GREDOR

Outcomes and **recommendations**

The increase of the capacity of renewable generation, the evolution of consumption modes such as electrical vehicles, and the changes in the electricity markets sector will raise several challenges in distribution systems in a near future.

Without re-thinking some features of the system, issues such as congestion, under and over voltage, and renewable power curtailment are likely to appear more often than today.

In addition to investing in traditional grid reinforcement, one of the key aspects is to accommodate the variability of renewable energy sources using demand flexibility and storage. The GREDOR project addressed these challenges from investment planning to real-time control.

Contents

List of abbreviations

TSO   Transmission System Operator

DSO   Distribution System Operator

DGU   Distribution Grid Users

SDR   Strategic Demand Reserve

FSP   Flexibility Service Provider

BRP   Balancing Responsible Party

DER   Distributed Energy Resources

MV   Medium voltage

LV   Low voltage

1 | Interaction models

1.1 » Interaction models for flexibility: situation and needs

Due to the massive impact of renewable and intermittent energy sources, there was a risk of peaking prices for ancillary services procured by the TSO (including balancing and strategic reserve). To mitigate the risk, Elia opened some of its ancillary services to FSP who proposed demand response for the tertiary reserve (R3 DP product in 2013) and strategic reserve (SDR product in 2014). The market was opened gradually in order to build knowledge of these products and of these new commercial relationships while allowing new actors to develop it. The market for R3 started with 60 MW limitation in 2013. But for 2016, this market is already opened to 200 MW corresponding to 50% of the market share. DGU can participate in R3-DP (since 2014) and SDR as of 2015-16.

A simple interaction model was set up for these particular markets with DSO connection points: a direct relationship between ELIA and the flexibility service provider with no exchange of energy between FSP and BRP. The experience gained from this interaction model initiated at the TSO level showed that the issue of transfer of energy between FSP and BRP has to be fixed if the volume of flexibility increases.

As DSOs are considering the use of flexibility to solve local congestion issues, it is necessary to define new interaction model(s) involving all the market parties and taking advantage of the experience at the TSO level. This is the aim of the task entitled "interaction models" in the GREDOR project.

1.2 » Major contribution

This package was central to the GREDOR project since it aimed at defining the relationships between the actors of an electrical distribution system – and how they should interact technically and financially to achieve the societal objectives, fostering demand and decentralized generation flexibility on one hand and ensuring compatibility with scenarios to be considered for the evolution of the electrical system from now until 2050, on the other hand. Table 1 summarizes the interaction models and cases studied during the GREDOR Project.

From a social welfare perspective, the quantitative and qualitative analyses carried out during the project do not clearly highlight an outstanding interaction model: it heavily depends on the local system and market characteristics, such as the flexibility penetration level and the number of activations required. Nevertheless, the benefits of these interactions are not equivalent to all stakeholders.

For instance, in case of congestion due to high local generation in a rural residential area, many devices must be activated to reach a sufficient volume of flexibility to solve

the issues on the DSO network. It may be easier to obtain this volume of flexibility in an industrial area. Therefore, the cost related to flexibility in a residential area, including communication assets, may be higher than the cost of demand response in an industrial area. As a consequence, for this local market characteristic, it may lead to lower grid costs for the DSO to use generation limitation or to reinforce the network instead of using demand response to solve a congestion issue.

Table 1 Summary of interaction models

Interaction Model / cases	Model characteristics				Chosen particular situations	
	Need for a FSP role?	Flexibility Framework Contract (**)	Flexibility Free bids (***)	Compensation of BRP when flexibilit is activated	Considered Flexibility Service (****)	Selected Flexibility Provider
Imposed Flex no fee(*)	No			No	PC	
Imposed Flex valorized (*)	No			Yes	PC	
Generation Flex Capa	Yes	Yes	No	No	PC	BRP
Demand Flex Capa	Yes	Yes	No	No	CI	FSP
Demand Flex Capa with transfer of energy	Yes	Yes	No	Yes	CI	FSP
Generation Flex Bid	Yes	No	Yes	No	PC	BRP
Demand Flex Bid	Yes	No	Yes	Yes	CI	FSP

(*) The first two models consider that a DSO has a right to use flexibility (mainly generation curtailment) imposed to network users (through the connection contract) but the DSO does not have the opportunity to use other sources of flexibility.

(**) The Flexibility Framework Contract: DSO chooses as purchasing strategy to pay a fee for the capability of being flexible. This contract defines a volume, a number of activations and an availability, depending on the needs. In other words, the DSO pays the service provider on the basis of its ability to achieve a number of flexibility activations of a contracted amount (MW or MVAR). There is no activation fee.

(***) Flexibility free bids: The DSO pays the BRP or the FSP trough free bids on the energy market (of course only bids solving the local issue are considered). The DSO organizes auctions when the risk of congestion is detected. The DSO subscribes the most interesting offer(s) and the provider is paid based on the actual activation.

(****) PC stands for "production curtailment", CI for "consumption increase".

1.3 » Recommendations

The following criteria should guide the DSO's decision to resort to flexibility and to select the correct interaction model:

- ⊙ The decision of using flexibility should be taken at the investment planning stage:
    - ⊙ considering the severity and criticality of the issues to be solved (e.g. thermal limits of equipment, voltage limits, etc.)
    - ⊙ after a comparison between classical network investment and flexibility. This stage will determine the volume and number of activations of the needed flexibility and its maximum cost
    - ⊙ if the needed volume of flexibility can be reasonably available on the long run (more than 5 years). This step can be done with the help of the information on flexibility means collected directly by the DSO (e.g. when establishing new connection agreement) completed by a market (FSP) consultation or survey
- ⊙ It is important to note that different interaction models may coexist
- ⊙ If the volume of flexibility and the number of activations are low, model 1 or model 2 may be applied. The switch between model 1 and model 2 (e.g. in terms of volume or activations) must give a correct signal to the DSO that it is still encouraged to invest and to reduce negative effect on BRP
- ⊙ The Model 3 or Model 4 can be promoted by the regulatory agency
    - ⊙ if the volume of flexibility or the number of activations are high
    - ⊙ if the volume of (locally) available flexibility is largely higher than the needed volume (It is a guarantee that the market is sufficiently liquid and mature)
    - ⊙ these conditions will probably be met in the period 2030 to 2050 (considering the scenario developed in GREDOR)
- ⊙ The selection of model 3 or model 4 is a purchasing strategy freely chosen by the DSO and has to be evaluated in terms of benefits versus complexity
- ⊙ The regulatory agency and/or decision makers have to put in place sufficient regulatory frameworks that:
    - ⊙ From a DSO point of view: allow the promotion of flexibility usage instead of investment (e.g. fair return on invested capital vs OPEX flexibility)
    - ⊙ From a FSP point of view:
        - ➜ Impose transparency on the (local) flexibility needs (actual and future) from the DSO in order to give correct signal for FSP to approach (commercially) grid users with flexibility capability
        - ➜ give enough stability and solid foundation in order to ensure correct return on investments on flexibility control means (including real time data gathering)
    - ⊙ From a BRP point of view: give clear rules on the transfer of energy and the impact on the balancing portfolio of the BRP (from BRP to FSP)
- ⊙ Take into account the ICT implication of interaction models.

The tools developed within GREDOR are not only for sizing or operation of the system. They can also be used to support regulatory decisions by quantitative analyses or to early identify some non-intuitive phenomena that can arise from new interaction models. In this context, we really believe that tools such as the open-source DSIMA tool developed in GREDOR can be appropriate.

Regarding the impact of the interactions models at planning stage, careful consideration has to be given in adopting one planning interaction model over the others since the advantage or disadvantage of an interaction model is very much dependent on the characteristics of the network under consideration. The type of interaction model to be adopted depends on many factors including the severity of the issue to be solved. For constraint violations, heavily priced DER flexibility may still be adopted in order to keep the network constraints within limits. However, with the network constraints remaining within limits, the type of flexibility and hence the long-term planning interaction models adopted will be more market-based (cost of flexibility versus cost of cables/transformers). Interaction model 1& 2 are targeted at generation flexibility and can be adopted in a network which is distributed generation intensive whereas interaction model 3 & 4 can be adopted in a network which has flexibility in generation and/or load.

2 | Estimation of the hosting capacity

2.1 » Current situation

DSOs have models of their system and currently evaluate their hosting capacity on request.

2.2 » Needs

Computing the hosting capacity a priori and globally for a distribution network allows
1. The DSO to have a comprehensive view on the capacity of his networks
2. To inform other stakeholders through an appropriate communication channel, and thus to encourage DG investment where the capacity is already available.

2.3 » Major Contributions

As an additional way to improve interactions between stakeholders and a way to increase the transparency on the state of the distribution networks, we have developed a methodology called GCAN (for Global Capacity ANnouncement) that helps DSOs in estimating the hosting capacity of their network for distributed generation. This methodology computes what can be connected to each bus in order to maximize the hosting capacity of the system, taking into account some technical constraints of the system such as voltage limits and rating of equipment. This method can account for planned reinforcements.

Figure 1 Generation connections for IEEE 33-bus system: first and second year of planning horizon. Capacity is connected at bus 23 during the first year.
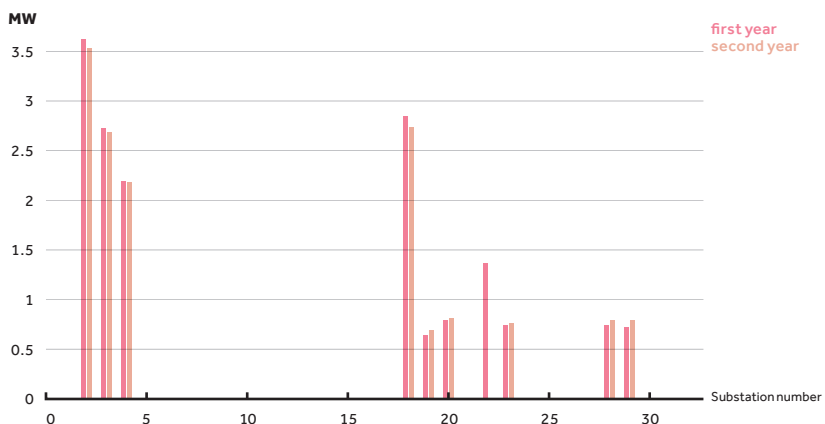
3 | Long term investment planning of smart distribution networks

3.1 » Current situation

Distribution planning is a complex and extensive problem, in particular the new planning problem due to the massive penetration of DER and new types of behaviors/products on the demand side, such as Electric Vehicles.

3.2 » Needs

Some of the high-level requirements for a new distribution system planning tool are:
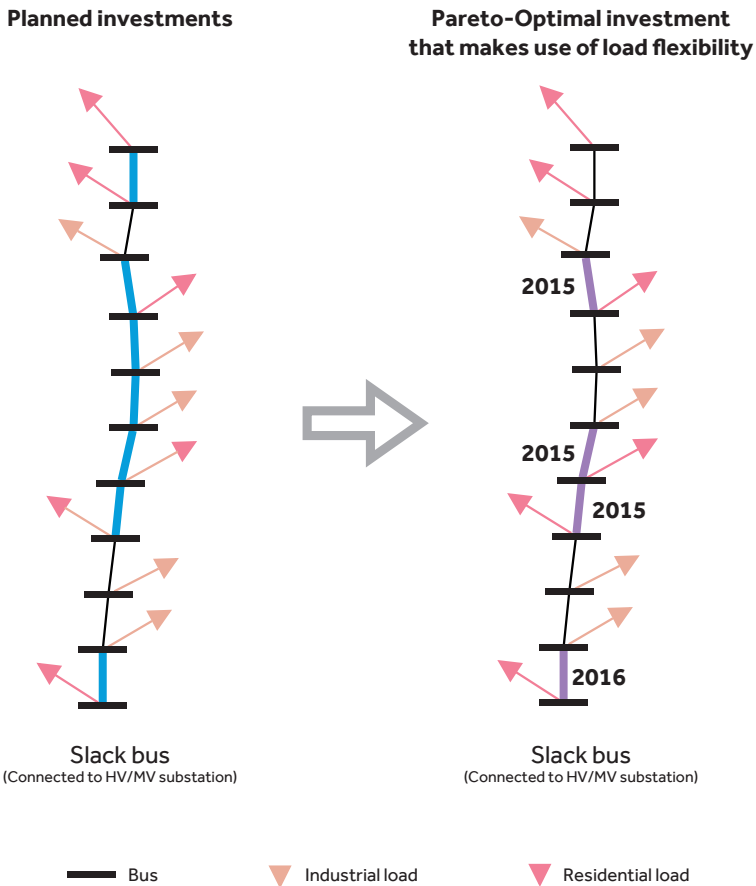- Uncertainty should be properly taken into account
- The sub-transmission network and distribution system should not be treated completely separately
- The objective function should be flexible enough to accommodate different viewpoints
- Investment cost, operation cost, and usage of load and generation flexibility should be taken into account in the planning of the network so that the results are optimal
- ICT infrastructure should be integrated in the problem.

3.3 » Major Contributions

- Developed a suite of digital tools called the 'Smart Suite' as a solution to meet the needs described above. The Smart Sizing tool and the Smart Planning tool are the key tools within the Smart Suite
- The Smart Sizing tool:
  - Smart Sizing aims particularly at the connection to the main transmission network, substation planning and main distribution feeders planning, in order to establish an ideal target network that leads to minimum cost solutions. This ideal target network can be used to define a subset of investments to be considered for future concrete investment problems
  - The outputs of Smart Sizing tool are the optimal sizes of transformers, cables, lines, and the investments in communication technology to exploit the potential load flexibility in addition to the optimal flexibility profiles required from the generation and load
- The Smart Planning tool:
  - Smart Planning is a distribution network expansion planning tool to aid grid planners in the development of grid expansion plans
  - The Smart Planning tool solves a bi-level problem: the upper-level solver optimizes investment decisions related to grid elements and ICT, while a lower-level problem assesses the quality of the candidate solutions.

The lower-level problem performs a grid operation simulation using the Smart Operation tool, which takes the flexibility of controllable resources into account

➡ The output of the Smart Planning tool is a concrete list of projects to expand the grid (new overhead lines, underground cables, transformers, communication networks required to obtain observability and controllability), a priority and a time schedule for these projects, a simulation of the grid operational environment which integrates demand flexibility and DER (generation, storage etc.) control.

Figure 2 Optimal grid investment plan accounting for availability of load flexibility.

Planned investments

Pareto-Optimal investment that makes use of load flexibility

2015

2015

2015

2016

Slack bus
(Connected to HV/MV substation)

Slack bus
(Connected to HV/MV substation)

▬ Bus   ▼ Industrial load   ▼ Residential load

3.4 » Recommendations

- Distribution network planning should no more be based merely on the instants of peaks and worst case scenarios but on load and generation profiles over time taking into account the growing needs of the distribution network in the presence of increasing DER penetrations

- DSOs need to take into account the tradeoff between 'smart investments' and 'traditional investments' in the network planning stage in order to minimize the planning total investment cost (TOTEX) which is the sum of OPEX and CAPEX

- DSOs should adopt newly developed grid planning tools which model not only the distribution network but also the various DERs that are connected to the network

- Due consideration has to be given to the type of ICT infrastructure taking into consideration its various characteristics like bandwidth, latency, scalability etc. in order to consider the ICT infrastructure as an alternative to traditional investments

- Right assessment has to be made of the degree of control required over the various flexible loads and generation using the digital tools in order to minimize the TOTEX

- Make use of accurate long-term forecasting tools in planning a distribution network. Accurate forecasting has to be made available on growth of load, generation, unit costs of equipment, type of flexibilities that will be available in the network (including active and reactive power flexibilities) and the associated cost, etc.

- Facilitate further research and development in the field of optimization in order to analyze and plan complex networks with multiple DERs and associated flexibilities. This is an important requirement especially for long term planning purposes since the time horizon involved is very large and hence is quite demanding in terms of computational power.

Figure 3 Pareto front of investment costs (CAPEX) and operational costs (OPEX).
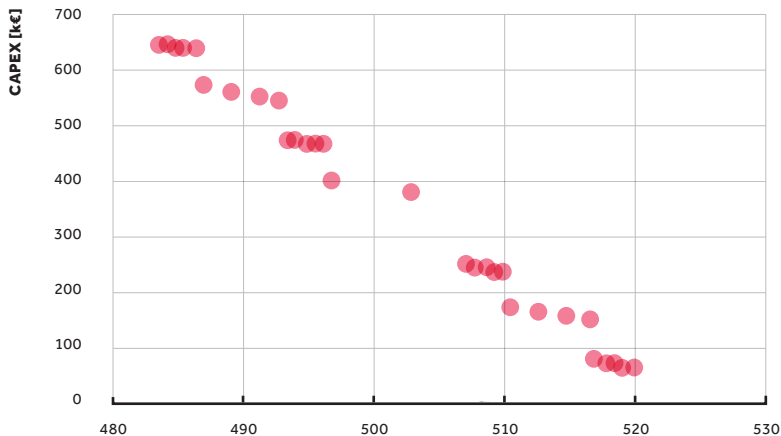
4 │ Operational planning

4.1 » Current situation

Distribution networks are operated in "fit-and-forget" mode: cables, transformers and protections are sized to withstand the peak load under some assumptions on the synchronicity of the consumption.

4.2 » Needs

Plan the operation of the system a few hours ahead in order to leverage forecasts of distributed generation, consumption, and flexibility that exists on both sides. Indeed, demand-side management and storage could be technically and economically appealing options for operating the system without having to rely only on curtailment of renewable energy sources and network reinforcement.

The types of actions considered are:
- The curtailment of renewable generation
- The modulation of steerable generation or storage systems
- The activation of flexibility services.

4.3 » Contributions of the project

Operational planning is very little used nowadays and one of the goals of the project is to determine whether it is technically feasible from a computational perspective and also economically pertinent.

In this project, we have
- Modeled the operational planning as an optimal sequential decision-making problem under uncertainty
- Developed algorithms to solve these problems:
  - One critical part is about making good forecasts of the evolution of generation and consumption sources
  - Another critical part is to find the good level of approximation for taking into account the uncertainty and the power flow equations
- Applied our solutions to academic and real test systems
- Simulation results show that operational planning is a valuable option although network reinforcements will be unavoidable. The key is in the representation of uncertainty and much less in the accuracy of the model representing the network, although recent research results show that it is possible to approximate very accurately the non-linear power flow equations with convex models. Three key steps are needed to improve the treatment of uncertainty

- Gather more data regarding the power flows at the MV nodes and the external local and global factors that influence these flows (temperature, wind, light, etc.)
- Improve the quality of the forecasting tools
- Improve the representation of the uncertainty in the decision-making problems. The more scenarios the better, but the solution time explodes.

4.4 » Recommendations

- Raise awareness of DSO staff and decision makers about the added value of operational planning processes
- Start implementing operational planning tools gradually from now on, where needed and where action means permit it
- Encourage transparent communication of the flexibility capabilities of relevant assets to DS stakeholders
- Continuously improve and monitor the quality of the network data
- Collect more data regarding the power flows at the MV nodes and the local and global external factors that influence these flows (temperature, wind, light, etc.)
- Research and development are still needed, mainly to
  - Improve the quality of the forecasting tools
  - Improve the representation of the uncertainty in the decision-making problems.

Illustrations of part of a 5-bus and low-flexibility simulation run, with a 3-scenarios look ahead model and a second-order cone programming network model
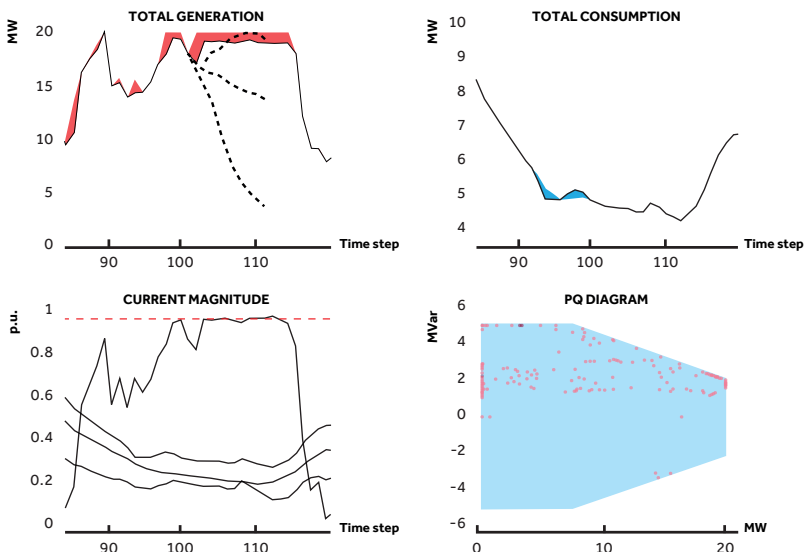
5 │ Real-time control

5.1 » Current situation

- Presently DGUs participate very little in TSO's ancillary services
- Relatively few measurements are available in the MV network, which can make it more difficult to detect emergency situations.

5.2 » Needs

- Postpone expensive network reinforcements as long as it remains cheaper to clear the emergency conditions by acting on DGUs
- Mitigate the limit violations and improve voltage quality for final consumers
- Devise automatic, real-time control schemes to assist Distribution System Operators in keeping the network within specified operation limits (and possibly provide support to transmission system).

5.3 » Contributions of the project

- A coordinated control scheme:
  - Gathering real-time measurements, and sending control corrections at regular time interval (in the order of 10 s)
  - Steering the DGUs smoothly until the emergency conditions are cleared
  - Accommodating different contexts of application (dispatchable vs. non dispatchable units, maximum power tracking vs. known schedules, etc.)
  - Giving priority to "cheap" controls (e.g. reactive power changes preferred to active)
  - Inspired of Model Predictive Control to compensate for modelling inaccuracies and uncertainties
- Extension to two-level control:
  - Lower level: "fast" reaction to voltage disturbances by local controllers
  - Upper level: "slow" coordination of local controllers for improved control of voltages
- State estimation: a novel formulation expressing MV bus powers as functions of a small number of load and generation components at LV level, treated as additional state variables (estimated together with network voltages).

5.4 » Future work

- Further investigate the benefits of using ultra-short-term prediction of load and/or generation in the coordinated control scheme
- Improve and simplify the identification of the MV bus power models used in the proposed state estimation
- Further investigate the possibility of actuating demand response for real-time control.

Illustrative example of thermal overload corrected by DGU reactive power adjustment and DGU active power curtailment. Subsequently, some load increase allows the DGU active powers to be partially restored
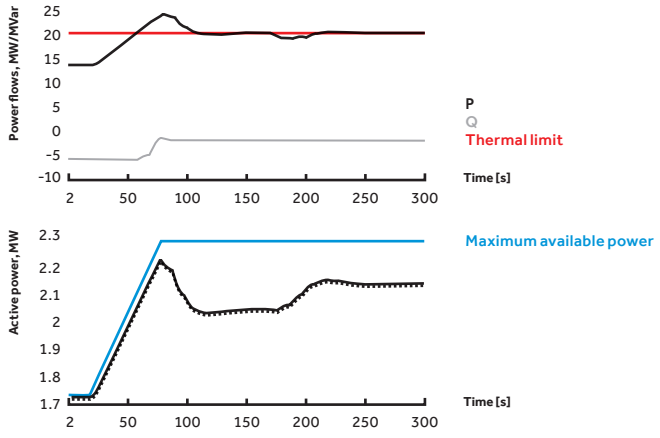
Ilustrative example of fast and coordinated voltage correction by the two-level controller, following an unforeseen disturbance in the transmission system
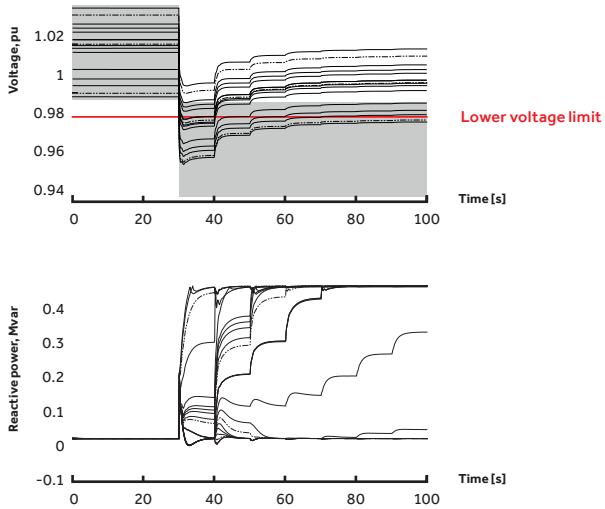
5.5 » **Recommendations**

- Improve situational awareness of distribution systems hosting significant dispersed generation: through additional real-time measurements, state estimation, etc.
- Implement real-time control schemes to assist distribution system operators in keeping the network within specified limits by steering the (active and reactive) powers of dispersed generation units and possibly other devices (e.g. load tap changer)
  - As an intermediate step, the actions are monitored/ validated by the operator
  - Before switching to automatic scheme when enough confidence is gained
- Reinforce communication infrastructure for the above monitoring and control purposes (e.g. refresh rate around 10 seconds)
- Consolidate network and component models: by cross-checking them with real-time information
- Real-time control: accommodate hybrid configurations since the deployment of the centralized level may not be feasible for all dispersed generation units (some of them under local control only, others coordinated by centralized controller)
- Extend real-time control to include support to transmission system (e.g. power factor at point of connection)
- Further test robustness with respect to loss of communication infrastructure.
- Investigate the need to update regulatory policies, including the way the various stakeholders interact, to encompass real-time corrective control.

6 | Data analytics

6.1 » Current situation and needs

The production of DGUs and the electricity consumption need to be forecasted to manage the distribution networks correctly. However, relatively few measurements are available in MV networks to build stochastic models, and the situation is even worse in LV networks.

A better observability of the MV network is needed, so that models can be produced to represent the uncertainty pertaining to renewables and electricity consumption. The same need is observed in LV networks, since the presence of DGUs in LV feeders significantly impacts the MV/LV exchanges. The proposed data models must act on the different time horizons involved in electricity distribution network planning, management and nearly real-time operation.

6.2 » Contributions of the project

Data analytics modules are available, pertaining to:
- ◗ DGUs MV production (active power): photovoltaics and wind,
- ◗ Consumption in MV (active power): industrial, tertiary load,
- ◗ MV/LV injections (active and reactive powers).

These modules are based on original machine learning techniques and advanced statistical models, and perform mainly two tasks:
- ◗ Prediction from 15 minutes ahead to a few hours ahead. Such models are employed to assist the quasi real-time operation and days-ahead/intraday management of distribution networks,
- ◗ Clustering of data in order to provide representative patterns of the studied quantities, useful for longer-term analyses such as network planning.

A particular attention is paid on the modelling of the stochastic nature of these quantities.

Figure 4 **Data analytics modules developed in GREDOR.**

HISTORICAL DATA
Renewable Energy Sources
MV Load   MV/LV bus injections

FIX IMPERFECT DATABASES
PROCESSING: missing data, etc.

CLUSTERING
LONG TERM: planning and investment decisions (task 2)

FORECAST
SHORT TERM: day ahead operational management (task 3) up to real time control (task 4)

- The observability of the MV network is improved, thanks to measurement campaigns organized during the project, so that data models are supplied with enough training data.

6.3 » Future work

- Continue to improve the observability of the MV network (and LV to a further extent), since a lot of areas suffer from a lack of monitoring
- Continue to improve the prediction and clustering modules, especially for the industrial consumption which is strongly dependent on external variables related to their economic activity
- Scale up the developed tools to the world of Big Data, since the quantity of data to process is expected to drastically increase.

6.4 » Recommendations

DSOs should

- Continue the roll-out of smart metering devices in MV and LV networks. This will provide a better controllability of the network through accurate data models, and facilitate market access to the different actors
- Improve the monitoring of reactive power, which has significant impacts on network power flows, and is still today often forgotten
- Store a significant amount of historical data (a few years is a minimum) so that data models provide acceptable performances. This may involve storing real-time data.

Tomorrow electricity distribution professionals require strong competences in data science.

Figure 5 Typical days of wind speed obtained using the clustering module. Plain lines: actual days (i.e. modeled by 24 components). Dash-dot lines: days represented with 3 principal components only. Dash lines: days modeled with 6 to 9 principal components. Peak days are in blue, max error days (i.e. days with the highest reconstruction error when using 3 principal components) in red and mean error days in green.
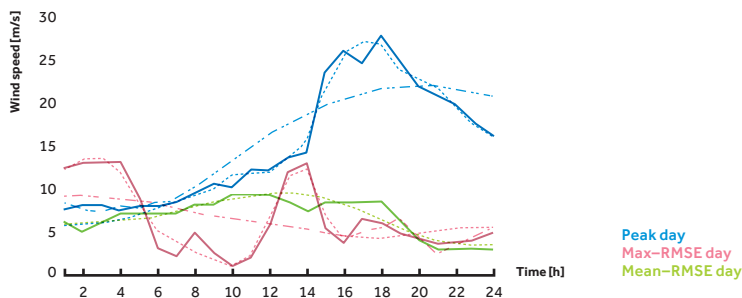
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