</th>
<th>Normal Mode</th>
<th>Failure Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line/Cable</td>
<td>1.0</td>
<td>1.1</td>
</tr>
<tr>
<td>Transformer</td>
<td>1.0</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Besides the limits imposed by the assets operation there are also the service quality standards required by the regulator or set internally as objective by the DNO. While the previous are verified by a power flow algorithm, e.g., AV, the latest, e.g., SAIFI, SAIDI, require fault simulation for which branch failure rates and average times for isolation, reconfiguration and repair must be defined.

3.2 Security of supply
Taking into consideration both high-probability low-risk events and low-probability high-risk extreme events, the selection of the most appropriated level of security depends on the relation between the expected frequency of the failure – a probability – as well as on the duration and power not supplied due to a failure – its impact. The product probability x impact is the basis to decide upon different redundancy levels for different assets and for different voltage levels.

Although DNOs typically use the N−1 security, i.e., the permanent failure of one asset cannot disable the network operation, different network infrastructures could be designed to achieve the same level of security. Different levels of security are also required for different load density areas.

3.3 Assessment methodology
The simulation platform must enable an expedite definition of the operational parameters and a clear visualisation of the operational assessment and simulation results, both as georeferenced and printed reports.

Structuring assessment order
Although a failure in the HV network has a major
potentially risk than a failure in the MV network, before evaluating the HV network limitations the MV network needs must be evaluated. If the assessment starts at the HV level, then probably one may find limitations that could be resolved at the MV level, e.g., a surcharge of a HV/MV transformer could be related with an incorrect load allocation in the MV network, and not related to the insufficient HV/MV transformation capability. This way the network assessment is structured by voltage level, starting from the lowest voltage level and pursuing to the highest.

Identification of limitations

To structure the assessment by voltage level we start by creating an ideal HV network, i.e., a HV network without limitations. This way, the MV assessment will not be affected by HV limitations. In the same way, the HV assessment is done with an ideal MV network. With this approach it is possible to identify

- the MV network limitations without the influence of the HV, e.g., when operating under permanent failure of a MV asset, the HV/MV transformer capacity could become a constraint to the MV network reconfiguration;
- the HV network limitations without the influence of the MV, e.g., when operating under permanent failure of a HV asset, the limitation of a MV feeder capacity to transfer load to another HV/MV substation could become a constraint to the HV network.

The simulation platform must allow the design of these ideal networks in a fast and reversible manner, so that after the independent assessment, a joint one could also be made. This approach enables the planner to understand all the relevant information needed to set for the next phase.

4. DEVELOPMENT STRATEGIES AND PROPOSALS

After the assessment phase, network development strategies must be built. These strategies will be the axis of network expansion. The strategies will be constrained not only by technical-economical options, e.g., existing voltage levels, normalised lines and cables, normalised transformer capabilities, but also by the quality of service as defined by the operational parameters and security of supply set earlier. Combining the available options with the area load type and density, standard network structures can be pointed out for the network development. Once the network structure has been chosen its implementation can be evaluated by the simulation platform.

The MV and HV networks technical-economical decisions are interdependent, e.g., the MV line or cable normalised capacity is necessarily related with the number of MV feeders set for a standard HV/MV substation and with the HV/MV transformer capacity. Despite being interdependent, a lot of design work can be done as if they were not dependent. This work must be iterated between voltage levels as depicted in Figure 4.

4.1 MV Strategy

For Luanda’s MV urban network we designed an underground feeder structure that connects the HV/MV substations between each other and/or with MV sectionalising substations, enabling the selection of supply of MV/LV substations by those feeders at least by two different ways, each feeder with a capacity of 11 MVA. The feeders’ paths are designed to minimize energy losses under normalized assets and existing load density.

For the peripheral urban network of Luanda where load density is lower, we designed an overhead feeder structure to connect HV/MV substations and MV sectionalising substations with MV/LV substations that consists in a main axis feeder with a capacity of 9 MVA, with derivations.
This structure enables the minimization of energy losses, but does not provide for a high quality of service. While in the underground network the N–1 security is always provided, with the overhead network it is not: N–1 is only provided for the feeder’s main axis. A failure in a derivation asset would affect the total load supplied by asset until its repair.

4.2 HV Strategy
For the HV urban network of Luanda we decided to change the existing HV loop structure into a radial feeder structure with a capacity of 40 MVA per feeder, where N–1 security is provided by the adjacent HV/MV substations through reconfiguration of the MV network.

Two factors lead to this change: (1) the increase in the number of available HV/MV substations that made possible the load shifting between adjacent substations, and (2) the difficulty in finding enough space for large substations that include the HV busbar.

Since the HV failures are low-probability high-risk events, the radial feeder structure does not increase significantly the risk exposition that results from a higher number of switching operations necessary to complete the network restoration. If this restoration is assisted by a network simulation platform, the increase in response time will be irrelevant and the decrease in quality of service very small when compared to the benefits of the structure: less expensive with larger number of substations and higher utilization ratio of the HV/MV transformers.

4.3 Proposals’ Simulation
With the knowledge acquired through the survey and assessment phases, a planning engineer supported by a user-friendly simulation platform, can rapidly evaluate the performance of its strategy under a few scenarios, verifying how each of them will impact on the network needs. To come up with a network proposal, the network could be simulated as a whole, but that is not practical for very large networks. Like in the assessment phase, simulation should be done by voltage level, from the lowest level to the highest. After a proposal being taken as accepted for the lower voltage network, the planner moves to the higher level. When at the higher level, the planner might conclude that the proposals accepted before do jeopardize other proposals to be considered within the defined strategy. Returning to the lower level, the planner may undertake the necessary changes to correct that. Such iterative process is very important and requires a flexible and easily to use simulation platform.

With a trustfully simulation platform it is then possible to quantify the benefits of the proposals undertaken and this way present a technical-economical investment assessment to the shareholders and regulators.

5. CONCLUSIONS
Collapsing under an accelerated growing load demand, Luanda’s distribution network required urgent attention. In this paper we presented our experience with the processes undertaken for network survey and problem assessment. We explained how the results of such processes were used to build up a strategic planning for network expansion. Focus was also given to the simulation technology that made it possible in just a few months. The experience reported constituted a giant step to regain the control of the network in order to prepare its evolution.

REFERENCES