WHAT SHOULD BE DONE TO MAKE REVOLUTION IN SMART DISTRIBUTION GRIDS?

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ABSTRACT

The paper is highlighting the conclusions and the lessons learnt from EU FP7 demonstration project "Ideal grid for all, IDE4L" from Distribution System Operator's viewpoint. Many technical demonstration projects of smart distribution grids, including IDE4L, have been realized successfully. This paper highlights the main results and lessons learnt of Active Network Management development and demonstrations in the project, and the roadmap how these results will be realized in practice.

INTRODUCTION

A great number of research publications, technical reports, etc. are published each year to promote novel and smart distribution solutions, devices and algorithms. A growing number of demonstrations in laboratories and in field are realized too. Despite of that, the majority of new distribution networks are still build as passive networks. What should be done differently to speed up the application of novel knowledge in distribution grids?

The objective of the paper is to explain why a demonstration of a technical solution only is not enough to create the real impact on Distribution System Operators' (DSOs') business. Secondly, the importance of a multidisciplinary approach of a demonstration project is explained to understand the practical limitations of a proposed solution. The demonstration results of IDE4L project [1] are utilized as an example in the paper.

Distribution grids have so far been designed and operated as passive networks that requires them to handle all probable loading conditions. This result into sub-optimizing the grid efficiency by over-dimensioning the capacity that is being fully utilized only a small percentage of time. Networks are over-dimensioned today due to quality of supply obligations and missing possibility to control Distributed Energy Resources (DERs).

Active Network Management (ANM) concept has been designed for distribution systems, which have a high share of Renewable Energy Resources (RESs) and other DERs. Active network combines passive grid infrastructure with active resources, ANM functionalities and Distribution Automation (DA) ICT infrastructure. Active resources are e.g. DERs like Distributed Generation (DG), demand response and storage, Micro-grids, flexibility services from aggregator, etc. The ANM concept is based on extensive monitoring and control of distribution grid utilizing direct control of grid assets and contracted DERs (based on grid code or flexible connection contract), indirect control of DERs based on dynamic grid tariffs, and market based flexibility services.

DERs are merged by aggregators, which have the roles of retailer and balance responsible party to utilize flexibility for several purposes like bidding in different markets (wholesale, balancing, reserve, Local Flexibility Market (LFM)), balance management and portfolio optimization. DSO has also a new role to validate flexibility service requests located in its grid and to purchase flexibility services like scheduled and conditional re-profiling products [2] from LFM to solve congestion in the distribution grid [1]. LFM is a novel market where bids must include detailed information about the location of flexibility, for example NODES [3] which is coordinated with TSO level flexibility markets, and ETPA [4] which utilize counter trading for coordination purposes.

AUTOMATION ARCHITECTURE

Distribution automation

Essential part of the implementation of ANM is DA. DA realizes the real-time monitoring and controlling of the whole Medium Voltage (MV) and Low Voltage (LV) networks, and direct control of DSO's assets and DERs [1]. The distributed architecture of DA consists of three layers: control centre information systems (Distribution Management System, etc.), Substation Automation Unit (SAU) or secondary SAU, and Intelligent Electronic Devices (IEDs). Central elements of proposed system are SAUs, which are dedicated to monitor and control a specific area, to store the collected data from IEDs and make independent decisions for example to optimize local network, and to alarm and report control centre. IEDs include measurement units, like strategically placed smart meters, RTUs, phasor measurement, power quality meters, and controllers, like DG unit production curtailment, DG unit voltage regulator and OLTC voltage controller. The role of the control centre is to monitor the grid as a whole, to manage the overall distribution system and to operate on LFM, while the SAU realizes near real-time and operator independent control of specified grid areas, and IEDs operate based on local information only in the hard real-time domain.

Distributed DA enables scalability of enhanced DA functionalities deep into distribution grid. The hierarchical system promotes robustness to information exchange delays and other disturbances. The real-time decisions are taken at local layers (IED or substation) and therefore the real-time requirements of DA becomes less demanding at the higher layers of the architecture.

The DA architecture is based on existing technology, international standards (IEC61850, DLMS/COSEM and CIM), protocols and interfaces, which will allow DSOs to gradually deploy the new solutions. Furthermore, the same architecture and cores of the automation are suitable for both primary and secondary substations. Monitoring, control and protection functions can be deployed locally in the substations, and can operate in a coordinated manner thanks to the hierarchical and distributed architecture. This fine granularity makes the individual local functions light, and the design of the architecture makes their integration highly scalable. Vertical and horizontal integration provides a complete view of the distribution network status. This yields business benefits in the short run, without demanding a complete replacement of the existing infrastructure, which would not be feasible.

Beyond the DSO

Data exchange between DSO, LFM and aggregator will further extend ANM capabilities of DSO from distribution grid to DERs and flexibility services provided by aggregators. Market based flexibility services for DSO congestion management are traded via LFM platform where several aggregators may compete and the coordination of flexibility requests by all market stakeholders may be realized. Aggregators as flexibility service providers are entering several European electricity markets, acting as third parties, contacting directly with customers for flexibility services and selling them in an aggregated manner on the wholesale electricity or TSO’s ancillary service markets. These independent aggregators must be compensated for the energy they inject and re-route – as it is already done in Switzerland, where clear rules on imbalances management have been recently set [5]. In the vision anticipated here, the balance responsible parties act as aggregators, preserving the chain of balance responsibility and simplifying the process with one main contact point for the customer [6].

The role of the DSO is to procure flexibility from LFM to hinder network congestion, and to validate the flexibility products of third parties (TSOs, balance responsible parties, etc.) traded in the day-ahead and intra-day markets. From the DSO’s perspective, the functionalities related to flexibility services should be integrated in the DA.

The Aggregator IT system collects and stores DER data, schedules DERs (building or a home energy management) to maximize the profit and communicates with the market operator platform for bidding and flexibility validation purposes. The second layer of aggregator is the DER automation, for monitoring and control. The lowest level of hierarchy consists of IEDs (e.g. thermostats) of DER.

Congestion management

In addition to indirect control of dynamic grid tariff, the distribution grid may also be controlled directly by DSO. Direct control is applied when fast and precise control actions are needed for example to maintain required voltage quality in the grid. European distribution grids have included very few control elements like on-load tap changer (OLTC) of primary transformer and reactive power compensation units at primary substation. Remote control of MV grid switches may also be utilized for congestion management by changing the location of normally open switch along MV feeders. Recently OLTC for secondary transformers has been introduced to mitigate voltage problems in LV grids. In future energy storage like batteries may also provide very interesting resource also for grid management (e.g. power quality enhancement, congestion management and outage management).

Some DSOs are forced to utilize production curtailment to manage networks due to very rapid growth of RES and delays in grid asset investments, or from extremely costly grid investments in case of occasional curtailment and therefore the socio-economic optimum is to replace grid asset investments with production curtailment. The production curtailment may be mandated by grid code like in Germany, or it may require a flexible connection contract between DSO and customer. Similarly, the voltage control of DG units may be mandated by grid code or a special contract to control the voltage or reactive power of a DG unit. The demand response and energy storage should be allocated to flexibility markets.

In future DSO may utilize flexibility services from aggregators. Two type of flexibility services called scheduled and conditional re-profiling of flexible DERs have been proposed [2]. Scheduled re-profiling is an indirect control method to prevent forecast congestion day-before for example in case of maintenance work in the distribution grid. Conditional re-profiling is a real option type product which is traded day-before but requires activation before operation in real-time. Therefore, it is more suitable for occasional and uncertain cases.

The implementation of congestion management system may be realized with the proposed DA architecture. The benefit of proposed architecture is its capability to manage the whole distribution grid in a coordinated way and to utilize market based flexibility services in ANM. The functionalities of congestion management are located in all three layers of automation architecture and they are called primary, secondary and tertiary controllers. These controllers interact by providing monitoring and estimation data to upward direction and by sending optimized reference values to downward controllers. The primary controllers are IEDs, operate continuously and possible examples of them are given above. The secondary controller is e.g. optimal power flow functionality in SAU minimizing e.g. network losses and production curtailment. It updates reference values of primary controllers periodically (e.g. 5 min). Tertiary controller operates in day-ahead basis and it reconfigures network topology, validates flexibility services requested by other market participants and purchases flexibility services from LFM when needed. [7-11]

DEMONSTRATIONS

ANM and DA have been demonstrated in three demonstration sites in Denmark (Ostkraft), Italy (Unareti) and Spain (Unión Fenosa Distribución). Demonstrations provided general knowledge about applicability of ANM, distributed DA and applications in real-life.

Results of DA architecture

The IDE4L project applied successfully a systematic method for the definition of DA architecture, which is based on the UC methodology [12] and the application of the SGAM (Smart Grid Architecture Model) framework [13]. This helped addressing the complexity of the DA system avoiding oversimplification.

The process of defining the abstract DA architecture consists of four major steps: 1) Development and collection of UCs, 2) Review for consistency and harmonization based on synthesis needed for UC refinement, 3) UC analysis for the extraction of the list of actors, functions and links; synthesis and harmonization of UC descriptions according to the final list of actors, functions and links, and 4) Mapping of UCs onto the layers of SGAM.

Three versions of UC templates, short, general and detailed, were utilized at different development stages. The short UC defines the concept of the architecture, functionalities and operational modes. The general UC defines the draft architecture with enough details for the first steps of integration and setup of demonstrations. The detailed UC defines the detailed architecture in all SGAM layers for implementation. This incremental process supports gradual growth of common understanding of UCs and architecture among developers, and allows for iterations to define and correct very early possible mistakes in the architecture definition.

The architecture was designed based on monitoring, control and business UCs, which effectively coordinates DER and control actuators to resolve congestions and power quality issues. The SGAM formulation of this architecture is derived and explained in details in [14].

The design and the implementation phases of the demonstrated solutions were very instructive. Project participants with different background shared and understood the system as a whole, thus avoiding the development of several sub-optimal architectures. Secondly each participant developing its own brick of complete system needed to participate in the design of interfaces and interactions of sub-components and to realize an intermediate step between development and demonstration called integration testing.

The first step is the testing of individual components. These tests performed in a simulated environment validates algorithms and devices. The second step is the integration step, executed in simulated/prototyping environments integrating architectures, algorithms and tools. This validates the overall integrated architecture and technology solutions that are applied in demonstrations. The demonstration phase is the final assessment phase, which is executed in simulated/real-life scenarios.

The development of the instances of DA and its functionalities must be based on the abstract architecture definition to guarantee the replicability and avoiding tailoring for each demonstration. Also a modularization of the implementations and the use of standard-based interfaces should be the basis of the complete system.

The definition of the demonstration was started in parallel to the development of the architecture by projecting the acrchitecture onto the specific demonstration site. The project introduced the so called physical model, which is an abstract model containing the minimum information needed to describe a specific demonstration. It includes in addition to grid topology and components all layers of SGAM: automation components, communication components, information exchange data flows and applications. The aim of the physical model is to identify the needed abstract components that are further specified by provider, type and model. The model provides also a list of interactions needed to test for the demonstration.

The implementation of demonstration is ready when all developments, interaction testing and components are supplied and installed on demonstration site. The UC specific key performance indicators determine what should be measured and how the data should be treated to verify the demonstrated UC.

Results of congestion management

The optimal and high performance management of a grid requires data of all network levels. In the monitoring system, SAU is in charge of collecting values, events and signals from its subnet to monitor the grid and reporting an aggregated view of network, after an internal elaboration phase, to the upper level. Measurement and static network data are stored in a local database with an increased granularity from the underlying grid to the control centre and it is maintained only where it is needed to perform forecasting, estimation and control algorithms locally. [8]

On one hand, the load forecast of individual customers turned out to be quite accurate and consistent across demo sites. On the other hand, the generation forecast showed less accurate and consistent solutions, due to the volatility of renewable generation plants and to their dependency on very local weather forecast, thus emphasizing the need for a more advanced and customized algorithm to predict the production of these kinds of sources. [14]

State estimation provides system quantities which are not directly measured and because real implementations of monitoring system are subject to errors in measurements, due to communication failures, corruption of the data or temporal unavailability of a meter. The proposed solution is based on pseudo-measurements of load and production forecasts and in case of missing forecast a fixed profiles. As learned from demonstrations, a backup solution should always be available to overcome potential problems of missing measurements. Therefore fixed load profiles were available for all individual load and generation points even if they deviate a lot from real-time consumption or generation of customer. Despite of challenges, the demonstration proved that the state estimation provides an improved view to the state of the LV grid. [14]

The demonstration results confirm that the secondary controller for congestion management operates in all demonstration cases as expected and that no adverse time domain operation occurs. The same controller is able to operate for MV and LV grids. It can be said that the weaker the network and the larger the amount of RES, greater the benefits of the secondary controller are. The annual benefits studies show that the secondary controller is able to both prevent voltage and current congestions and to decrease the annual network losses. The integration of MV and LV secondary controllers was also effective and resulted as correct operation all controllers. [14]

Results of DA solution

SAU is the core of the distributed DA architecture. The SAU realizes the local and remote monitoring and coordination of resources. Its definition in terms of interfaces, functions and database makes the SAU adaptable, it can be implemented with a subset of features, which are easy to extract from the general model, and as such it can be supported by hardware with very different performance characteristics.

The SAU may reduce the burden for computation, data storage and information exchange of the DMS, thanks to the local data processing and control. It may also speed up coordination/optimization of control actions and extend the monitoring and control of distribution network to every corner of MV and LV networks when compared to traditional control centre solutions.

The database component of the SAU is the core of the data storage related to the field measurements, network models, business models and SAU algorithms execution. The same database is used to exchange information among algorithms and interfaces implemented in the SAU.

Scalability is a critical feature in DA, because of the large number of nodes, substations and DERs. The monitoring system is expected to be able to handle millions of measurement points and a large volume of data. Therefore, the architecture is based on a hierarchical structure where on-line and automatic handling and analysis of data is performed to reduce the amount of data transfer to control centre. Distributed data storage allows tracking every detail without real-time communication to control centre. Same can be said for the functionalities like congestion management, which is carried out in IEDs and SAUs, without resuming to the control centre.

The automation system should also be based on standards. This is needed to enhance and simplify the integration of subsystems. Data acquisition and the interfaces between the SAU and the peripheral devices has been implemented using standard protocol such as DLMS/COSEM for smart meters and IEC 61850 MMS messages for IEDs. Quasi-static information such as the network topologies and network asset information is encompassed by the CIM.

ROADMAP

The project had a strong focus on technology development and therefore this aspect is probably the most advanced one of the selected viewpoints. However, the experiences collected from demonstrations should be utilized to further improve and extend the technology and therefore the second technology development and demonstration phases are required before commercializing the developed technology. Also the design and development of other viewpoints of roadmap are also required before a market for all solutions developed in project really exists.

Although the demonstrations were realized by three DSOs, the technology market still does not have concensus what are the winning technological solutions. The chicken-egg problem exists because the technology push does not function due to few customer requests and the technology pull is too diverse to create cost efficient products for the market. Many products are expensive, do not meet enough customer requirements, or are “hardcoded” for a specific UC and cannot be modified for customers’ diverse needs of ANM. In order to break this problem, there is needed more cooperation between DSOs and technology providers, and product silos must be taken apart in order to provide complete, modifiable and interoperable solutions deep inside each component. The belief of DSOs that they may buy necessary technology from market is not relevant when a major revolution in grid design and operation is realized by ANM, either the belief of technology providers that they know what DSOs need is not relevant because not so many know what they really need in the long run and the technologies, methodologies and concepts are evolving in coming years with increasing speed. Therefore forerunning DSOs are needed to test and provide feedback to technology providers to continously improve solutions.

LFM for flexibility services, which are validated and purchased by DSOs, does not exists yet anywhere in Europe. Some demonstrations of LFM exist, but the application of LFM in large-scale in distribution grids is still a long road to walk. Therefore, the LFM has to be designed first in EU member countries and then harmonized on the European level, which might in practice take several years. In addition to a design of LFM, common agreement on flexibility products and contracts common enough for all kind of flexibility needs are required to really create a well-functioning single flexibility platform of several flexibility markets, participants and coordination between them. The most important issue is to create continuity for profitable business and trust between market actors, as otherwise the LFM will not have enough actors.

Very important aspect for the success of ANM in smart distribution grids is the modification of grid regulation to allow efficient utilization of DERs for grid management and to enable existence of LFM for DSO use. Otherwise DSOs continue developing their grids as passive infrastructure. The existing grid regulation in most European countries favours investments for passive network because investment for capital expenditure provides higher profit than increasing operational expenditures. The utilization of ANM for example to increase network hosting capacity in weak network typically reduces capital expenditures and increase operational expenditures compared to passive solution. Therefore the large-scale utilization of ANM requires consideration of total expeditures in grid regulation.

Modification of grid codes and standards is a long process. Therefore, the objective of grid code and standard development should also focus on the future requirements of ANM in addition to the urgent needs of existing systems. Active participation of research and demonstration projects is required to understand future needs for the development of grid codes and standards, and to create a European vision of future smart distribution grid of diverse conditions and challenges.

The research and development persons of DSOs are very enthusiastic to develop and demonstrate new solutions, but the challenge is to implement the new ideas as a standard practice in a DSO. For this effort it is proposed that more information about real knowledge gaps in business and engineering tasks, while DSOs are making investment decisions, needs to be collected. In addition to this, sharing outcomes and collecting the best practices from other demonstration projects is needed before utilizing new ideas as the best practice in a DSO.

One challenge to be solved in a practical case is the design of distribution grid including both passive and active network solutions. Long-term grid development always requires passive network investments as well. The challenge is to decide what role the active network solutions has in overall design, where and how it should be utilizied or should it utilized only as a method to post-pone necessary passive network investments. Secondly, the overall design process within DSOs is mostly based on passive network solutions only. The design process to utilize active network solution is much more complex to realize, because practises and necessary automated design tools are missing. In many cases at the moment the design of active network is much more slower compared to the design of passive network which hinders the utilization of active network solutions in practice. The practical designer needs very simple guidelines, tools and methods how to utilize active network solutions in everyday design process, and information how much the solution will cost and what are the benefits and drawbacks of it compared to passive solution. Otherwise the role of active network solutions maintain as R&D projects and never become as a large-scale solution for grid design.

CONCLUSIONS

Demonstrations are absolutely necessary to start the revolution of distribution grids. Active distribution grids and ANM require, however, a systemic change in distribution grid design and operation, which requires time and effort to converge to a conclusion. The development process of systemic ANM solution is still in the beginning moving from demonstrations of a single functionality towards demonstrations of an ANM architecture like in IDE4L project. However, further development steps are needed to demonstrate and utilize the holistic system of systems approach needed for active networks in real-life. The required steps, created based on the experiences of the IDE4L demonstration project, are wide knowledge and positive attitudes to ANM among DSOs' investment decision makers, development of grid design processes to include active network solutions, broad utilization of harmonized grid codes and information exchange standards at component and system levels, grid regulation supporting the aims to utilize active network and ANM where seen as the most cost efficient solution, large-scale provision of flexibility services for DSOs via a local flexibility market, and the development of the winning technological products and solutions for active network.

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