The IDE4L Project

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Defining, Designing, and Demonstrating the Ideal Grid for All

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THE PURPOSE OF THE IDE4L PROJECT WAS TO define, design, and demonstrate the ideal grid for all, with an active distribution network that integrates renewable energy sources (RESs) and new loads and guarantees the reliability of classical distribution networks. The active distribution network consists of the infrastructure of power delivery, active resources, and active network management (ANM) and combines passive infrastructure with active resources, ANM functionalities, and distribution automation information and communication technology infrastructure. Active distributed energy resources (DERs) include distributed

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generation (DG), demand, response, and storage. The concept of a commercial aggregator offering flexibility services is also integrated in an ANM.

The boundary of the project comprises medium-voltage (MV) and low-voltage (LV) networks. The clean and reliable energy of the future requires a new kind of electric infrastructure capable of integrating and exploiting DERs. The large-scale penetration of RESs in MV (and increasingly in LV) networks and new type of loads such as heat pumps and, more pervasively in future, electric vehicles (EVs) are expected to adversely affect the operation of existing distribution networks. The integration of DERs requires power distribution grids to evolve into more dynamic and complex structures.

IDE4L was a three-year demonstration project (from September 2013 through October 2016) in Europe with a total budget of €8 million; funding was received from the European Union Seventh Framework Program FP7-SMARTCITIES-2013 under grant 608860 IDE4L–Ideal Grid for All. New functionalities for the active grid, fit for automation solutions, have been developed and demonstrated in laboratories and real field conditions for three distribution system operators (DSOs): Unareti Spa (UNR), Italy; Union Fenosa Distribution SA (UFD), Spain; and Østkraft A/S (OST), Denmark. Field demonstration areas consisted of three LV and two MV networks in different countries. The coordinator of the project was Tampere University of Technology, Finland (TUT). Other partners were Catalonia Institute for Renewable Energy, Spain; Danish Energy, Denmark; Kungliga Tekniska Högskolan, Sweden; RWTH Aachen University, Germany (RWTH); Schneider Electric SA, Spain (SCH); Technical University of Denmark; and University Carlos III de Madrid, Spain.

Main Objectives of IDE4L

The objective of the IDE4L project was to develop and demonstrate the next generation of active distribution networks that will fully comply with the new sustainable and energy-efficient electricity frameworks. Project partners are designing and developing a next-generation distribution automation architecture that enables flexibility services from DERs and aggregators. ANM is based on new monitoring, control, and network-planning functionalities, which were also developed and demonstrated in laboratories and on live distribution networks.

Distribution network automation includes the whole chain of electricity network management starting from the control center information systems through to substation automation, secondary substation automation, and, finally, customer interface (smart meters and home energy management systems). The automation concept revolves around three design points:

- ✔ hierarchical control architecture in distribution network automation
- ✔ virtualization and aggregation of DERs via an aggregator
- ✔ the large-scale utilization of DERs in network management.

A next-generation hierarchical and decentralized architecture for distribution automation has been designed and field tested in compliance with international standards, in particular International Electrotechnical Commission (IEC) 61850, Device Language Message Specification/Companion Specification for Energy Metering (DLMS/COSEM) (IEC 62056), and the Common Information Model (CIM) (IEC 61970 and IEC 61968). This automation enables real-time monitoring and control of the MV and LV grids and the trading of flexibility services offered by DERs through aggregators. Aggregators will offer flexibility services for a flexibility market, and grid companies may validate submitted offers and purchase flexibility services to avoid network constraints.

Working Methodologies

The architecture was designed based on the smart grid architecture model (SGAM) and semantic models of the components. About 30 cases of ANM have been used to define the model, and the description of the architecture is able to include additional use cases or to implement it in the form of alternative components, communication media or protocols, and information exchange methods and protocols.

Installing a complex automation system in a real operating environment is not a trivial task, especially if the target environment provides the electricity distribution grid as a public service. The leap from the design and development stage of single "bricks" of the architecture to the real testing of a subset of the overall system, needed to run a use case, is quite large. For this reason, an intermediate integration step was used where pairs of system components were tested together to validate their interaction before stacking many of them together. This intermediate step is called the integration lab because its main focus is on integration.

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Main Results

IDE4L Concepts

Electricity distribution networks have, to date, been designed and operated as passive networks according to a design point that requires them to handle all probable loading conditions. Distribution networks are overdimensioned today due to the quality of supply obligations and missing possibilities to control DERs. With that design point, the only way to increase the number of serviced users is to add network infrastructure assets in proportion to load growth.

The management of a power delivery infrastructure is enhanced by utilizing active resources in the ANM and especially by coordinating the operation of DERs from the whole system viewpoint to achieve synergy benefits, rather than optimizing their operation from a single party's viewpoint. To realize this vision, it is essential to integrate active resources as part of an active network instead of just connecting to the network with the "fit and forget" principle.

Control Methods of the Active Distribution Network

An active distribution network utilizes the controllability of DERs in addition to grid assets. Connection requirements (grid codes) are an efficient method to establish technical capabilities for the control of DERs. Examples of applicable connection requirements are production curtailment and the voltage or reactive power control of a DG unit. A dynamic or power-based grid tariff provides customers with incentives to shift load demand to the network during off-peak hours.

A distribution grid may also be controlled directly by the DSO. Direct control is applied when fast and precise control actions are needed, for example, to maintain the required voltage quality in the grid. The DSO may control its resources directly. Traditionally, European distribution grids have included very few control elements, such as on-load tap changers (OLTCs) at primary transformers and reactive power compensation units at primary substations. The remote control of MV grid switches may also be used for congestion management by changing the location of normally open switches along MV feeders. Recently, OLTCs for secondary transformers have been introduced to mitigate voltage problems in LV grids. In the future, energy storage-like batteries may also provide interesting resources for grid management.

The continuity of electricity supply to customers is one of the main concerns of DSOs today. Distribution automation reduces outage duration, while additional circuit breakers along MV feeders reduce interruption frequency. Automated fault location isolation and supply restoration (FLISR) solutions may combine both of these enhancements through FLISR logic in distributed intelligent electronic devices (IEDs) or a centralized distribution management system (DMS) and through direct control of circuit breakers and switches. The next step for reliability enhancement may be provided by microgrids capable of island operation by supporting supply restoration of a congested backup connection and automatically isolating fault conditions and resynchronizing after restoration phase.

The DSO's chance to realize production curtailment may be mandated by grid code such as in Germany, or it may require a special contract between the DSO and the customer. Similarly, the voltage control of DG units may be mandated by grid code, or a special contract might be needed to allow the DSO to control the voltage or reactive power of a DG unit. Grid codes and special contracts should be applied only to nonmarket-based control resources like reactive power or emergency control actions like production curtailment. Therefore, demand response should be allocated mainly to flexibility services.

In addition to more traditional control methods, DSOs may utilize flexibility services from commercial aggregators. Two types of flexibility services, called scheduled and conditional reprofiling of flexible DERs, have been proposed by the Address project, and those have also been used in the IDE4L project. Scheduled reprofiling is an indirect control method to prevent forecast congestion a day ahead due to, for example, maintenance work in the distribution grid. Conditional reprofiling is a real option-type product traded a day ahead but requires activation before operation in real time. Therefore, it is more suitable for occasional and more uncertain congestion cases in the grid, such as unexpected high or low demand and correspondingly low or high production.

Active Network Management

An essential part of implementing ANM is distribution automation and integration of more parties into the electricity market and power system management. Figure 1 presents the vision of a complete automation solution for ANM based on previously described control methods.

Distribution automation (shown inside the DSO box in Figure 1) includes control center information systems, substation automation, secondary substation automation, and IEDs, including multiple types of devices like smart meters in the customer interface. It realizes the real-time monitoring

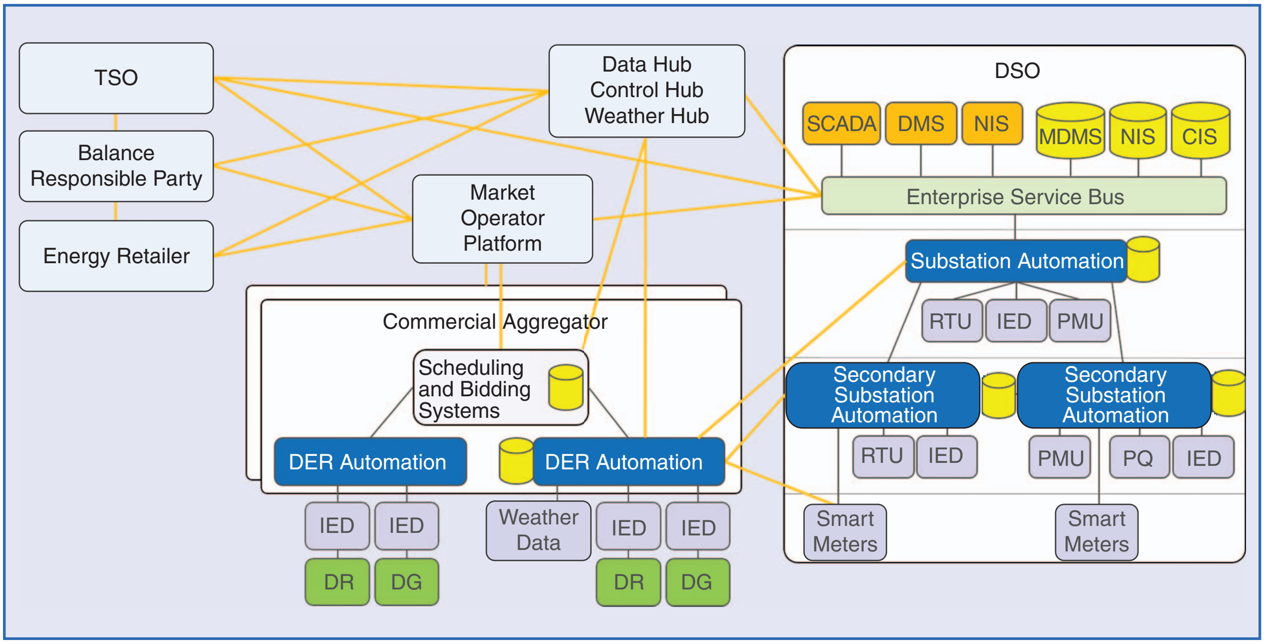

figure 1. An overview of the IDE4L automation solution.

and controlling of all MV and LV networks and direct control of DERs. Traditional distribution automation solutions [e.g., centralized supervisory control and data acquisition (SCADA)/DMS] are not rapid and scalable enough to monitor and control large-scale DERs in real time on both MV and LV networks.

Therefore, a novel hierarchical decentralized automation architecture is proposed for ANM and implemented by three actors: IEDs, substation automation units (SAUs), and DMSs. The primary and secondary substations are the central elements of the architecture. The SAU manages monitoring and control within the substation, stores the collected data, and makes independent decisions. Externally, the SAU sends alarms and reports to the control center (and possibly to other substations). The majority of real-time data is seen by the SAU only, although data can be retrieved by the control center if needed. The SAU data are received and sent from/to the IEDs, which are heterogeneous devices not limited to the typical substation IEDs. The SAU has external links (the DSO's communication infrastructure) to DER automation, which is part of the commercial aggregator's automation system. This link is used to send, in an emergency, direct control commands to DERs, which are considered a type of IED in the architecture.

Control center information systems consist of several IT systems used for operational and planning purposes, and the integration of these systems is necessary to get the most out of the available data. For example, smart-metering data is primarily used for billing, but it may also be used for planning purposes to create enhanced customer load profiling and clustering, which is becoming more challenging due to prosumers, consumers capable of producing their own energy. Similarly, the smart-metering data may be used for operational purposes like outage alarms and voltage deviations. Alarms go directly to SCADA/DMS, and everything else is stored in the meter data management system, which is further integrated with the customer information system for billing and the network information system for customer profiling and clustering.

The second major automation system is owned and operated by the commercial aggregator that, in addition to its current market operations, is assumed to be selling flexibility services to the DSO to prevent or resolve congestion. This automation system is also hierarchical and decentralized, and the first central layer includes IT systems to collect and store DER data, schedule DERs to maximize profit, and communicate with the market operator platform for bidding and flexibility validation purposes. The second layer is DER automation (possibly including building or home energy-management systems monitoring DERs), which coordinates local DERs and realizes the activation of DER scheduling. The lowest level of the hierarchy consists of the IEDs themselves, which are programmable logic controllers or advanced thermostats of DER units. The development of the automation system for the commercial aggregator is not in the focus of IDE4L project, and, therefore, further implementations details are not included.

Commercial Aggregator

Flexibility can be described as the modification of consumption patterns and generation injection in reaction to a price signal or activation request to provide a service within the energy system. The sole source of flexibility is assumed to be prosumers, in the form of industrial, commercial, and domestic providers.

Potential services to be provided by means of flexibility within the power system are traded in electricity markets. Given that most consumers and prosumers lack the means and the size to trade directly into wholesale electricity markets, they require the services of a commercial aggregator. The main role of the commercial aggregator is to gather flexibility from its consumer/prosumer portfolio and optimize its trading in electricity markets to maximize profits.

To ensure a transparent and equitable market design for flexibility aggregation, the relationships among commercial aggregators and other market parties [i.e., customers, balance responsible parties/suppliers, and transmission system operators (TSOs)/DSOs] should be clarified. Commercial aggregators are entering several European electricity markets, with some of them acting as third parties, contacting customers directly for flexibility services, and selling them in an aggregated manner on the wholesale electricity or the TSO's ancillary service markets. In this context, responsible parties/suppliers must be compensated for the energy they inject and that is rerouted by these commercial aggregators acting as third parties. For the future, the simplest scheme, as proposed here, is one in which the balance responsible parties/suppliers act as commercial aggregators, keeping the chain of balance responsibility and delivering simple arrangements such as one main contact point for the customer.

From the DSO perspective, flexibility should be integrated as part of ANM where new functionalities can help realize the new roles of DSO: 1) as a flexibility procurer to feed the DMS and its functions to hinder network congestion and 2) as the party responsible for the technical validation of the distribution network located flexibility products coming from day-ahead and intraday markets, and technical validation before its activation when requested by third parties (such as TSOs and balance responsible parties).

In Figure 2, the interaction among actors and its functionalities is depicted; a flexibility market where TSOs and DSOs can gain access is proposed to avoid market fragmentation and ensure the effectiveness of system operation.

A Solution for Hierarchical and Decentralized Distribution Automation

Hierarchical and decentralized automation architecture is the basis of the entire IDE4L project. The architecture has been designed for complete distribution grid management and is based on real-time, scalable, decentralized, and interoperable (standard-based and modular) field automation and control center IT systems.

Real-time monitoring must be extended from primary substations only, to secondary substations, down to final customers, where the advanced metering infrastructure is present or underway in many countries. The control of the distribution grid, which is active at all voltage levels and equipped with pervasive monitoring, should be designed coherently: decentralized, to use locally available measurements and estimates, and coordinated to smoothly control over different time horizons and vertical positions within the distribution network, and to harmonize commercial and technical decisions.

The IDE4L project has designed an architecture based on monitoring, control, and business use cases and using the SGAM formulation. The architecture is technology neutral as far as standards are used, so it can be implemented with heterogeneous types of measurement devices, controllers, and computation units. All data exchange and modeling are based on international standards IEC 61850, DLMS/COSEM, and CIM to enable interoperability, modularity, the reuse of existing automation components, and the faster integration and configuration of new automation components.

An SAU is the core of the hierarchical/decentralized architecture (see Figure 1 for the architecture and Figure 3 for the implementation of an SAU) and realizes the local and remote monitoring and coordination of resources. Its definition in terms of interfaces, functions, and databases makes it adaptable. An SAU can be implemented with a subset of features, which are easy to extract from the general model, and it can be supported by hardware with very different performance characteristics. It can be exploited for measurement and control devices that are already installed in the field, thus reducing the investment for automation upgrade.

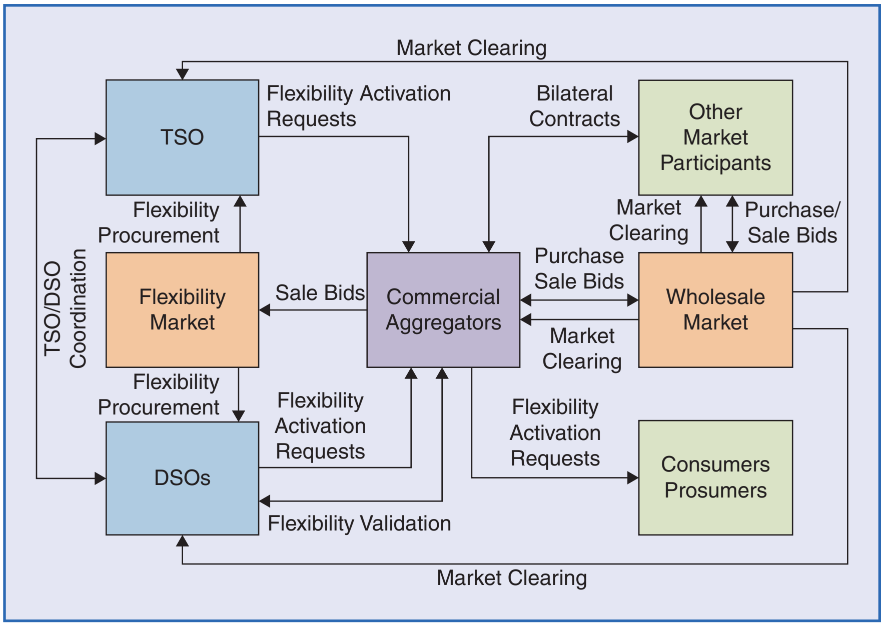

figure 2. The commercial aggregator market setup.

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

The SAU's database component is the core of data storage related to field measurements, network models, business models, and algorithm execution. The same database is used to exchange information among algorithms and interfaces implemented in the SAU, for the state estimation/forecast, and for the control and monitoring of the grid connected to the SAU. The measure and control schema of database has been defined from IEC 61850 data model. The network model schema has been designed from the CIM.

Use Cases

Monitoring

In the monitoring system, the SAU is in charge of collecting values, events, and signals from its subnet to monitor the grid. After an internal elaboration phase, the SAU reports an aggregated view of the network 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 center and are maintained only where necessary to locally perform forecasting, estimation, and control algorithms. State estimation provides system quantities that are not directly measured. Second, it is needed because real implementations of monitoring systems are subject to errors in measurements, due to communication failures, data corruption, or the temporal unavailability of a meter. Load and production forecasting algorithms are needed for daily and day-ahead forecasting.

State estimation and forecasting are two advanced functionalities to provide information about a complete network using incomplete and uncertain information. The distribution of these functionalities to SAUs is a completely novel idea. Decentralized advanced functionalities enable the real-time scalability of monitoring systems, may reduce investment and operational costs of monitoring systems, and provide a tool to detect broken or unreliable measurement units.

Decentralized IEC 61850 FLISR Solution

The FLISR application can reduce outage duration and, therefore, considerably impact the profitability of DSOs. The distributed FLISR scheme with peer-to-peer communication proposed in the project is based on logic selectivity and IEC 61850. In addition to alternative network reconfigurations, DERs and microgrids may be considered to manage service restoration to minimize outage duration and the number of affected customers.

Automated protection reconfiguration is needed to optimize protection system performance independently from the grid or DER configuration. Adaptive protection schemes enhance the coordination of IEDs and, therefore, the availability of protection systems in complex scenarios. IED operation parameters will respond to changeable operation situations, eliminating the need for technical crews to be dispatched to the installation point and for the protection system to be interrupted. The use of the IEC 61850 configuration language and the IEC 61850-MMS service for configuration update reduces integration work.

The FLISR solution designed for the IDE4L project is based on the principle that future secondary substations will be provided with circuit breakers. This will require logic selectivity to be deployed not only between fault passage indicators but also among circuit breaker controllers. Considering this, a decentralized approach to be performed by distributed IEDs has been deployed based on the use of IEC 61850 and the generic object-oriented substation event (GOOSE) communication service, which is indicated for this kind of application. The application divides the network operations in three steps:

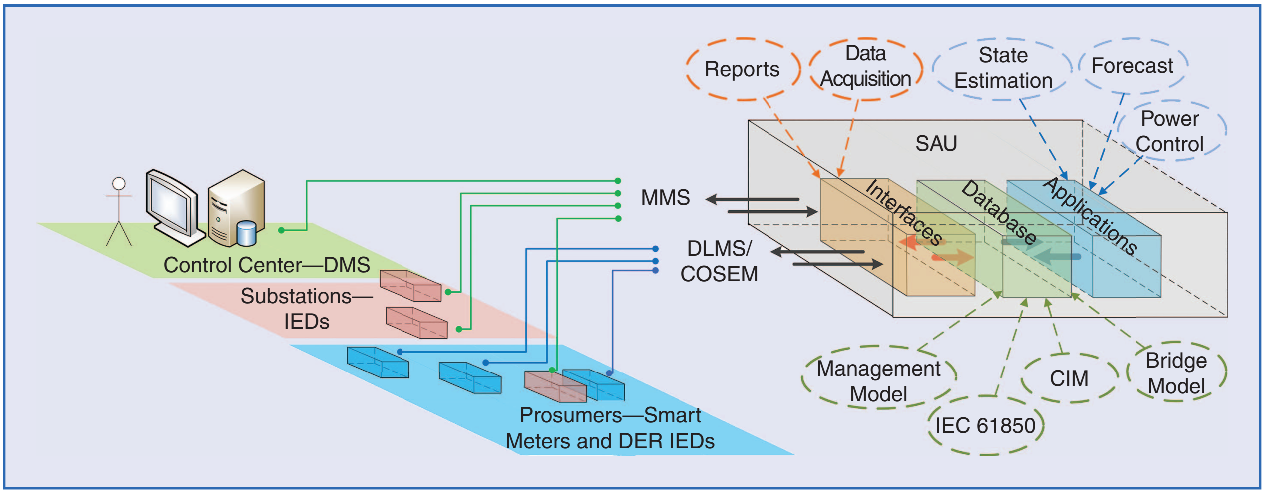

figure 3. An SAU.

1) The first isolation step will be performed between distributed IED controlling circuit breakers, and this IED will be provided with protection functions.
2) The second isolation step will be performed between distributed IED controlling switches once the first isolation step is finished; this IED will be provided with fault passage indicators.
3) The restoration algorithm will be run at the SAU level to consider DER capacity and alternative branches for mesh networks, thus obtaining a more efficient restoration.

Both isolation steps integrate a backup chronometric selectivity allowing for the provision of backup operations in case the logic selectivity fails. In this way, the reliability indexes are even better. In addition, DER coordination commands are included to command disconnections of DERs when required to avoid islanding situations or unnecessary reclosings. Blocking commands to avoid unnecessary disconnections are also sent from FLISR IEDs to avoid unnecessary disconnections from the distribution grids.

Congestion Management

Congestion management is a three-layer control hierarchy. First, the tertiary controller calculates dynamic grid tariffs to be introduced for commercial aggregators and retailers to prevent congestion conditions before day-ahead market closing. Second, the tertiary controller validates flexibility service actions of commercial aggregators within the DSO's network and purchases flexibility services if needed to solve congestion. This controller also plans the optimal network topology for the next day to prevent congestion. In addition to the main algorithms, the tertiary controller also contains a state estimator and a forecaster to provide states and forecasts as inputs for the other algorithms.

The secondary control for distribution grid congestion management optimizes the settings of primary controllers to enhance the hosting capacity for DERs and solve occasional congestion problems. The secondary controller, which runs in real time, is based on optimal power flow to minimize operational costs like losses, production curtailment, and demand response. As an input, it needs the state estimation of the control area. The secondary controller is of greatest benefit for cases in which congestion occurs occasionally, network reinforcement costs are high, and the control area includes several controllable DERs and network elements. In a weak distribution network, the hosting capacity provided by the secondary controller is typically three to four times greater than the hosting capacity of a passive network and two to three times higher than the hosting capacity of an active network utilizing only primary controllers.

Figure 4 illustrates the hierarchy of the controllers and their interactions. Secondary controllers are located at primary or secondary SAUs depending on which network, the MV or LV grid, they are managing. The tertiary controller is located in the DMS.

DSO/TSO Information Exchange

Phasor measurement units (PMUs) located in distribution grids provide valuable information for a TSO to determine real-time and adaptive reduced models of active distribution networks for transmission system management. This helps the TSO determine reduced models more accurately and includes complexities and interdependences between transmission and distribution systems. One crucial piece of information, of immediate interest to the exchange between DSOs and TSOs, is the equivalence of distribution network models. PMU data can also be exploited for dynamic line rating at the distribution level, small-signal oscillation detection, and voltage stability assessment.

The work carried out in IDE4L shows that accurate time synchronization is paramount for the use of PMU data in the different applications discussed earlier, which use PMUs as input. Hence, one key recommendation from IDE4L is to support

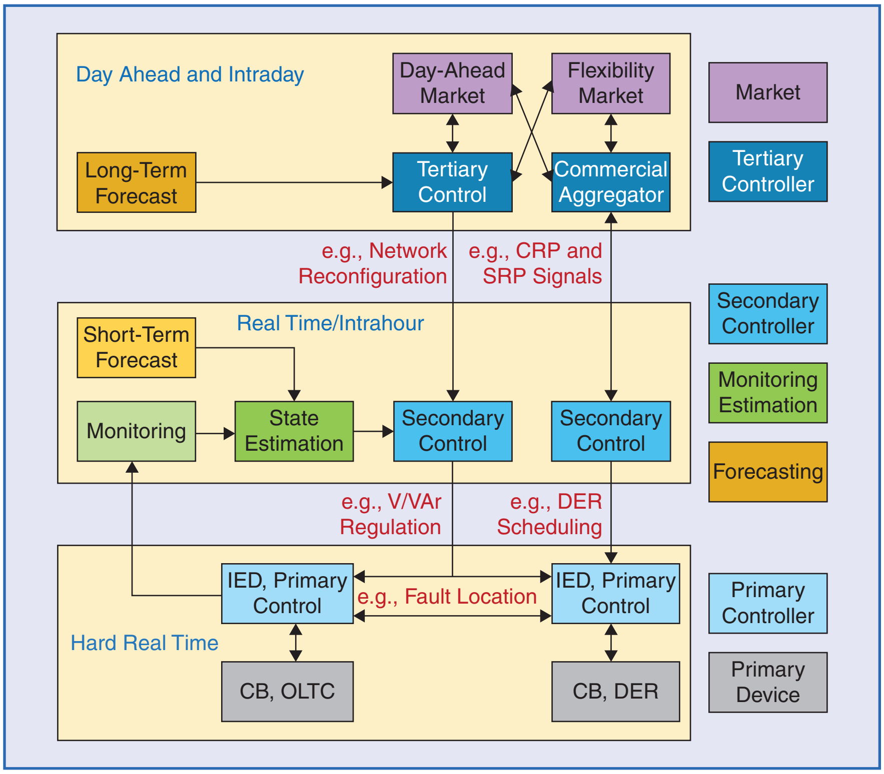

figure 4. The hierarchy of controllers.

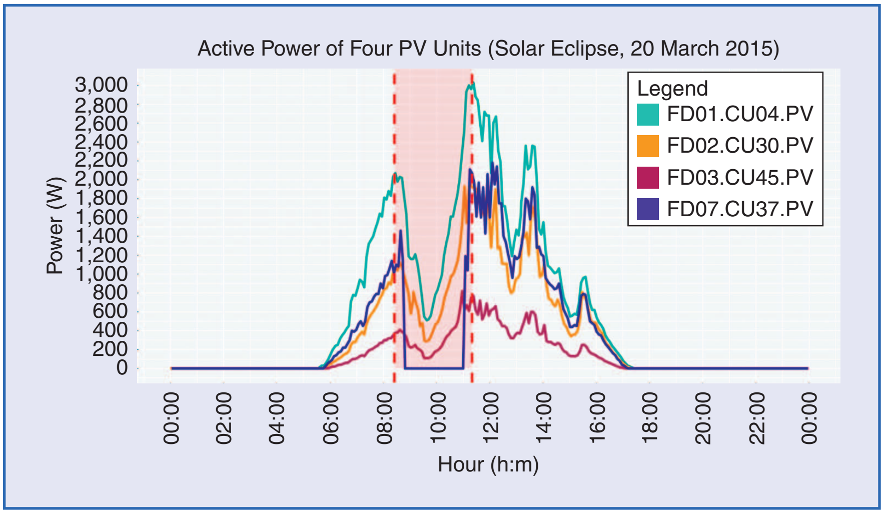

figure 5. PV output monitoring in an LV grid in the UNR demonstration site.

work to move forward the adoption of IEEE Standard 1588 for time synchronization in embedded devices (i.e., PMUs and other control and protection equipment) to directly support the development, implementation, and use of IEEE/IEC 61850-90-5 for both data and time-synchronization data transfer. The project has also proposed an implementation of the latest IEC 61850-90-5 protocol for synchrophasor data transfer, which will be released as open source software and can be used to support interoperability and facilitate market access to new integrators or hardware providers.

Demonstrations

Demonstration Sites

The OST demonstration site is located on the northern part of Bornholm Island, Denmark, in a residential area in the village of Tejn. It consists of two secondary 10/0.4-kV substations (numbers 29 and 370) and an LV network. The network consists of four LV lines with 126 customers. This area was selected because of the relatively high percentage of customers with heat pumps and photovoltaic (PV) panels.

In this area, 12 smart meters have been connected using a general packet radio service communication technology and transmit data every 15 min with a resolution of 5 min. Additionally, the remaining 114 smart meters use a power line communication technology and transmit data every 2 h with a 5-min resolution. The data from the meters are collected once a day.

The MV network is composed of one MV/MV (60/10 kV) substation, one MV line (number 7) and 18 MV/LV (10/0.4) kV substations. Two MV/LV substations (numbers 29 and 122) have been fully automated with IEDs for monitoring, control, and protection. To enable MV automation, an Ethernet/IP network has been implemented using optical fibres.

The UNR field demonstrator is located in the city of Brescia, Italy, in the Il Violino district. This district was recently designed to promote an eco-friendly lifestyle: it is characterized by a high percentage of customers equipped with PV panels (the total PV installed capacity is about 40% of the total peak demand), and the district uses a combined heat and power plant.

The LV field demonstrator consists of the whole LV network of an MV/LV substation, which has, in total, ten LV lines and feeds 294 customers, mainly residential ones. Out of all the network nodes, 45 (belonging to six out of the ten LV lines) have been equipped with a new generation of smart meters, for a total of 60 meters that are able to monitor in real time a wide set of electric parameters for customers and PV units. Moreover, six new PV inverters also have been installed for voltage and power regulations. Figure 5 represents an example of monitoring output of a demonstration site. For communication purposes, a broadband power line over LV cables communication system has been used.

The MV network demonstrator consists of one MV/MV substation, three MV lines, 40 MV/LV substations, and nine MV customers. Out of the three MV lines, two have been fully automated with monitoring, control, and protection systems, while the third has been involved primarily in simulations and for the LV field trial. To enable the MV automation services, a proper communication network has been implemented by using a mix of technologies, specifically optical fibers, broadband power lines over MV cables, and Wi-Fi.

The UFD demonstration site, located at its headquarters in Madrid, consists of an LV network connected to an MV line fed by the primary substation Puente Princesa. The substation is located on the southern edge of Manzanares River, close to the street, and it shares the facilities of the University Corporate Company and offices of the high-voltage network operation.

The UFD LV demonstration site has different facilities connected (already existing before the project) such as an amorphous PV installation (10 kW), a monocrystalline PV installation (20 kW), a polycrystalline PV installation (20 kW), a gas generator (5.5 kW), a wind turbine (3.5 kW), two three-phase EV chargers, and a meteorological station. Most of these installations are smart meter connected, and all PV generators have controllable inverters.

What Was Realized

In the three field demonstrations, some use cases have been tested. Those components were selected because, together, they constitute two very important business cases:

The IDE4L concepts and technical solutions extend the monitoring and control of the distribution grid to all voltage levels.

- ✔ a congestion management business case, where
  - a portion of the network is monitored by collecting data from IEDs (monitoring use case)
  - its status is determined through a state-estimation algorithm (state estimation use case)
  - pseudomeasurements are sent to the state estimator based on a forecast of load and production profiles (load and production forecast use case)
  - in case that forecast is missing, fixed profiles are used as a back-up input (not a use case)
  - eventually, the network performance is optimized by the secondary (power) controller, issuing set point to IEDs
- ✔ the FLISR, where IEDs are communicating based on a peer-to-peer paradigm to clear faults on the network.

Table 1 shows the mapping between the use cases tested in the project and the demonstration/lab site where the test was performed. The laboratory demonstration sites are TUT, RWTH, and SCH.

Conclusions of Demonstration Use Cases

The LV load and production forecast demonstrations were successfully finalized in the field as well as in lab sites, proving that the proposed algorithm works even if its performance may differ depending on the conditions of use. On one hand, the load forecast turned out to be quite accurate and consistent across demonstration sites. On the other hand, the production forecast showed less accurate and consistent solutions, due to the volatility of RESs and their dependence on the weather forecast, thus emphasizing the need for a more advanced and customized algorithm to predict production. Finally, demonstration results showed that, for both load and generation, the algorithm is very consistent in predicting power/energy data over a one-day horizon.

The demonstration of the LV network state estimation proved to be more difficult than expected. Problems in monitoring were frequent, and since the state estimator relies heavily on input measurements, its performance was often affected by issues in the monitoring systems. As learned from demonstrations, a fail-safe backup solution should always be available to overcome potential problems from missing measurements. In the UNR site, fixed load profiles were available for all individual load and generation points through an algorithm designed and developed for this site. Despite several challenges, the LV network state-estimation demonstrations were finalized, and it was proven that the state-estimation algorithm works properly and provides an improved view of the state of the network.

The demonstration results confirm that the proposed and implemented secondary controller for congestion management operates in all the demonstration cases as expected and that no adverse time-domain operation occurs. The same controller is able to operate for MV and LV grids. The results also show that the algorithm is able to enhance grid performance in all the demonstration cases. In general terms, it can be said that the weaker the network and the larger the amount of generation connected to it, the greater the benefits of the secondary controller. The annual benefits of the secondary controller were evaluated and show that the secondary controller is able to both prevent voltage and current congestions and decrease annual network losses. The integration of the MV and LV secondary controllers was also effective and resulted in correct operation interactions. Coordinated time delays of the automatic voltage control relays seem to be an adequate measure to prevent back-and-forth control operations in most of the cases.

The FLISR solution proposed in IDE4L is distributed based on IEC 61850 GOOSE communication between IEDs deployed along the distribution network, on processed local measurements, and on a logic selectivity that depends on the switching technology available at each secondary substation. This kind of implementation has shown to be able to completely isolate faults in fewer than 2 s (with time settings selected for the SCH demonstration site) while reducing the number of customers affected by momentary interruptions. The deployment of circuit breakers along the MV feeders

table 1. Use cases versus demonstrators mapping.

Use Case	TUT	RWTH	SCH	UFD	OST	UNR
MV load and production forecast		X				
MV power control in real-time operation	X	X				
Decentralized FLISR	X		X		X	X
LV load and production forecast	X	X		X	X	X
LV state estimation	X	X		X	X	X
LV power control in real-time operation	X	X				X

allows for a significant reduction in the average interruption duration experienced by customers. Each circuit breaker will further reduce the average interruption duration when decentralized FLISR ensures selectivity. The System Average Interruption Frequency Index and breaker-energized operations also show better results for the IDE4L solution and even are more effective in those cases where the second isolation step is performed for those secondary substations that do not have circuit breakers.

Final Remarks

The IDE4L project has successfully designed, implemented, and demonstrated the concepts of ANM, hierarchical and decentralized automation architecture, and a commercial aggregator to provide flexibility services for grid management. The concept implementations have been validated by successful demonstrations both in integration laboratories and in the field. The same IDE4L automation system was implemented in all field demonstration sites. Results proved it effective in the tested configurations (functionalities chosen by the DSO) and hardware implementations.

The IDE4L concepts and technical solutions extend the monitoring and control of the distribution grid to all voltage levels, increase the distribution-grid hosting capacity for RESs and DERs, and enhance the reliability of the power supply. The improvement of the quality of supply and the management of network outages are based on decentralized FLISR, which, when compared to traditional manual or partly automated solutions, significantly reduces the number of customers experiencing an outage and speeds up supply restoration to other customers. Secondary and tertiary controllers of congestion management are the key components for the increment of distribution grid hosting capacity.

The hierarchical and decentralized automation architecture designed and validated in the IDE4L project is based on existing devices and standard 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 operate in a coordinated manner. 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 total replacement of the existing infrastructure, which would not be feasible.

The IDE4L project has used international information model and interface standards [IEC 61850, DLMS/COSEM (IEC 62056) and CIM (IEC 61970/61968)] for the design of the automation architecture and the implementation of devices and interfaces (FLISR IEDs, SAUs, and PMUs) and all demonstrations. Concepts and implementations have been proved to be interoperable and scalable.

Exploitation Road Map: Moving to Business as Usual

The road map to exploit the IDE4L project outcomes has been divided into five viewpoints: knowledge and attitudes,

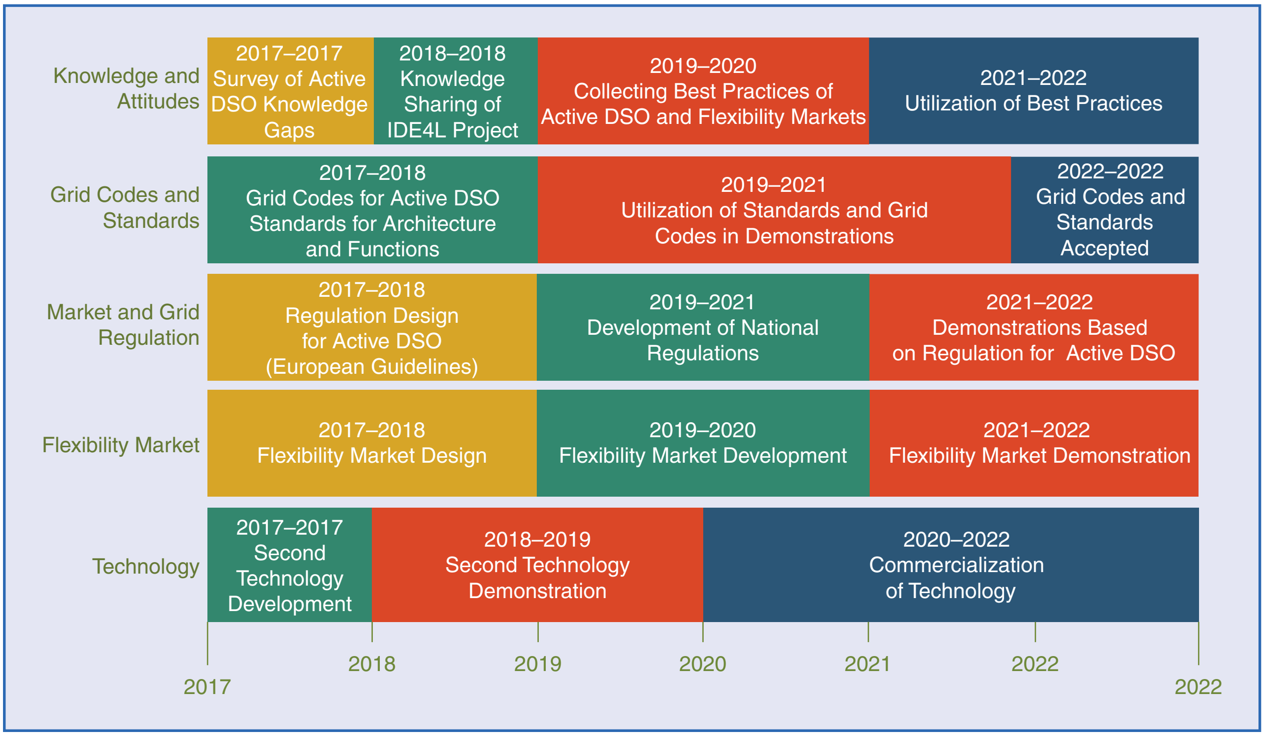

figure 6. A road map to exploit IDE4L outcomes.

The IDE4L project has a strong focus on technology development, and this aspect is probably the most advanced of the selected viewpoints.

grid codes and standards, market and grid regulation, flexibility market, and technology. Figure 6 shows how these viewpoints have been scheduled for the design, development, demonstration, and commercialization phases.

The IDE4L project has a strong focus on technology development, and this aspect is probably the most advanced of the selected viewpoints. However, the experiences collected from the demonstrations should be used to further improve and extend the technology, and, therefore, the second technology development and demonstration phases are required before commercializing the developed technology. The design and development of other viewpoints are also required before a market for all technologies developed in IDE4L project really exists.

The market for flexibility services, which are validated and purchased by DSOs, does not yet exist in Europe. Therefore, the flexibility market has to be designed first in EU member countries and harmonized on the European level. In addition to market design, common agreement on transactions and contracts is needed to create a well-functioning flexibility market, which should be followed by a demonstration phase of several commercial aggregators operating at the DSO domain. The most important issue is to create continuity for profitable business and trust between market stakeholders, otherwise the flexibility market will not have enough players.

A very important aspect for the success of ANM in distribution grids is the modification of grid regulation to allow efficient utilization of DERs for grid management and enable the existence of a flexibility market for DSO use. Otherwise, DSOs will continue developing their grids as passive infrastructures. The design, development, and demonstration of regulation goes hand in hand with the flexibility market.

The modification of grid codes and standards is a long process. Therefore, grid code and standard development should focus on the future requirements of ANM in addition to the urgent needs of existing systems. The IDE4L project used the SGAM for automation architecture development and also provided the description of use cases to be used in the standardization work. The 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 for an active distribution grid.

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

For Further Reading

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