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1. Introduction

IDE4L has been a 3-year demonstration project. At first we defined the concept of active distribution network, then we developed several functionalities that are required to run the network of the future, when the large-scale penetration of renewable distributed generation will be a reality of the distribution networks. The functionalities were tested firstly in real-time-simulation environment and integration laboratories and then in three real demonstration networks.

The IDE4L project goals were:

- improving distribution network monitoring and controllability by introducing hierarchical decentralized automation solution for complete real-time Medium Voltage (MV) and Low Voltage (LV) grid management,
- using existing distribution networks more efficiently and managing fast changing conditions by integrating large number of distributed energy resources in distribution network through real-time automation and market based flexibility services,
- ensuring continuity and quality of electricity supply through a distributed real-time fault location, isolation and supply restoration (FLISR) solution, interoperating with microgrids, and
- improving visibility of distributed energy resources to:
  - TSOs by exchanging consolidated dynamic information from distribution system and
  - commercial aggregators by validating and purchasing flexibility services.

The conceptual development of active distribution network, automation architecture and active network management formed the basis for the whole project.

We have elected to base the implementation of active distribution network on existing technologies and solutions and future requirements. The project has defined, developed and demonstrated the entire system of distribution network automation and functionalities for active network management.

The IDE4L project had 3 field demonstration sites operated by Unareti Spa in Italy, Østkraft Holding A/S in Denmark and Unión Fenosa Distribución, S.A in Spain. The demonstrations validated the architecture, the monitoring, control and protection systems developed in IDE4L. Demonstrations have been proven in real physical grids, with presence of photovoltaic panels, wind turbines, heat pumps and electric vehicles connected to urban and rural networks, as well as actual customers.

Demonstrated functionalities in Distribution System Operator (DSO) environment and implemented in Substation Automation Units (SAU) and Intelligent Electronic Devices (IED) are:

- MV and LV real-time monitoring
- MV and LV state estimation
- Load and production forecast
- Distributed FLISR with a high degree of Distributed Energy Resources (DER) penetration
- Network description update
- Logic selectivity and Protection configuration update
- MV and LV network power control (secondary control of congestion management)
2. Expected Results

The IDE4L project was expected to generate the following exploitable results. Main points are taken from the description of work of IDE4L project and following sub-points highlight the expected results.

1) Active distribution network planning tools will be used in other purposes like forthcoming research projects and further developed to include future smart grid characteristics by universities using them as research tools.

1.1 Planning tools for distribution grid target network planning, expansion planning and operational planning including set of active distribution network functionalities have been implemented and applied for cost-benefit analysis of future scenarios of Unareti MV distribution grid.

1.2 An operational planning tool has been developed specifically for the process. This tool allows to model the flexibility of domestic and non-domestic loads correctly and to obtain the optimal strategy of flexible demand management according with a market price forecast. The tool is flexible to adapt to different regulatory frameworks (to be developed in the next future). An enhanced probabilistic scheduling tool has been also developed, which include the uncertainty of the information that the aggregators will have to face. However, the benefits of this enhanced tool have not been quantised because the lack of reliable data. Both tools are described in [1]. Furthermore, a strategy of using the flexibility for solving congestions in the distribution network has been also developed, and it is described in [2].

1.3 Planning tools will be used and further developed in forthcoming research and consultation projects like national smart grid projects. The implementation of a larger set of active distribution network functionalities need to be continued and enhancement of algorithms for large-scale grid studies. In order to fully understand the benefits and the most relevant locations/sites of active distribution network from grid planning viewpoint, further case studies need to be realized with different type of distribution grids and future scenarios.

1.4 Integration of proposed planning principles and tools for commercial distribution network planning software will require further investigation, simplification of planning processes and tools, and wide acceptance of proposed ideas in DSO domain. This topic is extremely important because otherwise DSOs may not apply active distribution network solutions in wide scale and compare the life cycle costs of active and passive solutions. Planning tasks has to be automated as much as possible and solutions should be available almost immediately. Developed tools are too complex to be used in practical planning tasks because they are aimed for research purposes and therefore a demonstration project focusing on active distribution network planning and required processes and tools would very much be needed.

1.5 Planning tools are a good basis to start exploiting the real-time LV network management. The developments performed in IDE4L have been fully functional and exploitable, and could also help to foster the active distribution network planning in MV network through projects or pilots.

2) The outcomes of IDE4L concept and its benefits may be utilized to impact on regulation of DSO businesses. Practical experiences and proof of concepts are required before realizing these as a standard solution.
2.1 Regulatory aspects have been considered during the project as much as possible. Veli-Pekka Saajo (Director of networks, Energy authority in Finland) has been actively participated in advisory board meetings and provided valuable insight for the project about regulator perspectives. However, many regulatory aspects are in different phase in member states and therefore there does not exist single European regulation which might be followed as a reference in all cases. The most problematic cases were the role of aggregator, market based demand response and balancing practices. Inevitably the mind set of researchers and developers is dominated by their national regulation and practices. Distribution network regulation has also been implemented in many countries in a such way that most DSOs are interested mainly in passive network solutions at the moment. Due to these reasons the existing regulations and practices have been forgotten on purpose during the project in case of flexibility market, aggregator, dynamic locational grid tariffs and distribution network planning. However, the main principles of European regulation like unbundling of retail and network businesses and the main roles and responsibilities of electricity market participants are respected.

2.2 The cost-benefit analysis realized in IDE4L project and in many other projects [D2.3 and D3.3] has clearly shown that active distribution network is more cost effective from societal viewpoint than corresponding passive network. This is very clearly visible for example in occasional network congestion problems where the control of DERs directly and via flexibility market would solve the problem instead of expensive and time consuming network reinforcement actions. Therefore, IDE4L project highlights the need to develop distribution network regulation in such a way that investments in distribution network observability and controllability, i.e. real-time monitoring and congestion management, would become a real alternative for passive network investments. Quality regulation applied in many countries already encourage DSOs to invest in distribution automation to reduce outage frequency and duration. Similar incentive should be developed for other distribution automation functionalities which support societal targets like increment of existing network hosting capacity for Renewable Energy Sources (RES) and energy efficiency solutions like EVs and heat pumps.

2.3 First of all, the proposed active distribution network concept functions as expected, it may be implemented to support MV and LV networks in practice, and it provides additional value for DSOs and society as whole. Proof of concept consists of several demonstrations, laboratory experiments and simulation studies and the final proof is based on overall analysis of realized tests [D2.2].

2.4 The automation concept was developed based on the Use Case methodology and was formalized in the SGAM framework. This formalization is accompanied by the semantic model of the individual components and the detailed interactions between them expressed according to existing standards, in particular the IEC 61850 series. This work has yielded an abstract representation of the automation architecture to realize the active distribution network concept. The various levels of details and the use of the standards allow for a ready application of this architecture in different distribution networks, by different business actors, and with different power and computational capacities. The IDE4L architecture has been used both in lab and field demonstrations, thus proving its feasibility. The performance was quantified via indicators that show scalability and technical and economic return.

2.5 Within IDE4L project the feasibility and the technical viability of the aggregator and its interaction with DSO and the markets has been shown. Regulatory and technical issues have been analyzed and the aggregator has been defined taking into account the conclusions of theses analysis [D6.1]. Moreover, the technical viability has been tested by implementing and emulating the optimal
management and technical control of distribution networks involving the participation of DERs (including microgrids), aggregators and DSOs [D6.3].

2.6 Practical experiences

The IDE4L project has allowed Unareti to gain practical experience on several innovative aspects of smart grids. Firstly, we have had the possibility to develop and/or strengthen our internal knowledge and skills on innovative functions for the congestion management of MV and LV networks with the aim of handling extreme network conditions. We have indeed integrated and tested into our demo site a set of new algorithms that is load and production forecast, state estimation and power control. Additionally, to this, we have also focused on automatic fault location, isolation and supply restoration functionalities, both working on their design and development, as well as their integration into the demo field and testing. To this end, we have strengthen our theoretical expertise on all these methods, while also developing practical skills on all the aspects associated with their design, integration and everyday usage such as data modelling, data management, smart metering, congestion management algorithms and protections installation, configuration, monitoring and maintenance, etc. The practical experience gained in the project will be essential to the development of our distribution grid and will definitely speed up its innovation process.

In the case of UFD, IDE4L project has allowed us to have a fully monitored LV area with real consumptions, with real-time information. The previous situation was having different monitoring systems for different parts of the demo: a SCADA for DER and meteorological station based on MODBUS, and smart meters which use DLMS/COSEM protocol and which were monitored once a day just for billing purposes. The integration of these systems has been possible with the deployment of the Substation Automation Unit in our demo, achieving a monitored environment based on the standard IEC 61850. Besides, the whole environment has been improved by the execution of algorithms such us load and production forecast and state estimation, performing an advanced observability that will be exploited in other projects.

2.7 Within IDE4L project, Power Line Communication (PLC) in electrical distribution networks is going to be thoroughly analysed and tested, so IDE4L will contribute to the maturity of the technology and its use in DSOs for LV networks. By shortening the time needed to achieve a maturity level of PLC technology, IDE4L will contribute to make this technology more robust, more reliable and more easily adopted by DSOs from both perspectives: technically and economically.

Smart metering systems of UFD and Unareti described in the previous paragraph have been based on PLC technology.

3) Vertical integration of distribution automation equipment in MV and LV networks using IEC 61850 will be exploited in the products and integration projects of distribution automation vendors. This result will also be exploited globally via standardization activities.

3.1 Substation automation standard IEC 61850 has a central role in the automation architecture developed in the IDE4L project. IEC 61850 is utilized both the information exchange between substation automation unit and other components (e.g. IEDs, other substation automation units and distribution management system) and the data modelling within substation automation while storing and publishing data for functions and reports. The proposed automation architecture, developed substation automation unit and especially the way how IEC 61850 has been utilized may
serve as a reference for commercialization of advanced solutions for substation and secondary substation automation.

3.2 The use of IEC 61850 applied to protection functions in medium voltage networks together with logic selectivity functionalities are far from a real deployment. Unareti’s medium voltage demonstration site is one of the first operating environment where the concept is tested. Real demonstration has allowed us to corroborate that the adoption of the IEC 61850 for IDE4L FLISR makes it easily to integrate in existing solutions in EU networks and to operate together with other third-parties IEC 61850 IEDs and functionalities.

3.3 Several manufactures of distribution automation have contacted to commercialize substation automation unit. These will be conducted as industry funded development projects.

3.4 As a collateral, external activity of IDE4L, the Cloud-based Substation Automation Unit (SAU) was developed and its functionalities for real-time low voltage monitoring implemented and tested in the FIWARE framework. The preliminary results show that, even with current expected performance of cloud platforms and communications, the cloud-based SAU can fulfill the operational requirements. These results open the way to the deployment of the IDE4L architecture with huge savings on the deployment of new hardware. In a broader perspective, this may also facilitate a service based operation of the distribution grid and the new businesses.

3.5 DSO knowledge to utilize IEC 61850, DLMS/COSEM and CIM for MV and LV automation

Unareti is working on the investigation and test of new technologies and solutions with the aim of increasing its knowledge, the performance of its distribution system and the quality of services provided to its customers.

Within IDE4L, Unareti has had the opportunity to improve its expertise on several standards that are becoming the reference points for modelling, control and metering in modern smart distribution systems. In particular, in the project, we have used the following standards:

- **IEC61850**: it is becoming the reference data-model and protocol for the control, monitoring and protection of Unareti grids. The experience gained within the project has allowed Unareti to identify the standard architectures for the monitoring and control of future primary substations and of medium voltage distribution networks in which a key role is played by IEC61850 MMS protocol and data-model. GOOSE protocol and logic selectivity represent the best practice for Unareti in order to increase the quality of the service for its customers by decreasing the outage time in case of faults in MV feeders;

- **CIM model**: it has been used in the SAU database to model the grid for the execution of IDE4L algorithms and is used in internal projects to redesign the asset management system data-model based on the main types and parameters defined by the standard;

- **DLMS/COSEM**: it is becoming the reference data-model and protocol for the future metering systems. Performances and capability of this standard are pushing Unareti and other European DSOs to consider the smart meter as a low voltage and low cost sensor. The data provided by the smart meters in the IDE4L demonstrations proved that it is possible to increase the observability, and thus the controllability, of the low voltage grids, hence satisfying the requirements coming from the high penetration of DERs.

Unareti believes in the standards application as a way to simplify and improve its performances in terms of processes simplification and technological enhancement. For this reason, it is engineering and re-utilizing the IDE4L experience for its standard applications.
In the case of UFD, the previous experience with standard IEC61850 has been only at HV level, mainly in substations. The use of a standard protocol to integrate different systems at LV has been very rewarding. The monitoring and data collection in our demo have two different sources:
- MODBUS for generation and meteorological station
- DLMS/COSEM for smart meters
Both different data models have been translated to IEC61850 data model based on logical nodes, with a proper correspondence of every parameter. CIM model has been also used to model the topology of the demo site, which was only modelled using PSS-E.
Both conversions to standard models have been useful for the potential exploitation of the demo site for other pilots and projects, which was not possible without an integration of the information and the codification of the information in common standards.
With this experience, UFD is deploying this year 30 reclosers with standard 61850 as a wider pilot in the region of Segovia. If the experience is successful, UFD may initialize the road to merge to 61850 in the MV grid, mainly in reclosers and pass fault indicators.

3.6 Feeder automation functionalities are not currently included in the approved parts of the IEC 61850 standard, although some efforts are being performed. Missing functionalities have been identified and proposed through the National Standardization Committee for IEC TR 62689-100: Requirements and proposals for IEC 61850 data model extensions to support Fault Passage Indicators applications.

4) The RWTH researchers own a patent for dynamic synchrophasor measurement that will be tested thoroughly in this project, so validated under various operating conditions and distribution network characteristics reflecting diverse situations in Europe. The architecture will be fit for integration of these dynamic synchrophasors. The patent may then be sold for commercial applications in this framework.

4.1 Commercialization of dynamic synchrophasor measurement application was not in the scope of the project.

5) The work carried out in WP3 will determine the limitations of current Phasor Measurement Units (PMU) commercially available. This will help in determining which are the technical requirements for a distribution level PMU that can be used for delivering fast real time data in the use of different monitoring, control and protection applications. KTH then plans to utilize these results for further development of specifications and prototyping of PMUs for distribution networks.

5.1 Different time sources and time distribution methods have been investigated and compared for their usability as time sources for PMU time synchronization. Timing requirements of various commercial PMUs were tested by means of real-time hardware-in-the-loop tests. The results were published in [3]. As result of this work, a hardware-in-the-loop laboratory test set-up was developed to assess the time synchronization requirements of Phasor Measurement Units. Details can be found in [4].
6) In WP6, one of the tasks will be to determine the feasibility and to test if transmission of synchrophasor data is achievable in practice using IEC 61850 and what the limitations are. It will also explore if the use of IEC 61850 can have other benefits over other standard protocols (IEEE C37.118.2). These results will be used by KTH to develop applications that use PMUs at the distribution level which meet requirements for data transmission through standard protocols.

6.1 A library functioning as an IEEE C37.118.2-IEC 61850-90-5 gateway was developed with the IDE4L project. The source code was implemented based on standard C libraries (i.e. independent from any operating system). This way, the library can be used in different platforms, in particular on embedded systems with minimum hardware requirements, enabling fast cyclic transfer of synchrophasor streams over wide-area networks, thereby minimizing latencies in real-time applications. The library is designed, implemented and validated to

1) Receive and parse synchrophasor data originating from a PMU or Phasor Data Concentrator (PDC) using the familiar IEEE C37.118 protocol,
2) Map it to the IEC61850 data model and
3) Transmit the synchrophasor data through either Routed-Sampled Value or Routed-GOOSE services defined in the IEC 61850-90-5.

In addition to the IEEE C37.118.2-IEC 61850-90-5 gateway functionality, the library is capable of acting as the receiver and parser of IEC 61850-90-5 messages (i.e. Routed-Sampled Value and Routed-GOOSE), extracting raw synchrophasor data and feeding it to subscriber applications. The functionality of the library has been validated in a real-time hardware-in-the-Loop (RTHIL) simulation environment to assess its conformance to the functional requirements of the IEC 61850-90-5 standard. The results were published in [5].

7) Integration of aggregator to DSO IT-systems and extension of market based Demand Response (DR) to be used by DSO will set a new framework for active network management. The expected results will be conclusions such as how the DR market should be build up and integrated to be accessible by a DSO. Results will be exploited by early adapters: DSOs and IT-system providers.

7.1 DSO does not control active power of DERs directly during normal conditions, but utilize them via flexibility market. Flexibility market may include different markets like day-ahead and intra-hour markets and products like scheduled and conditional reprofiling. Flexibility market is common for all market participants. This will enhance the utilization of flexibility resources, enhance competition especially on local DSO level, and will enable the coordination of conflict of interest much easier than separate markets.

7.2 DSO will also validate all flexibility requests, done by different market participants, from flexibility market which are connected to DSO’s network. In case of DSO level congestion, real data from Unareti MV and LV networks as well as realistic customer’s data has been used to build up different scenarios. These scenarios have been used to test how the flexibility sources are exploited to answer the needs of the DSO. It has been demonstrated that energy storage systems are a good means to accommodate additional Photo Voltage (PV) power into the system and avoiding related congestion at the same time. It has also been demonstrated how “pass-through” methodologies can be improved including real-time measurements from smart meters as feedback for the algorithm. From DSO’s standpoint, congestions consisting of MV branch thermal overloads have been eliminated via flexibility activation. In these tests, positive side-effects of power curtailment are also voltage level improvements in locations close to the nodes where power is curtailed.
7.3 Aggregator contracts, collects information and controls DERs. Aggregator should also be balance responsible party in order to respect existing balancing practices. Otherwise he need to inform balance responsible parties about reprofiling actions well before market closures.

7.4 The automation system of aggregator has not been in the focus of IDE4L project. However, we see that some kind of local automation system for homes, buildings, commercial services and industry is needed to collect information for aggregator, and make local decisions based on requested services. These systems are typically called in generally energy management systems.

7.5 DSO’s congestion management is based on hierarchical and decentralized automation solution. Hierarchical system consists of three layers called primary, secondary and tertiary controllers. The most real-time controller is the primary controller which typically are Intelligent Electronic Devices (IED) like automatic voltage controller of On-load Tap Changer (OLTC), protection relay or thermostat in case of aggregator resources. Secondary controller coordinates primary controllers at specified control area. The aim of secondary controller is to minimize operational costs of control area in near real-time and to restore system within control limits if primary controllers are not able to realise it or are not aware of such problem. Typical control areas are MV and LV grids and therefore the locations of secondary controllers are primary and secondary substations. Tertiary controller operates in control centre in day-ahead and intra-day phases, reconfigure MV network while considering capabilities of secondary controllers, and interact with flexibility market to validate and purchase flexibility services.

7.6 UC3M has developed a tertiary controller for solving congestion problems which appears on DSO networks. The control tool integrates two main functionalities: a network reconfiguration tool and a market DSO tool. The market tool helps the DSO to manage the flexibility of domestic and non domestic loads according with market prices. The functionality of the market tool has been tested by simulations where different congestion network situations have been analysed and solved. The network reconfiguration tool tries to find the optimal network topology whenever a congestion problem appears in the network. This tertiary controller is able to find also the optimal set points of the DER units directly controlled by the DSO. The tool can be executed both during real time operation and also for day-ahead operation (24-hour day ahead) and it interchanges information with commercial aggregator, market services, real time monitoring services, and forecast tools (load demand and renewable generation) for day-ahead operation.

7.7 At DTU, the dynamic tariff concept has been further developed to motive end-users through aggregators to provide demand side flexibility. The dynamic tariff can mitigate possible day-ahead congestions in distribution networks. The dynamic tariff is combined with distribution network reconfiguration to alleviate congestion and minimize losses. Sensitivity analyses were conducted to deal with the uncertainties of flexible demands. The dynamic tariff concept can be integrated into the control room to alleviate congestions and minimize losses under uncertainties.

7.8 TUT has developed optimization based secondary controller (power control algorithm) and implemented it for SAU. Algorithm utilizes the outputs of state estimation algorithm, which is also developed and implemented by TUT for SAU. According to the architecture of SAU, secondary controller is not itself sending control commands to primary controllers, but interfaces of specified IEDs are utilized. IDE4L project has utilized only commercial primary controllers (IEDs).

8) Telvent will enhance the algorithms of automatic FLISR, state estimation and congestion management by utilizing the methodologies developed in the project. Telvent has the intention to exploit the results with an international vision. Moreover, the presence of Telvent in the US market
and in Latin America can be an excellent opportunity for European companies to become leaders of this new field. Due to Telvent international presence and its leadership in the sector, the exploitation of the project result is guaranteed and the end users will have the privilege to access these technologies in preferable conditions.

8.1 Decentralized FLISR solution based in IEC 61850 and integrating PLC logic control blocks for DER coordination, breakers and switch controllers interactions has been implemented. The solution has been presented by Schneider-Electric in the International Standardization Committee meeting in China, in June 2016. The feedback provided has been very positive. SC will introduce in the coming IEC 61850-90-6 what is needed to support IDE4L Use Case.

8.2 Online remote configuration function has been integrated in the firmware of the IEDs used for the FLISR solution deployment. This feature allows remote reconfiguration of IEDs when the network topology changes, thus favouring FLISR solution to continue working after congestion management or power service restoration algorithms are applied.

8.3 As part of the tests on the FLISR algorithms, their performance has been analysed under stochastic conditions such as the statistical nature of fault location and malfunction of switching devices and communication channels. In order to do so, a new event-based simulation model has been developed by UC3M on OMNeT++.

9) The study of PLC signal to detect perturbations in the cables could be of great use as many DSOs like Unareti and UFD are using PLC signals in its Smart Metering system and communication in secondary substations.

9.1 An analysis has been provided on the impact of DC/AC power converters (typically used to interface RES with the grid) on the quality of Power Line Communication (PLC) signals sent through cables and lines.

10) The paradigm shift towards Smart Grids also requires a tighter integration of the operation of transmission grids (HV) with distribution grids (MV and LV). Coupling the use of PMU data from both the HV grid and MV and LV grids (but specially HV grid) coherently with advanced communication protocols can allow for a tighter interaction between transmission and distribution.

10.1 Advanced PMU-based monitoring applications were developed to extract key information out of the active distribution networks. The information is intended to be sent to TSOs to be used in their grid management functions. The work has been conducted at KTH SmarTS Lab where all applications have been developed, implemented and tested using real-time hardware-in-the-loop simulation.

11) RTDS simulation environment for general purpose smart distribution grid testing will be available for university research after the project.

11.1 AT KTH SmarTS-Lab, a laboratory setup was designed and developed to assess time synchronization requirements of PMU which will be used to test commercial products. In addition, the reference active distribution grid model, developed within the IDE4L project for grid dynamic studies, will be available for future research work [6]. In addition, it will be incorporated as ARTEMIS demo in RT-LAB Real-Time Suite to be available to all users of OPAL-RT simulator.

11.2 Also, the IEC61850-90-5 gateway and parser are fully integrated in the real-time hardware-in-the-loop simulation setup at KTH SmarTS-Lab.
11.3 At DTU, the real time emulation setup was established with a real time digital simulator (RTDS), the MatrikonOPC communication protocol gateway server and two computers emulating a DSO and two aggregators.

11.4 TUT RTDS laboratory includes commercial automation devices (smart meters, Remote terminal units (RTU), primary controllers for OLTC and DG unit, and FLISR IEDs) connected as hardware-in-the-loop and SAU prototype connected as software-in-the-loop. Information exchange between automation devices and SAU is based on IEC 61850 MMS, IEC 61850 GOOSE and DLMS/COSEM. Automation devices are connected to RTDS by utilizing analog signals through signal amplifier or self-designed signal adapters, or by utilizing digital signals for control commands and IEC 61850 sampled values for measurements. Self-designed current signal amplifiers were also designed for 5 ampere input of FLISR IEDs. In addition to those, external information is transferred directly between SAU and RTDS by utilizing socket TCP interface of RTDS. The laboratory environment will be further utilized and developed in future research projects to include new elements like use cases, automation devices, SAU implementations, communication emulator, cyber security features, and power-hardware-in-the-loop simulations.

11.5 IDE4L automation architecture has been tested, as dictated by WP7, in RWTH laboratory exploiting the RTDS to simulate in real time the MV and LV grid of Unareti. The use cases demonstrated are MV and LV State Estimation as well as power control. The results permitted to test the use cases under stress situation (computation and communication) that were hardly achievable in the field.

12) The controller for transition from grid connected to island mode might be utilized in countries like Spain where island operation is permitted to enhance distribution network reliability and to avoid disconnecting DG units in the part of non affected network. That means that such island, will guaranty the power quality and balance demand with generation. The DSO could use the controller in locations where there is storage or DER, and such devices can be controlled based on the developed controller connected at the PCC.

12.1 An Interconnection Switch (IS) and its controller have been implemented and tested in IREC Smart Energy Lab. More information in 13.1.

13) Beyond the scope of IDE4L project, other possibilities would be to explore such control prototype in real networks, for example part of distribution grid with renewable penetration and Distributed Generation (DG). In any case, IREC provides the capability of testing such device under different conditions of the network, so reproducing different scenarios before such devices is placed in real network. In such case IREC could contact a company, if there is not any within the consortium to license the design with control routines and to manufacture it for the exploitation.

13.1 An Interconnection Switch (IS) and its controller have been implemented and tested in IREC Smart Energy Lab. Voltages and frequencies are continuously monitored in both sides of the IS, so it is able to hold open when necessary, isolating part of the grid so that the voltage is not synchronized with the bulk network power supply. Additionally, the islanded part of the grid is able to reconnect to the bulk network when the synchronization conditions are achieved.

The setup in IREC included a synchronous generator as islanded part of the grid and two use cases where tested: “fault detection” and “Protection using Communication Commands”. The aim of the fault detection test was to show the capability of the IS to detect a grid fault in the form of loss of synchronization and, automatically, isolate the microgrid within the required time without requiring any IEC 61850 command. On the other hand, the main goal of the “Protection using Communication...
Commands’ test was to verify the capacity to remotely manoeuvre the islanded part of the grid to fulfil the needs of the grid operator via reception of IEC 61850 commands from FLISR.

14) Industrial implementation of developed solutions is based on commercial decisions of DSOs and manufactures. The aim of DSOs is the development of an exploitation plan, including an economic evaluation of the developed concept and the most promising and suitable solutions designed and tested in IDE4L project, mainly regarding their reliability, scalability and interoperability. For example the results on FLISR can be applied in order to improve the results on continuity of supply in development projects focused on that area. The objective of DSOs is to increase distribution network observability (and hence, improve the visibility of DERs), so the results regarding this field can be highly valuable to enhance MV and LV monitoring system. The other solutions developed during the project may be exploited similarly in the development projects of DSOs to fulfil future needs.

14.1 Telvent hardware and software developments for IDE4L project have proven its efficiency to cover DSO needs in terms of reliability, scalability and interoperability for the deployment of decentralized automation functionalities based on IEC 61850 GOOSE and MMS communications.

14.2 DSO view: exploitation plan
Unareti strongly believes in distribution network automation and it has basically doubled its investments in the next 5 years for monitoring, control and protection of MV equipment. The test done during the IDE4L project make the business case more ‘solid’. The feature of remote reconfigure the protection device when the network topology changes allow for a maximization of the investment, since the protection system can be used not only in the standard configuration, but even after a fault. We expect to buy IEDs like those tested during the project.

In addition to FLISR and MV monitoring functions, Unareti’s exploitation plan extends also to congestion management tools proposed with IDE4L project. The Italian Authority is now asking DSO to test forecast algorithms to foresee – on the short and medium term – the distributed generation on the MV and LV levels. We expect that this feature will be made mandatory in the next regulatory period. For this reason the experience done during the IDE4L project turned out to be very profitable. Moreover, we are also evaluating to extend the use of the production forecast in other primary substations.

As for state estimation and power control algorithms, Unareti is currently in a tender phase for a Distribution Management System including those type of tools, so we will use the knowledge and the results obtained during the project to select the best product.

Finally, as for standards, standards like 61850 and the CIM are becoming more and more a core part of our business. We are currently redesigning the data model for our Asset Management System and the new one will be based on the CIM standard (to be completed by Dec. 2016). We recently released (May 2016) the technical specification for the primary substation automation systems and those specification mandates the fully compliance with the 61850.

In the case of UFD, there is a high interest in the testing of automated distribution network solutions. The experience gained in IDE4L project has allowed a full monitored environment in LV level, which would not have been possible without the solutions. Currently, the LV level of monitoring is not very high, so these kind of solutions has given us the experience to analyze the functionalities applicable to LV and the interest to continue testing similar solutions in a pilot environment. However, a massive deployment of these LV solutions is far by the moment; it will depend mostly on regulatory issues.
15) The project is expected to result in the development of new algorithms to be integrated in equipment and software that will be commercially exploited, either as an individual product or as a part of a solution for grid automation. The utilization of algorithms in commercial products may be realized by project partners or other companies when e.g. patents or licenses are sold to them.

15.1 FLISR specific solution has been tested as proof of concept by using PLC logic based on IEC 61131-3 standard showing the validity of the architecture and logic design. This implementation will become a specific, optimized and customized firmware controller customized under DSO request.

15.2 The concept and definition of Substation Automation Unit (SAU) is available for further development and commercialization. The central part of SAU is the database schema which will be published under the GPLv3 license. Similarly, the implementations of MMS and DLMS clients have been based on open source libraries libIEC61850 and GXDLMSDirector. Exploitation of SAU applications has been commented in other parts of the deliverable.

15.3 The IDE4L reference active distribution system, which was developed at KTH SmarTS Lab, is already published and is publically accessible under the terms of the GNU Public License version 3 (GPLv3) on a designated github repository at https://github.com/SmarTS-Lab. In addition, all applications, developed at KTH SmarTS Lab in order to extract key information of distribution networks out of the dynamic measurements (time series) of PMUs, will be accessible publicly under the terms of the GPLv3 license on the same repository within 5 years of the end of the project.

15.4 The network reconfiguration tool developed in the tertiary controller has been tested under different sceneries considering also the voltage regulation capabilities of the MV controllable units. The developed algorithm has been submitted to the Spanish Patent and Trademark Office for the application of the License software registration.

16) The experiences of the project will provide an edge for future collaborations of universities with industry, in particular with reference to the public-private partnership for innovation.

16.1 Cooperation with sister projects (evolvDSO, Dream and INCREASE), financed from the same EU FP7 call as IDE4L project, has been realized according to description of work.

16.2 Cooperation with following national projects has been realized: Unareti’s national projects, SGEM - Smart Grid and Energy Market program (TUT, finalized), FLEXe – Flexible Energy Systems (TUT, finalized), Social Energy – Prosumer Centric Energy Ecosystem (TUT, ongoing), SAU as a cloud service (RWTH, ongoing), SEMIOTIC: Semantic IoT Data Integration and its use in the energy management of Smart Grids and Smart Cities (IREC).

16.3 IDE4L project have had a contribution to following international project proposals: SABINA SmArt Bi-directional multi eNergy gAteway (IREC+SCH, EU grand approved), Synchronphasor based holistic and interoperable analytics controls and protection for smart grid (KTH and TUT, submitted), Grid Enabled Flexible Ecosystems for Future Energy Markets (TUT, not accepted), etc.

16.4 IDE4L project have had a contribution to following national project proposals: Åland demo platform (TUT, not accepted), Voltage regulation at medium voltage networks (DE and TUT, submitted), Distributed management of electricity system (TUT, submitted), etc.

16.5 Future project ideas by all universities: Proposal for project on the exploitation of dynamic tariffs in ERA-Net project (RWTH+DTU) etc.
17) “Forschungscampus – Electrical Networks of the Future” at RWTH and “Smart grid and energy market” program at Finland are examples of such initiatives. The unique competences accumulated from the IDE4L experience, particularly with reference to future architecture and algorithms, are expected to draw private partners in the sector. Therefore, contacts to additional industrial partners are also one way to exploit the results of the project. Also acquisition of real world detailed case studies with actual data that will be available for future research providing an edge for further research projects.

17.1 IDE4L project automation use cases were exploited by the project “IDE4L to cloud” of Forschungscampus framework. In particular, the monitoring use case was tested for operation into the cloud, in order to improve the total investment and the robustness of the architecture.
3. Main results of IDE4L

In IDE4L project we identified 78 exploitable results what we have developed in project. There are several results what will increase general advancement of knowledge in EU level, but we also find out the results what will be commercially exploited to EU markets soon. In some countries there are limitations in regulation what need to be changed before developed issues can be taking to use in all EU countries. We have also effected to standardisation that the developed issues can be taken to use.

The main exploitable results from IDE4L project are:

- Decentralized IEC61850 FLISR Solution
- SAU device
- Database (CIM/61850)
- SAU applications
- DMS applications: Tertiary controller of congestion management
- PMU applications
- Commercial aggregator interactions

Main exploitable results are described in Ideal Grid for All – IDE4L final result brochure, which is in Annex 1.

As the result of IDE4L project there are also commercial products and licenses coming.

- **Commercial products**
  - FLISR: Schneider Electric Saitel DR hardware platform has proven its efficiency for the deployment of decentralized automation functionalities based on IEC 61850 GOOSE and MMS communications. IDE4L field demonstration deployment and FLISR performance will be used as reference for the commercial promotion of Saitel DR Platform and its IEC 61850 brick.

  After following the internal processes for software release of the IEC 61850 version that has been created for IDE4L, it is expected to be available in the market in December 2016 (TRL-9).

  FLISR specific solution has been tested as proof of concept by using PLC logic based on IEC 61131-3 standard showing the validity of the architecture and logic design (TRL-7). This implementation will be transferred to a specific and customized firmware controller.

  Being able to deploy IDE4L FLISR Solution in four different demo sites with different electrical conditions, hardware and software requirements has proven the versatility of the design to be adapted to operate on different environment while fulfilling customer needs. Just with minor changes in the databases and automatisms were required. Thus, the solution will be promoted as project specific, which entails as benefits, flexibility and optimal integration.
Deliverable 1.2 Plan for the use and dissemination of foreground

- **Licenses**
  - The network reconfiguration software developed by UC3M researches has been submitted to the Spanish Patent and Trademark Office for the application of the License software registration.
  - Active Distribution Grid Model for Real-Time Simulation compatible Opal-RT model is released to the public under the GPLv3 license: [https://github.com/SmarT-S-Lab/FP7-IDE4L-KTHSmarTSLab-ADN-RTModel](https://github.com/SmarT-S-Lab/FP7-IDE4L-KTHSmarTSLab-ADN-RTModel)
  - Substation Automation Unit database schema will be published under the GPLv3 license.
4. Outcomes of IDE4L

The project was expected to generate the following outcomes (Expected outcomes from DoW and realized outcomes in the column of right):  

<table>
<thead>
<tr>
<th>IDE4L objectives</th>
<th>Expected IDE4L outcomes</th>
<th>Realized outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Develop and validate methodologies and tools to enable DSOs to take on new roles and evolve existing roles required by the DERs connected to distribution networks.</strong></td>
<td>IDE4L concept and roadmap</td>
<td>The project has defined three concepts: Active network management (ANM) (D2.1), Automation (D3.1) and Commercial aggregator (D6.1). The ANM concept is the general framework for a DSO to design and operate distribution network as an active network. Automation concept describe in more detail the hierarchical and distributed architecture for the automation of active distribution network. The concept of commercial aggregator further expands the utilization of DERs for ANM by validating all flexibility services from DSO’s service area, and by purchasing flexibility services from flexibility service market. The roadmap for ANM has been described from several viewpoints: knowledge gaps, grid codes and standards, regulation, flexibility market and technology. The aim of the roadmap is to describe what needs to be changed or further develop in order to move from trial phase of ANM to business as usual.</td>
</tr>
<tr>
<td>IDE4L concept and roadmap will be constructed based on DSOs use case requirements and project outcomes.</td>
<td>IDE4L concept and roadmap</td>
<td>Planning tools to design active distribution network and to evaluate costs and benefits of developed concept and technical solutions.</td>
</tr>
<tr>
<td>Target network planning tools are developed to design active distribution networks including functionalities of active network management developed in the project.</td>
<td>Planning tools for target network planning, grid expansion and operational planning in the context of active distribution network are developed in the project. These planning tools include functionalities of active distribution network in addition to traditional passive solutions to reinforce the grid or postpone grid investments. A case study of cost-benefit analysis of future scenarios of Unareti’s MV distribution grid has been realized. Single study case however is not enough to generalize the findings. The outcome is the cost-benefit analysis methodology instead of general knowledge about circumstances and networks where developed solutions are profitable compared to traditional passive network. Profitability is also strongly dependent on distribution grid regulation.</td>
<td></td>
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</table>
Entire system of distribution network automation, IT systems and applications will be defined, developed and demonstrated.

| Automation architecture to manage fast changing conditions and integrate large number of DG and DR. | The SmartGrid Architecture model (SGAM) architecture, was developed based on use cases, which describe the automation functionalities required in smart grids managed by modern DSOs. Such architecture has been linked with the laboratory and field demonstration through information and communication standards, off the shelf devices and open source software in order to allow a straight implementation in the future EU distribution grids. |

**Observing and balancing of variable renewable generation and loads with decentralized flexible generation, active demand and local storage.**

Developed automation system will extend monitoring and control functions deep in the distribution network.

| IDE4L automation architecture | Monitoring and control functionalities have been enhanced through the Substation Automation Unit (SAU) which performed advanced functions such as state estimation, forecast and optimal power flow at substation level. In this way the computation and communication burden of the Distribution Management System (DMS) is easier and the overall robustness of the system is improved. Moreover, the commercial aggregator permits distributed energy resources managers in distribution grid to participate to grid flexibility services. In this way the electrical market benefits are expanded to distribution actors. |

Distribution state estimation algorithm utilizing near real time measurement data from MV and LV networks will be developed to estimate fast changing network conditions, to estimate network conditions more accurately when measurements are missing or network data is incorrect, and to estimate status of MV and LV networks.

| Function will be implemented in control centre and secondary substation levels. | State Estimation (SE) algorithm has been developed and tested in laboratory environments as well as through fields demonstrations. The algorithm is utilizing near real time measurement data from MV and LV networks and estimates fast changing network conditions. The algorithm also estimates network conditions more accurately when measurements are missing or network data is incorrect. The output of the algorithm is a set of network states (V, I, P, Q) and used by the power controller to estimate the state of the network. Load and production forecasters are two other algorithms that also base developed in WP5. The output of the two algorithms is to provide an input for the State Estimator developed in WP5. |

Functions for the congestion management of MV and LV networks are defined and developed to handle extreme network conditions.

| Function will be implemented in control centre and secondary substation levels. | Functions for congestion management have been defined, developed and tested. The developed functions in WP5 for congestion management are:

1. Secondary Power Control algorithm (PC) to be installed at secondary transformers (LV + MV) and on control center. The PC used input date from the SE.
2. Tertiary Controller (TC). The TC is installed at control center level and includes six algorithms. |
<table>
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<tr>
<th>A study of the boundary conditions will be done and microgrid aggregator’s business models will be evaluated as well, contemplating the maximum exploitation of available resources and infrastructure and the feasibility of their participation into the ancillary services provision.</th>
<th>Optimal management algorithms will be defined from the microgrid aggregator point of view.</th>
<th>The algorithms for the optimal management of the aggregator have been defined and implemented. Business models have been simulated and the foreseen benefits have been analyzed. The feasibility of the participation into the ancillary services has been evaluated through IREC Smart Energy Lab demonstrations.</th>
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<tr>
<td>Network Reconfiguration Algorithm (NRA). Market Agent (MA) Dynamic Tariff (DT), Load &amp; Production forecasters and State Estimation algorithm.</td>
<td>The NRA changes the topology of the MV distribution network to eliminate congestion. The NRA also functions as a slow restoration functionality that supports the FLISER system in case not all costumers can be resupplied by the FLISER system. The DT algorithm forecasts the market price and sends a new dynamic tariff to all retailers in the network to eliminate predicted congestions. The MA algorithm is responsible for the communication between the DSO and the flexibility market. The algorithm functions in such a way that it receives a signal from the NRA in case the NRA cannot entirely solve a congestion. The MA then communicates with the flexibility market to purchase flexibility to eliminate that congestion. Not all algorithms were tested through field demonstrations. Some of the developed algorithms were in RTDS labs and others have been tested on filed demonstrations.</td>
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<tr>
<td>Network operations and grid maintenance will need to be upgraded.</td>
<td>The communication infrastructure has to be enhanced and better distributed to substation environment as well as to flexibility services providers. The requirements for communication have been specified through use cases in IDE4L. The growing presence of DERs and the objective of constantly increasing the quality of the service provided to...</td>
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### IDE4L Deliverable 1.2 Plan for the use and dissemination of foreground

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<tr>
<th>DERs are integrated to network.</th>
<th>including significant amount of DG.</th>
<th>final customers is mandating to evolve the way the distribution network is presently operated. For example, the monitoring of the LV network is becoming an essential part of the DSO’s activity, and smart meters have to play the role of the” sensors” beside to provide billing features only. According to that, the amount of data to be collected will increase exponentially and new paradigm for the network monitoring will emerges. IDE4L is testing those new models both in labs and in real operating environments to prove their viability before moving to the roll-out stage.</th>
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<tbody>
<tr>
<td>Automatic fault location, isolation and supply restoration (FLISR) algorithm will be developed and demonstrated to improve the reliability of distribution network.</td>
<td>Enhanced FLISR algorithm to take into account effects of DG and to utilize DERs in supply restoration.</td>
<td>FLISR algorithm reduces the number of customers affected by faults in the same time of traditional solutions, thus reducing considerably the loss of load. Additionally, it integrates a backup selectivity to make solution more robust and reliable. In case of DER connected to MV lines, FLISR decentralized IEDs will integrate actions to command their connection and disconnection from the grid in order to minimize their effect in case of faults. Event-based simulation model developed on OMNeT++ that includes electrical components and communication events. Satisfactory tests of the FLISR algorithms under conditions that include random malfunctions in switching devices and communication channels.</td>
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Further roles include short- and long-term forecasting and long-term planning.

| Day ahead and intraday planning of active network requires short-term forecasts of load and production. IDE4L project will utilize short-term forecasts in congestion management and microgrid energy management. | Comparison of developed functions with and without forecasts. | In the IDE4L project, forecasting algorithms have been developed and utilized to provide inputs to all the controllers located at all voltage levels. The forecaster outputs play a crucial role in the accuracy of the power controllers, therefore they are one of the important elements of the congestion management system. Forecasting allows predictive measures – i.e. adjustment of the dynamic tariff in the Day-Ahead market clearing and trading with commercial aggregators – and thereby enable to DSO to prepare for potential congestions in the long term planning. Forecasts are also important for active power control. If grid measurements are unavailable, pseudo-measurements from the short-term forecasted load and production are used as |

IDE4L is a project co-funded by the European Commission
IDE4L is a project co-funded by the European Commission

| IDE4L automation concept is based on standard protocols like IEC 61850. Data exchange based on standardized messages is an essential requirement of DSOs to develop automation and IT systems for smart grid. | IDE4L automation architecture | In order to improve integration of heterogeneous automation actors as well as different automation systems, IDE4L proposed a mapping of the information stored and exchanged onto smart grid communication standards such as IEC 61850 and CIM. With regards to Synchrophasor data transfer, a library functioning as an IEEE C37.118.2 to IEC 61850-90-5 gateway, was developed, implemented and validated to (1) Receive and parse synchrophasor data originating from a PMU or PDC using the familiar IEEE C37.118 protocol, (2) Map it to the IEC 61850 data model and (3) Transmit the synchrophasor data through either Routed-Sampled Value or Routed-GOOSE services defined in the IEC 61850-90-5. In addition, the library is capable of acting as the receiver and parser of IEC 61850-90-5 messages (i.e. Routed-Sampled Value and Routed-GOOSE), extracting raw synchrophasor data and feeding it to subscriber applications. More in general, standard based solutions are the only sustainable way to evolve from the today’s grid model to the smart grid one. Indeed, standards have a positive impact both on CAPEX – different provides can make available a product with the same features on the marker though promoting the competition and therefore leading to a lower unit cost – and on OPEX – using the same standard simplify installation, commissioning and maintenance phases.

The project has three DSO from three different EU countries, with different characteristics in the distribution grid, different penetration levels and types of DERs and with different regulatory frameworks. | Demonstration results will be therefore general enough to be considered valid also for other countries. | The three field demos tested some common use cases with the purpose of comparing results and assess the scalability and the replicability of the solution. This assessment took advantage of a common definition and understanding of Key Performance Indicators – used as tools to evaluate results.

Wide applicability of methods and tools in European contexts for both urban and rural areas.
Cooperation with TSOs where responsibilities need to be shared. New roles of market players.

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<tr>
<th>The concept of supervising protection zones will be used to develop an interface between transmission and distribution allowing key information exchange of specific distribution network dynamics to the TSO.</th>
<th>Supervision of transmission and distribution networks coupling by exploiting PMU data from both levels.</th>
<th>Dynamic measurements (time series) from PMUs have been utilized systematically to extract key information to be used in DMS functions and also to be sent to TSOs to be used in their operational functions. The following advanced PMU-based monitoring applications were developed, assessed, and validated at KTH SmarTS-lab:</th>
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Small to medium-scale residential, industrial and commercial “prosumers”.

In the demonstration networks there already are connected large and small scale PV, wind power, heat pumps and EVs located in urban and rural areas.

DERs have been a constant component of the IDE4L project. All the three LV field demos included a high presence of DERs and involves, especially domestic PV.

IDE4L was an outstanding opportunity to monitor and control those network elements in order to experimentally determine their behavior and their sensitivity to external operations.

Innovation in business models.

The distribution network automation system will also be integrated with an aggregator to merge information from small scale DERs and provide ancillary services for distribution network management.

IDE4L automation architecture

The aggregator developed in IDE4L allow the entry of small DERs into the energy and flexibility markets. Their participation allows to reduce network losses and average energy price. Furthermore, the rate of integration of renewables is improved. The aggregator exploit forecast services to manage optimally the energy and flexibility portfolio. The communication with the prosumers is done through Home Energy Management Systems (HEMSs) RWTH laboratory tests show results of monitoring application with virtual IEDs (software entities running on virtual Linux machines) and commercial smart meters and PMUs. The
**IDE4L Deliverable 1.2 Plan for the use and dissemination of foreground data**

| Aggregator within the project interacts with DSO to avoid technical constraints in its operation, but it may also provide ancillary services for DSO and TSO. | Outcome of investigations is recommendations to create distribution network level DR market organized by an aggregator and used by DSO, TSO and electricity market participants. | The feasibility and technical viability of the aggregator with the DSO to avoid violation of technical constraints in its operation has been demonstrated. Moreover, the participation of the aggregator in the markets has been simulated showing some examples of economic benefits for the aggregator and the end-users. For congestion management, the aggregator concept has been utilized to provide the necessary flexibility to eliminate congestions in the distribution system. A specific algorithm called Market Agent has been developed within the scope of WP5. When all other algorithms fail in eliminating the congestion, the Market Agent algorithm communicates with the flexibility to purchase the required flexibility to eliminate the congestion. D5.2/3 presents details, specifications and test scenarios for the design and operation of the Market agent algorithm. Based on the simulations and the demonstrations of the aggregator concept and its interaction with the congestion management system within the IDE4L project; it can be concluded that it is an efficient way of providing flexibility for the DSO and helps with a great deal in moving towards an active and smart network instead of a passive one. However, further development and more demonstrations are very important to create common roles and regulations in this field because of its sensitivity and direct interaction with the end-users. |

**Validation of the approaches and tools through simulation and pilot-scale trials.**

| The objective of planning studies is to find out which circumstances and networks the developed active distribution network concept and applications of active network management are profitable compared to traditional passive network solutions. | Planning tools to evaluate costs and benefits of developed concept and applications. | Operational, expansion and target network planning tools for distribution grid including large-scale DERs and variety of ANM functionalities have been designed and implemented during the project. Tools have been utilized to study the future scenarios of Unareti’s MV grid as an example case. Single study case is not enough to say which circumstances and networks the ANM concept and functionalities are the most profitable. However, the developed tools are general enough to be applicable for other case studies. |

| Interoperability of developed automation system and applications will be tested in RTDS laboratories using | Automation system and application are well tested before | RWTH laboratory tests show results of monitoring application with virtual IEDs (software entities running on virtual Linux machines) and commercial smart meters and PMUs. The demo results show that the integration of... |
hardware and software in the loop testing strategies and in network integration laboratory using real equipment.

field demonstrations.

heterogeneous devices is possible thank to open source interface software and databases together with standardized data models.

TUT RTDS laboratory has been used as one of the integration laboratories to verify the interoperability of SAU and functionalities with automation devices (smart meters, RTUs, primary controllers for OLTC and DG unit, and FLISR IEDs).

DTU laboratory test setup consists of a real time digital simulator, three desktops representing the DSO and two aggregators and the communication channels by DNP3 and OPC protocols.

The lab demo of the dynamic tariff (DT) has demonstrated the efficiency of using the DT for congestion management in an environment close to a real grid and provided some recommendations for improving the DT.

1. The convergence of the centralized and distributed optimization is demonstrated;
2. The efficiency of the prices determined by the DC OPF was tested in an AC power system;
3. The impact of uncertainties on the efficacy of the DT concept was tested;
4. Recommendations were made to improve the DT, i.e. set a margin of the line capacity to consider the reactive power flow, or use AC OPF for calculating the DT.

IREC Smart Energy Lab has been used as a test site for the operability of commercial communication and logic devices within the developed Interconnection Switch setup. Additionally, a soft power hardware in the loop setup was developed including real battery storage systems and emulated DERs building up a microgrid.

KTH SmarTS Lab were used to verify the interoperability of the developed advanced PMU-based monitoring applications with WAM components (PMUs, PDCs, data mediators) through a designated hardware-in-the-loop simulation setup.

Concerning FLISR solution, it has been tested in TUT RTDS lab and Telvent lab, as well as in OSTKRAFT and Unareti Demo Sites. In these tests interoperability and ease of integration with different commercial equipment have been verified.
### Automation system and applications

Automation system and applications will be tested in field demonstrations where significant DER installations exist and fast changes and bidirectional power flows arise.

### Demonstration results

Three field demonstrations sites equipped with IDE4L automation system were run and tested. In the demonstration networks there were connected large and small scale PV, wind power, heat pumps and EVs located in urban and rural areas.

### Family of projects and contribution to the implementation of EEGI.

The starting point for research and development work of automation system and management solutions for distribution network are the existing products and prototypes from previous projects. Especially the outcomes of INTEGRIS project is the basis for the development of automation system.

ADDRESS and INTEGRIS projects provided some starting use cases for what concerns, respectively, economic and operative use cases.

### Number of international and national smart grid projects

Number of international and national smart grid projects has a strong links to IDE4L project.

Cooperation with sister projects (evolvDSO, Dream and INCREASE). Cooperation with national projects: Unareti’s national projects, SGEM - Smart Grid and Energy Market program (TUT, finalized), FLEXe – Flexible Energy Systems (TUT, finalized), Social Energy – Prosumer Centric Energy Ecosystem (TUT, ongoing), SAU as a cloud service (RWTH, ongoing), SEMIOTIC: Semantic IoT Data Integration and its use in the energy management of Smart Grids and Smart Cities (IREC). Contribution to international project proposals: SABINA SmArt Bi-directional multi eNergy gAteway (IREC+SCH, EU grand approved), Synchrophasor based holistic and interoperable analytics controls and protection for smart grid (KTH and TUT, submitted), Grid Enabled Flexible Ecosystems for Future Energy Markets (TUT, not accepted), etc. Contribution to national project proposals: Åland demo platform (TUT, not accepted), Voltage regulation at medium voltage networks (DE and TUT, submitted), Distributed management of electricity system (TUT, submitted), etc. Proposal for project on the exploitation of dynamic tariffs in ERA-Net project (RWTH+DTU)
**Participation of major players. Committed participation of DSOs, TSOs and market players. The participation of market players should be consistent with unbundling principles.**

<table>
<thead>
<tr>
<th>The IDE4L concept will be demonstrated by DSOs from Denmark, Italy and Spain. Involvement of other DSOs will be arranged within workshops.</th>
<th>Proof of concept by field test and wide acceptance of the developed concept.</th>
<th>The participation of 3 DSOs from 3 different EU countries was a key ingredient not only to evaluate the replicability of the IDE4L architecture at EU level, but also to widen the dissemination of the results obtained during the project. Several DSOs from Finland and Italy participated in project dissemination events.</th>
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</thead>
<tbody>
<tr>
<td>DSOs participating into the project experience already today many of the challenges which the IDE4L project is looking for solutions.</td>
<td>Unareti: The Italian Authority is now asking DSO to test forecast algorithms to foreseen – on the short and medium term – the distributed generation on the MV and LV levels. We expect that this feature will be made mandatory in the next regulatory period. Additionally, we are also evaluating to extend the use of the production forecast in other primary substations. As for state estimation and power control algorithms, those tools are two important ‘bricks’ in the supervision on the today’s distribution network and/or this reason, we are currently in a tender phase for a Distribution Management System including those type of algorithms. Finally, Unareti is currently investing also into monitoring, control and protection of MV equipment, with solutions that will be very similar to those investigated within the project.</td>
<td>UFD: As we aforementioned, the National Regulatory Authority is focused on the smart meter deployment, just for billing purposes by the moment. There is high interest in developing and testing other advanced solutions, but just in pilot and demonstration environments. In this sense, UFD has found the experience gained in IDE4L very satisfactory, and will use the output of the project as an impulse to participate in future smart grid projects. However, the scope of smart metering is expected to be extended, so it is an added value for us to investigate in these advanced functionalities that the smart meter enable.</td>
</tr>
<tr>
<td>Committed participation of TSOs and market players is ensured in the project by an advisory board.</td>
<td>Advisory board provides recommendations for the project.</td>
<td>Advisory board participated in project meetings actively and provided clarifying comments as a feedback for the project. Especially the comments of aggregator concept were very relevant for the project.</td>
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**Increasing the hosting capacity of MV and LV networks.**

<table>
<thead>
<tr>
<th>Project will define an integrated distribution automation concept capable of monitoring, controlling, managing fast changing conditions and integrating large number of DG and DR in distribution network.</th>
<th>IDE4L automation architecture</th>
<th>Deliverable D3.1 presented the automation architecture concepts, with use cases, actors and functions. D3.2 showed how to implement this architecture, following the standardized SGAM methodology. Eventually D3.3 asses the performance of such architecture and compare with other FP7 proposals and the state of the art.</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDE4L project will define and develop functions for congestion management of MV (control centre level applications) and LV (secondary substation level applications) networks.</td>
<td>Applications based on IDE4L automation system: State estimation, power flow control, coordinated voltage control and grid tariff congestion management</td>
<td>A complete congestion management system has been developed in the IDE4L project within the scope of WP5. The developed congestion management system consists of several controllers installed at different voltage levels. Secondary controllers are installed at LV and MV transformers and a tertiary controller installed at the control centre. All controllers receive input from state estimation and forecasting algorithms developed also in the project. The developed congestion management system has a heretical structure and all the controllers within the system can work independently as long as they receive the required inputs. D5.1 presents details about the state estimation and forecasting algorithms. D5.2/3 presents details about the different level controllers developed in the IDE4L project. D5.4 presents details about the dynamic tariff method and algorithm that is also one of the solutions employed by the tertiary controller for congestion management.</td>
</tr>
<tr>
<td>Development of microgrid models considering generation, storage and demand elements. In addition, control and protective devices impacting on distribution network dynamics will identified for modelling, simulation and analysis tasks.</td>
<td>Control schemes validation through the emulation of network models representing the reality of different microgrids composed of a great variety of DERs.</td>
<td>Reference network models have been generated and used to test aggregator algorithms under different selected scenarios including uncertainty of: network topology, type of loads (including electric vehicle) and RES generation units. Different RES and storage penetration levels have been considered in the tests with the common feature of residential/tertiary microgrids as significant flexibility sources within aggregators’ customers’ portfolio. A reference active distribution grid model has been developed at KTH SmarTS-lab to serve as a benchmark for grid dynamic studies. The grid includes different voltage levels and numerous components of different types, each with electrical and mechanical parts, various controllers and protection systems, to emulate the behavior of an active distribution grid.</td>
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</table>
### Synergies with Smart Cities and Communities

<table>
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<tr>
<th>Exploit the load and generation flexibilities of the smart city to support the energy management and the grid operation.</th>
<th>The interaction between the smart city and the DSO could be realized using dynamic price signals, fixed or dynamic tariffs, etc.</th>
<th>D3.1 and D3.2 includes some use cases on how to convey and offer flexibility to DSOs. Dynamic Tariff is one of the solutions used by the congestions management system developed in WPs to eliminate congestions. A dynamic tariff algorithm has been developed and installed within the tertiary controller that is located at the control center. Based on day ahead forecasts of market price, load and generation profiles; the dynamic tariff algorithm calculates the required tariff for the next day and send it to all the retailers in the network. The dynamic tariff algorithm has been demonstrated at DTU RTDS labs. It has proven to be an efficient way for eliminating the forecasted congestions. However, this concept might contradict with the regulations in some European countries and therefore more investigation might be required in this area. D5.4 presents details and explanations of the dynamic tariff concept developed in the IDE4L project and the demonstration results. The simulations performed within WP6 and the IREC Smart Energy Lab tests showed how a smart district is able to interact with the DSO and exploit the load and generation flexibility. The time scales, information to be exchanged, communications etc. have been defined and evaluated.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Augmented grid monitoring. In the case of a smart city, the data could be aggregated by the smart city and forwarded to the DSO together with information on the availability of time-shiftable loads.</td>
<td>Distribution automation architecture will have interfaces to service provider and also to customers.</td>
<td>In IDE4L architecture, the SAU level of data aggregation permits to better manage the storing and exchange of monitoring data, maintaining proper robustness and security of the automation system. Substation level matches with quarters of the smart cities that have same power supply and therefore similar congestions and power quality issues.</td>
</tr>
<tr>
<td>In the control mechanisms to support the grid management and the integration of renewable generation, the smart city can take charge according to the level of autonomy.</td>
<td>At the same time the quarters may coordinate the control of their DERs in order to solve power congestions and power quality issues. The SAU actor, proposed in IDE4L, may be the right actor to manage these control functionalities from the point of view of the DSOs. Similarly, the aggregators may respond to the request of energy and flexibility services and guarantee proper remuneration to distribution prosumers.</td>
<td></td>
</tr>
<tr>
<td>Service platform for the smart city with different services and products which could be beneficial for the smart city, e.g. emergency assistance mechanisms, applications in various fields (energy efficiency, traffic jams, weather conditions, local events) and offering business models for smart city players with high potential.</td>
<td>Distribution automation system provides data and platform for smart city applications</td>
<td>IDE4L architecture requires continuously generation, wheatear and load forecasts. Therefore, IDE4L actors may participate to the business cases of several service platforms. Similarly platform for distributed data storing and purchase/exchange of energy and flexibility services may support IDE4L functionalities in the future.</td>
</tr>
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</tr>
<tr>
<td>The DSO has to guarantee grid access neutral facilitation of the provision of energy efficiency services by competitive players and equal right on grid access.</td>
<td>Distribution automation system provides data and neutral platform for energy market participants</td>
<td>Through the figure of DER managers, as well as microgrid controller and aggregators, IDE4L “open the doors” of grid automation to a wide range of third new actors. IDE4L proposes some instances of architecture (devices, software and hardware) to support the integration of these new actors. However, we expect that many other technologies may be applied for this goal. As mentioned in the previous points cloud platform for sharing of data and access to forecasts allow newer actors to enter into the framework of automation of smart grid.</td>
</tr>
</tbody>
</table>
5. Use and exploitation of IDE4L results

Plan for the use and dissemination of foreground by partners.

Vendor:
Telvent Energia S.A., Spain
Telvent R&D team has been able to enrich their know-how about IEC 61850 exploitation and about needs of Utilities that can be fulfilled thanks to its application. After the project, the team is able to confront more complex objectives with regard to IEC 61850 applications and distributed intelligence along MV lines.

Besides this, Saitel DR hardware platform has obtained, thanks to IDE4L project, some proven experiences of its performance for GOOSE communication in real distribution networks and logic selectivity schemes.

Once the project is finished, a commercial promotion of the different developments and new available technological possibilities will be performed through Telvent usual marketing channels. Demo results will be internally presented to Telvent account managers for Distribution Energy Companies in Spain.

DSO’s:
Unareti Spa, Italy

FLISR and MV monitoring
Unareti strongly believes in distribution network automation and it has basically double investments in the next 5 years for monitoring, control and protection MV equipment. The test done during the IDE4L project make the business case more ‘solid’. The feature of remote reconfigure the protection device when the network topology changes allow for a maximization of the investment, since the protection system can be used not only in the standard configuration, but even after a fault. We expect to buy IEDs like those tested during the project.

Load & production Forecast
The Italian Authority is now asking DSO to test forecast algorithms to foresee – on the short and medium term – the distributed generation on the MV and LV levels. We expect that this feature will be made mandatory in the next regulatory period. For this reason, the experience done during the IDE4L project is very profitable. At the moment we are also evaluating to extend the use of the production forecast in other primary substations.

State estimation and power control
Those a two important bricks in the supervision on the today’s distribution network. We are currently in a tender phase for a Distribution Management System including those type of algorithms, so we will use the knowledge and the results obtained during the project to select the best product.
Standards
Standards like the 61850 and the CIM are getting more and more a core part of our business. We are currently redesigning the data model for our Asset Management System and the new one will be based on the CIM standard (to be completed by Dec. 2016). We recently released (May 2016) the technical specification for the primary substation automation systems and those specification mandates the fully compliance with the 61850.

Project management and architecture design
The PM methodologies used by Unareti – e.g. to lead the WP7 – and the design techniques exploited during the IDE4L project (e.g. use cases approach, semantic model, integration lab., etc.) are being used to manage other research and deployment project, so they constitute a major achievement for us obtained with the IDE4L project.

Union Fenosa Distribution, Spain
UFD LV demo site has performed the implementation of a real-time active environment, where a part of a field LV network is monitored and controlled in real time. This includes the use of the standard IEC61850, which has allowed the integration of different monitoring and control systems already developed in the network, and their global management. This idea, applied to a LV network, is quite innovative and hasn’t been performed before. Also, the belonging to an European consortium of different DSOs, technology providers and research organisms has been quite rewarding, due to the exchange of knowledge and synergies.

Load & production Forecast
The load and production forecast are essential for a good network planning, and the tests performed in IDE4L are going to be used as a basis to expand this functionality and explore the exploitability in current planning tools.

State estimation and power control
Power Control could be fully exploited if the Regulation allowed the interaction with DER. Currently, there is more a regulatory barrier rather than a technological one, so the exploitability of this functionality would be medium-long term.

Standards
The use of standards like IEC61850 and CIM are being nowadays quite frequent in our developments. However, as they are very familiar applied to MV networks, the experience of using them for LV management has been innovative and useful. The integration of the different monitoring and control systems could not have been possible, and the possibility to exploit this is very promising.

Ostkraft Holding A/S, Denmark
Load and production forecaster
By 2018 all consumer in Oestkraft area will have smart meters and due to the fast change in the way we use and produce electrical energy and the fact that it could in the near future be the main carrier of energy, we believe it is of great importance to find a way to exploit the data that will become available. The load forecaster and production forecaster have shown us that the algorithm made available, works. The
knowledge from this we will use in other developing project and in the way we design and purchase components for the network.

MV monitoring and FLISR
When electrical energy is going be of greater importance for the society, there is going to be a demand for bigger regularity of the network. Monitoring, control and the use of FLISR in MV network are all technology that support this. We believe that we will install technology like this in our network in the next decade. It has also given us tools to a better understanding of where and how to install this technology in our network.

Other partners:

Tampere University of Technology, Finland
TUT will continue developing concepts of ANM, hierarchical and distributed automation and commercial aggregator in future research and development projects in national and international levels. The concepts of IDE4L project will be the key input for future projects. For example, the existing use cases and the implementation of SAU including interfaces, database and algorithms may be further developed and commercialized by automation system vendors together with universities. Similarly, the RTDS laboratory environment at TUT will be utilized and further developed in future projects.

In addition to further enhance the capabilities of SAU, the development and testing of cyber security and the understanding of communication dependability becomes crucial issues. Distributed automation architecture supports these issues, but it also makes automation system very complex to maintain and understand. Therefore, auto-detection and auto-configuration type services for automation system components should be developed.

The outcomes of IDE4L project will also support educational activities of TUT. RTDS laboratory environment and implementations of state estimation and secondary controller (power control algorithm) will be utilized to demonstrate and practice smart grid functionalities at master program level. Similarly, the FLISR solution will be utilized as a demonstration of advanced distribution automation solution. Utilization of SGAM framework, use case methodology and IEC 61850 and other standards will be included in distribution automation course. One post-graduate research training course “Active network management and distributed automation” will be organized during 2017 based on outcomes of IDE4L project.

RWTH Aachen University, Germany
RWTH leaded the development of the automation architecture. Such architecture, has been fully developed: from concept and use case to SGAM layers and laboratory implementation. The documents and tables in the deliverable summarized the technical details of the architecture, which may be exploited for further developments in the field of smart grids. We implement a real time testing infrastructure for aggregators. The electrical simulation is performed in RTDS environment, connected with DSO and aggregator simulators.

The laboratory HW /SW developed in RWTH for testing of monitoring and control use cases of IDE4L, represent an advanced testing framework that, will be exploited for future project. In particular, some projects for the implementation of IDE4L use cases in “cloud” have already started and show to provide interesting results.
IDE4L Deliverable 1.2 Plan for the use and dissemination of foreground

RWTH is preparing, together with other project partners, some open access publications to explain the architecture and the substation automation unit roles. Furthermore, RWTH participated over the 3 years of the project to the IEEE AMPS international conference, which has hosted some workshops and special sections where IDE4L architecture was one of the focuses. RWTH presented IDE4L use cases and architecture to some Smart Grids European Energy Research Alliance (EERA) internal conferences, where IDE4L obtained great attentions in the FP7 framework.

Denmark Technical University, Denmark
A. Dynamic tariff based distribution locational marginal prices (DLMPs) through quadratic programming
B. Optimal Reconfiguration Based Dynamic Tariff for Congestion Management and Line Loss Reduction in Distribution Networks
C. Uncertainty Management of Dynamic Tariff Method for Congestion Management in Distribution Networks
D. A Sufficient Condition on Convex Relaxation of AC Optimal Power Flow in Distribution Networks
E. Dynamic subsidy method for congestion management in distribution networks
F. Real-Time Congestion Management in Distribution Networks through Swap of Flexible Demands

results A-D are published as IEEE Transaction papers and results E-F are submitted to IEEE transactions on Smart Grid. All the results from DTU are publicly available.

Catalonia Institute for Energy Research (IREC), Spain
IREC leaded the development of the aggregator concept, the definition and the implementation of the aggregator optimal management algorithms. The results will be used for future proposals and projects and will be shown to Spanish utilities to promote and push the development of smart grids within Spain. Specifically, the results of IDE4L will be used:

• To further investigate the developed algorithms and their applicability to the Spanish electric system. Improve IREC Smart Energy Lab to test new scenarios and market regulations.
• To disseminate the aggregator concept and its implementation within IDE4L project to promote the necessary regulatory changes to allow the participation of such agents in the different markets. The dissemination will be done in appropriate conference, fairs or publications.
• To register the aggregator optimal management algorithms developed within IDE4L projects in order to use them in future industrial and competitive projects. Specifically, SABINA project (EU proposal 731211, approved July 2016) will use and test aggregator algorithm in the new cluster of IREC microgrid labs (Smart Energy Lab and SEILAB).
• IREC will continue the collaboration with some IDE4L partners to further develop results on active distribution networks.

Danish Energy Association, Denmark
The Danish energy association (DE) believes in future energy systems and smart grids. With the fast growing share of distributed energy resources connected to the distribution systems in Denmark, new challenges (such as: overloading, voltage limits violation and so on) are rising. Therefore, it is of great importance to find new solutions to overcome those challenges.
DE believes that distributed automation systems that are monitoring, calculating and forecasting the state of the distribution system and automatically reacting to eliminate congestions is one of the very important solutions that DSO’s shall take into consideration. However, the scalability and implementation of such automation systems will be quite dependent on the size of DSO, number of consumers involved, number of distributed energy resources connected to the distribution system and so on. Thus, it might not be necessary to implement a full-scale automation system at all DSOs rather than implementing only the necessary parts. In the IDE4L project, a full-scale-automation system has been developed and one of the great advantages of the developed system is that it is scalable.

As a member organisation for the Danish DSO’s, DE will use the gained knowledge from the IDE4L project as below:

1. Further investigate the developed algorithms and their applicability to the Danish DSO’s network.
2. Present the benefits of implementing advanced distributed automation systems for the Danish DSO’s and present the developed functionalities in the IDE4L project.
3. Further develop ADMS functionalities and concepts; according to the Danish market, regulations and the state of art technology.
4. Participating in national and international projects where IDE4L concepts and functionalities can be reused or further developed and demonstrated.

University Carlos III of Madrid, Spain

IDE4L load and production forecasters are based on the real time measurements as well as other external data sources, such as current and predicted status of weather and additional static data which allows to predicts consumption and production in the medium and Low voltage network. These two forecasters (Load and production) will be used by UC3M to improve the controllability of large number of DG and DR in distribution networks. RTDS Lab demonstration will be used to test the operational functionalities in forthcoming projects.

Technical aggregator developed in IDE4L project is composed by both the network reconfiguration algorithm and the market agent tool. These two algorithm works closely with the commercial aggregator, market services, and forecast services. The technical aggregator will be utilised in RTDS lab environments to show the benefits of implementing the developed technical aggregator in the IDE4L project.

Development of a simulator on OMNeT++ to test FLISR algorithms on distribution networks. The simulator will be used to continue the research on FLISR systems. It will be made publicly available through an open-access repository.

UC3M has improved their know-how about the active network management of smart grids, such as; knowledge about Standards like the 61850 and the CIM, advanced automation solutions in smart grids, new supervision and forecasters services for the DSO, technical aggregator functionalities and flexible demand control labilities, benefits.
The network reconfiguration software developed by UC3M researches has been submitted to the Spanish Patent and Trademark Office for the application of the Licence software registration. Main results will be published in international conferences, international journals and workshops.

UC3M is member of the Spanish Association for Standardization and Certification Technical committee AEN/CTN 217. Benefits of implementing the IDE4L active distribution management developed tools will be share with the rest of members of the national committee AEN/CTN 217.

**KTH Royal Institute of Technology, Sweden**
The IEEE/IEC gateway and the PMU-based applications (listed below) will be released to the world as Copyleft Software under the terms of the GNU Public License version 3 (GPLv3).

1. IEC 61850-90-5 Gateways for Transmission of PMU Data
2. PMU Data Curation, Fusion, and Extraction of Components from PMU Data
3. Steady State Model Synthesis for Distribution Systems
5. Voltage Stability Indicators for Distribution Systems
6. Oscillation Detection Indicators for Distribution Systems
7. Adaptive Auto-Reclosing for Distribution Systems
8. Adaptive Network Clustering for Distribution Systems
9. Dynamic Feeder Rating for Distribution Systems

Also, the IDE4L referenced grid, developed for dynamic studies, will be incorporated as ARTEMiS demo in RT-LAB Real-Time Suite. The model will be available to all users of OPAL-RT simulator.
6. Dissemination

IDE4L results have been disseminated to both scientific and public level. Our main target group in dissemination have been the scientific audience, but we have also distributed lot of information to DSO’s manufacturers, regulators and standardisation parties.

During the IDE4L project we have been published over 80 scientific articles and presented our results in different conferences. Also several presentations of IDE4L has been kept in different type events, meeting and seminars. There have been over 100 all kind of dissemination activities during project period. We have also organized two dissemination events for DSO’s and other relevant participants, organized cooperation meeting with Energy ENERGY.2013.7.1.1 projects and participated to Energy exhibitions in Finland and Denmark and other similar events were we have presented concepts and results of IDE4L. All presentations of organized events are available in IDE4L web-pages www.ide4l.eu.

The main dissemination events organised by IDE4L were:

- **Future flexible distribution system seminar**
  IDE4L – project organized dissemination event in Tampere 4th December 2015. In event the concepts, demonstrations and expected results of IDE4L were presented. In event there was 62 participants mainly form Finnish DSO’s, manufacturers and also the Finnish regulators, authority and standardisation parties were participating to event. There were also participants from other Finnish Smart grids projects which IDE4L has been work with. The event was recorded and the video is available in YouTube.

- **IDE4L Symposium**
  IDE4L Symposium was organized in May 18th 2016 in Brescia, Italy. In the event the concepts and demonstration results of IDE4L were presented. Also in here participants were from DSO’s, manufacturers, regulators and standardization parties and other Smart grids projects.

- **Future role of DSO with large-scale DERs**
  The Co-operation workshop with ENERGY 2013.7.1.1 projects was organized Thursday 19th of March 2015 in Aachen, Germany. The workshop consists of short introductory presentation of each project and then there was discussion of the future role of DSO.

For Scientific audience IDE4L organized and participated tutorials and special session in conferences. Some examples of those are:

- **Tutorial “Distributed and hierarchical congestion management in distribution network containing distributed energy resources”** in ISGT 2016 Europe, October 9-12, 2016
- **A special session named “monitoring platforms for distribution system”** in AMPS 2014 conference
- **Workshop on Resiliency for Power Networks of the future 8th May 2015** in Stockholm

IDE4L also participated to several other events like:

- **INNOGRID2020+ Conference 27-28 June 2016** in Brussels
- **European Utility week 15-17, November Barcelona, Spain.**
- **Bornholm Energy 2016 - on June 2, 2016, in Denmark**
- **2nd Joint Technical ELECTRA/ETP Smart Grids WG1 Workshop 10th December 2015**
IDE4L project has planned to make following publications of project results after the project period:

- Architecture paper (SEGAN)
- On-line reconfiguration of protection devices (SEGAN)
- Demonstration results of monitoring (SEGAN), State estimation, and Power control
- Aggregator (SEGAN)
- Test environment of RTDS for automation (IET)
- Summary of lab test environment
- Real-time congestion management with demand swap (IEEE smart grid)
- Optimal EV scheduling using game model (IEEE smart grid)
- Distributed voltage control
- Convex relaxation of AC OPF based on SDP
- Improved model of WP6 (IECON)
- Use of IEC61850 gateway for protection of SST
- Dynamic line rating (SEGAN)
- Validation of dynamic line rating with field measurements (SEGAN)
- DLR software (Software X)
- Architecture of gateway and implementation (EPSR)
- Gateway (Software X)
- Steady-state equivalent (IEEE power delivery)
- Sensitivity analysis of steady state equivalent (IEEE PES GM)
- Validation of steady state equivalent method using EPFL data
7. References

Deliverables:

D2.1 Specification of active distribution network concept
D2.2 Final vision and roadmap of active distribution network concept
D2.3 Simulated benefits of active distribution network concept and applications
D3.1 Distribution Automation Concept
D3.2 Architecture design and implementation
D3.3 Laboratory test report
D5.1 State estimation and forecasting algorithms on MV & LV networks
D5.2/3 Congestion Management in Distribution Networks
D5.4 Report on congestion management in distribution networks with day-ahead dynamic grid tariffs
D6.1 Optimal scheduling tools for day-ahead operation and intraday adjustment
D6.3 Emulation of the aggregator management and its interaction with the TSO-DSO

Other references:


8. Annex

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Description of the project

The IDE4L project is a 3 year demonstration project (September 2013 – October 2016) with a total budget of 8 M€. The research leading to these results has received funding from the European Union seventh framework program FP7-SMARTCITIES-2013 under grant agreement 608860 IDE4L – Ideal grid for all. The coordinator of the project is Professor Sami Repo (sami.repo@tut.fi) from TUT.

- 5 universities: Tampere University of Technology (TUT), Finland; Technical University of Denmark (DTU), Denmark; RWTH Aachen University (RWTH), Germany; University Carlos III de Madrid (UC3M), Spain; Kungliga Tekniska Högskolan (KTH), Sweden
- 1 energy association: Danish Energy, Denmark
- 1 research institute: Catalonia Institute for Renewable Energy (IREC), Spain
- 3 distribution system operators: Unareti Spa, Italy; Union Fenosa Distribution SA, Spain; Østkraft A/S, Denmark
- 1 manufacturer: Schneider Electric SA, Spain
**Project summary**

The main aim of the IDE4L project is to define, design and demonstrate “ideal grid for all”, an active distribution network which integrates Renewable Energy Sources (RESs) and new loads, and guarantees the reliability of classical distribution networks. The scope of the project is within medium and low voltage networks. Enhanced solutions to be applied therein are distribution automation and planning of active network. Novelties of the project are Active Network Management (ANM) based on Distributed Energy Resource (DER) and flexibility service, distributed automation to monitor and control a complete distribution grid, new roles of DSO and aggregators, interactions of Distribution System Operator (DSO) / Transmission System Operator (TSO) and DSO/market actors and decentralized FLISR Solution based on IEC 61850 GOOSE.

**Motivation**

- RES, active consumers, prosumers and commercial third parties increase the complexity of network planning and operation. Real time monitoring needs to be improved to supervise fast changing conditions and to be aware of new phenomena in complete system.

- Advanced distribution automation and flexible DERs like distributed generation and demand response enable active network management to integrate more RES and new loads into distribution grids, i.e. increase the hosting capacity. Improved controllability of distribution grid enables completely new ways to design and operate distribution grids.

- Existing and new networks and resources should be fully utilized to avoid over-dimensioning of grids due to quality of supply obligations and missing possibility to control DERs

- Guaranteeing continuity and quality of electricity supply by distributed real time fault location, isolation and supply restoration solution cooperating with microgrids

To realize the project, project partners have designed, developed and field-tested the next generation hierarchical and distributed architecture for distribution automation, based on international standards, in particular IEC 61850, DLMS/COSEM (IEC 62056) and CIM (IEC 61970, IEC 61968). This automation enables real time monitoring and control of the medium and low voltage grids, and 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.

The architecture has been designed based on the Smart Grid Architecture Model (SGAM) and semantic models of the components. About 30 use cases of active network management have been utilized to define it. As a result, the description of architecture is reusable to include additional use cases for the model or to implement it in the form of alternative components, communication media or protocols, and information exchange methods and protocols. The proposed architecture also reuses existing automation solutions by integrating them like control centre IT systems (SCADA, Distribution Management System (DMS), etc.) into proposed architecture. Therefore, the proposed solution may easily be expanded from the existing systems when needed.

New functionalities for the active grid, fit for the automation solution, have been developed and demonstrated in laboratories and real field conditions of three DSOs Unareti, Union Fenosa Distribution and Østkraft.
• Distributed Fault Location Isolation and Supply Restoration (FLISR)
• Microgrid integration
• Real time monitoring
• State estimation and forecasting
• Real time and day-ahead congestion management
• Phasor Measurement Unit (PMU) information synthesis for TSO
• Scheduling of DERs based on flexibility demand

In future network planning, trade-offs between investments in primary equipment and control strategies of DERs must be considered. For this purpose, the project has developed new planning algorithms for operational, expansion and target network planning. The economic verification of developed automation solutions is proved by planning tools which are developed to evaluate the costs and the benefits of active network management like the increment of distribution grid hosting capacity for RES or cost savings due to postponed infrastructure investments. The aim of the tools is to find out if active network management may replace passive network enforcement actions in future distribution networks, instead of a business as usual evolution.

Working methodologies

The IDE4L project has defined three concepts:

• The ANM concept to design and operate future distribution grids and to define roles and responsibilities of stakeholders,
• The distributed automation concept for ANM, and
• The aggregator concept for validating and purchasing flexibility services for ANM from DERs and offered to flexibility service market.

Developing

• Use case definition
• Implementation of functionalities, interfaces and database of Substation Automation Unit (SAU)
• Planning tools
• Laboratory testing facilities

Demonstrating

• 3 demonstration sites of DSOs utilizing the proposed automation solutions and validating 10 use cases
• 6 laboratory demonstration sites utilizing hardware and software-in-the-loop real time digital simulation
Demonstration sites

Installing a complex automation system in a real operating environment is a non-trivial task, especially if the target environment provides a public service as the electricity distribution grid.

From the design and development stage of individual “bricks” of the architecture to the real testing of subset of the overall system, the leap needed to run a use case is quite big.

For this reason, IDE4L has devised an intermediate step where pairs of components of the system are tested together to validate their interaction, before stacking many of them together. This intermediate step is called Integration Lab, because its main focus is on the integration.

The result of adding the integration lab is the testing approach becoming a three-step procedure, as depicted in Figure 1.

Figure 1. The testing approach.
Figure 2. Development, integration and demonstration sites.
The first step is the testing of individual components of the overall architecture. The place where this test is performed is called “Development Laboratory” by project partners. These tests, executed in simulated/emulated environments, were carried out for each automation module and algorithm to validate them before the integration phase.

The second step is the integration, carried out during “the Integration phase”. These tests were executed in simulated/prototype environments integrating architectures, algorithms and tools provided by development laboratories. The integration phase validated the overall integrated IDE4L architecture and technologies that were later applied in the real demonstration scenarios.

The demonstration phase is the final assessment phase, which is carried out by demonstrations owners and supported by integration laboratory group. These tests were executed in real and simulated scenarios. They validated the IDE4L architecture in real applications.

According to the classification reported in Figure 1, Figure reports the list of Development sites, Integration labs, lab. and field demonstrators.

**Active network management concept**

ANM concept is the basis for the whole project and includes the following key ideas and methods:

1. **Enhanced utilization of DERs for ANM**
   a. Connection requirements of DERs technically enable the control of DERs
   b. DSO’s own resources are controlled directly by advanced distribution automation
   c. Control of contracted DERs of non-market based DERs (e.g. reactive power of DERs)
   d. Flexibility services from commercial aggregators through flexibility market

2. **Advanced distribution automation is the key for ANM**
   a. Automation of medium and low voltage distribution grids to monitor and control DSO’s resources and DERs in real time
   b. Hierarchical and distributed automation to easily enlarge existing automation and control centre systems and to provide necessary scalability
   c. Integrated with national HUBs, flexibility market, and automation of aggregators.

3. **Aggregator interacts with DSO to meet technical constraints in its operation, but it may also provide flexibility services to DSO and ancillary services to TSO through flexibility market.**
Figure 3. Active network management concept of IDE4L.

The central part of the automation solution is the Substation Automation Unit (SAU) located at primary substations and selected secondary substations. The SAU merges real time data from IEDs and smart meters. It includes a database where all information is stored to be used by functionalities or to be reported to other SAUs or control centre. Automated functions send control commands to IEDs.

By partly vertically and horizontally distributing the decision making, the problem solving and communication requirements may be relaxed, the scalability of automation system may be guaranteed, the reaction time to varying network conditions, disturbances, outages, etc. may be decreased and the workload of control centre systems and operators may also be decreased which might otherwise become very demanding.

More information

D2.1 Specification of active distribution network concept
D2.2 Final vision and roadmap of active distribution network concept
Automation concept

The IDE4L project has designed an architecture based on monitoring, control and business use cases, which effectively coordinates DER and power and voltage control actuators to resolve congestions and power quality issues. The SGAM formulation of this architecture is derived and explained in details in the IDE4L reports. Selected implementation instances are presented, and the performance of the architecture is assessed based on indexes such as communication traffic and level of distribution of automation functions.

The IDE4L architecture is technology neutral as far as standards are used; hence, it can be implemented with heterogeneous types of measurement devices, controllers and computation units. All data exchange and data modelling are based on international standards IEC 61850, DLMS/COSEM and CIM to enable interoperability, modularity, reuse of existing automation components and faster integration and configuration of new automation components.

However, implementation instances are also proposed for the sake of the demonstration and as such are easily reproducible.

The development methodology is complete: it starts with use case definition (monitoring, control and business), followed by SGAM layers definition and eventually implementation of software and hardware in the field. Operatively, we have proceeded systematically, specifying the requirements for information exchange following the parameters of IEC 61850-5 standard; the actors have been defined in terms of interfaces, databases and functions, and the information exchanges have been clustered in data objects of IEC 61850 and CIM data models.

More information

D3.1 Distribution automation concept
D3.2 Architecture design and implementation and Annexes
D3.3 Laboratory test report

![Figure 4. Example of information layer.](image-url)
Commercial Aggregator concept

The Commercial Aggregator is defined as the player who buys and sells energy and controllable power (flexibility) in the electricity markets or via other forms of trading (bilateral contracts, call for tenders, etc.), by shaping the consumption of their customers. This is achieved by either sending incentives to the consumers or by “directly” controlling the consumer's consumption via active power set points. The Scheduled Re-Profilings (SRPs) are formed by means of price incentives, triggering the load re-profiling of the prosumers. The Conditional Re-Profilings (CRPs) requires a more immediate control by means of direct control signals. The commercial aggregator does not sell a specific level of demand but a deviation from the forecasted level.

Commercial aggregators interact with DSOs in different time horizons (day-ahead, intra-day, real-time) for two main purposes. On one hand, commercial aggregators need network acceptance from DSOs for demand response actions that have been previously traded in the market. In fact, the activation of a flexibility product must not cause new violations of constraints. This is the reason why they must be checked and validated before their activation. On the other hand, commercial aggregators sell flexibility services (SRPs, CRPs) to DSOs in flexibility markets.

CRPs are procured for defined time periods by DSOs, i.e. the capacity for a specified generation/demand modification for a defined period of time is procured. Optionally, such CRPs are activated by tertiary controllers when grid congestion cannot be solved only with more cost-efficient tools, such as the operation of DSO distribution assets.

Figure 5. Interactions of flexibility market participants.
in flexibility markets/platforms are able to bid/tender their CRPs in a transparent, non-discriminatory and competitive manner (supervision of competent power system regulator needed).

The commercial aggregator will communicate with the customers thanks to a communication device, which becomes the gateway between them. This device acts as a DER automation, which is in charge of the coordination of load, generation and storage at prosumers’ premises to re-schedule the consumption profile by running a specific optimization algorithm.

More information

D6.1 Optimal scheduling tools for day-ahead operation and intraday adjustment - Part II: Commercial Aggregator concept

Main exploitable results

Decentralized IEC 61850 FLISR Solution

Design and proof of concept of a decentralized Fault Location Isolation and Supply Restoration (FLISR) solution fully based on the IEC 61850 standard. GOOSE interlocking messages are used for the implementation of the two-step logic and chronometric selectivity schemas, and for the integration of the control functions for DER connected to the medium voltage grid.

Benefits

• Minimize impact of DER connection:

GOOSE interaction with FLISR IEDs allows the DER controller to manage connection or disconnection from the grid. Interlocking messages to be exchanged depends on fault locations and actions being performed on circuit breakers or switches. Microgrids with DER are integrated with remote or local control based on interconnection switch, with appropriate fast and soft switching conditions according to interconnection switch requirements and, providing IEC 61850 connectivity with SAU. Local monitoring is included at the PCC. In such points, power quality issues have been also implemented (power smoothing by storage elements due to i.e. flicker noise).

• EU Market exploitability and reduction of Integration Efforts:

The use of IEC 61850, the global standard for communication in substations, applied to protection functions in medium voltage networks together with logic selectivity functionalities are far from a real deployment. Unareti’s medium voltage demonstration site is one of the first operating environment where the concept is tested.

Real demonstration has allowed us to corroborate that the adoption of the IEC 61850 for IDE4L FLISR makes it easy to integrate into existing solutions in EU networks and to operate together with other third-parties IEC 61850 IEDs and functionalities.

• Fast response to changeable conditions

The main limitation of FLISR solutions is that every time the grid changes, protection settings and logics are no longer valid. IDE4L proposes an adaptive FLISR solution where settings and communication schemas can be adjusted to the network configuration and load currents, without interrupting operation. Solution is based on MMS communication with an IEC 61850 client.
• Reliability index improvement

IDE4L FLISR solution allows reducing the number of customers that experience power outages in the event of a fault and the isolation of the outage area in few seconds, thus reducing the duration of loss of load in comparison with traditional schemas where protection functions are only applied at primary substation and with logic selectivity where decisions are taken at control centre level.

Limitations

Feeder automation functionalities are not currently included in the approved parts of the IEC 61850 standard, although some efforts are being performed.

Missing functionalities have been identified and proposed through the National Standardization Committee for IEC TR 62689-100: Requirements and proposals for IEC 61850 data model extensions to support Fault Passage Indicators applications.

More information


D4.3 Preliminary assessments of the algorithms for network reliability improvement: Laboratory verification of algorithms for network reliability enhancement by FLISR
SAU device

The Substation Automation Unit (SAU) is the core of the hierarchical/distributed IDE4L architecture. The SAU, installed in the substations, conceptually identical in primary and secondary substations, 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.

Benefits

The SAU was designed for substation automation for distribution, and was not adapted from hardware and software solutions developed for the much more automated transmission networks. As such it is naturally slim, and scalable. Its computation and communication requirements can be modulated to meet specific needs, thus avoiding over-design.

The SAU may reduce the burden for computation, data storage and information exchange of the Distribution Management System (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 medium and low voltage networks when compared to traditional control centre solutions.

The SAU can be exploited for measurement and control devices that are already installed in the field, thus reducing the investment for automation upgrade.

Limitations

The hardware and software requirements are dependent on the size of the grid. Algorithms of state estimation, and similarly optimal power flow algorithms, may perform differently with networks of 10 or 100 nodes.

The communication requirements with remote units and customer smart meters have to be specified with regards to the requirements of the power control and fault location algorithms.

More information

D3.2 Architecture design and implementation and Annexes
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 and used for the state estimation/forecast, for the control and monitoring of the grid connected to the SAU.

The two most important schemas of the database are the Measures and Commands and the Network Models, designed to be compliant with the main standards of the automation area: the IEC 61850 and the CIM.

The **Measure & Control** schema has been defined starting from IEC 61850 data model. The model, structured in physical device, logical device, logical node, data object and data attribute, has been expanded with a set of entities used to collect real time and historical data retrieved from the field and with a set of information to parameterize the communications interface to any other physical device (such as IP addresses, TCP ports, users and passwords, etc.). A group of tables has been defined specifically to model forecast profiles.

The **Network Model** schema has been designed starting from the Common Information Model (CIM). It contains a set of table per each of the most relevant CIM classes. For example the ‘ConductingEquipment’ table is used to model the parts of the AC power system that are designed to carry current or that are conductively connected through terminals.

**Database (CIM/61850)**

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Figure 8. Example of SAU database.
**SAU applications:**

**Real time monitoring and control**

The decentralized applications are executed in the SAU device. The Real time monitoring application collects data from IEDs in the monitoring and control zone of SAU, stores the data in a local database for further use and for reporting of data, events and alarms to higher layers of distribution automation architecture.

The load and production forecasting utilizing real time monitoring and weather data, provides a short-term view of loading and production condition for state estimation. State estimation computes the grid quantities based on monitoring and forecasted data and grid model.

IDE4L has delivered feasible and proven technical solutions for real time congestion management in medium and low voltage grids. It is realized by primary and secondary control schemes. Primary control like voltage control of tap changer is based on local measurements and may operate extremely fast, but it is lacking information about the complete system. The objective of secondary control is to coordinate primary controllers (including DER controls like load shedding, production curtailment or utilization of energy storage) in the network area to minimize operational costs within technical constraints. The secondary controller is located in SAU.

**Benefits**

The distribution of applications to primary and secondary SAUs allows utilization of real time data from a complete grid. This will enhance distribution grid observability and controllability compared to existing centralized systems. Scalability of applications is also enhanced because single application is responsible for a rather small grid area and therefore the computation performance of algorithms is not a limiting factor. Applications may also be re-used in all layers: DMS, primary SAU and secondary SAU. The modular structure of SAU allows replacing applications when needed because they are completely independent of the implementation of SAU interfaces.

Real time monitoring is a basis for the rest of applications and it extends real time monitoring to the complete grid without overloading centralized SCADA/DMS systems. It does not need to have IEDs in all grid nodes because state estimation is able to provide accurate enough data when real time measurements are correctly selected and reading frequency and data resolution are high enough. State estimation is also enhancing the accuracy of monitoring by correcting erroneous and missing data.

The aim of the secondary controller is to enhance the hosting capacity of distribution grid for DERs. Case studies have shown that the hosting capacity for distributed generation connected into a weak medium voltage grid may increase three times compared to a passive network solution and more than two times compared to a primary control scheme.
Figure 9. Costs comparison of congestion management in weak medium voltage grid [*].

Limitations

The proposed solution will not be implemented as a standard or an alternative solution to passive network reinforcement unless grid regulation allows DSOs to include congestion management investments as part of grid assets or service quality which define how much profit the DSO may make. The value of congestion management from the grid regulation perspective should be somehow comparable to passive network reinforcement, or otherwise profit maximizing DSOs will always invest in passive solutions. Similarly, the increased operational cost of congestion management compared to passive solution should not penalize DSOs in grid regulation if the lifecycle costs of congestion management are cheaper than the total costs of the passive solution.

More information

D5.1 State estimation algorithm
D5.2/3 Congestion Management in Distribution Networks
D2.3 Simulated benefits of active distribution network concept and applications

DMS applications: Tertiary controller of congestion management

One major result of IDE4L is the improved network management through the use of control system designed to operate with high penetration of DER and capable of using market based flexibility services. Tertiary control of congestion management is located in the control centre (DMS) and its main tasks are to verify the state of the medium voltage network, set the topology of the entire network, coordinate secondary controllers and order flexibility services from
Aggregator to minimize operational costs within a given voltage range and component ratings. The tertiary control will evaluate the current and future states of the network by using the data series provided by the state estimator/forecaster. Day-ahead rescheduling of controllable loads (demand response), production units and storage devices by technical aggregator may be realized by utilizing smart metering infrastructure, home and building automation systems or micro-grid management system.

**Figure 10. Interactions of hierarchical and distributed congestion management.**

**Benefits**

Coordination of controllers provides significant enhancement for distribution network hosting capacity compared to passive network and primary control and operates in different time frames. Passive approaches can lead to high connection cost of DERs.
Congestion management scheme developed in the IDE4L project will allow the DSO to manage congestion and control voltage at minimum costs (reduced losses, production curtailment and outage times) by allowing a higher penetration of distributed generation with less network investments. Moreover, using system flexibility services for voltage control and congestion management could further enhance the benefits for the DSOs.

**Limitations**

New regulatory frameworks should include mechanisms that both allow DSOs to procure system flexibility services and to recover their cost. European Network Codes, such as Demand Connection, Operational Security and Electricity Balancing should not hinder the use of system flexibility services at distribution level.

**More information**

[D5.2/3 Congestion Management in Distribution Networks](#)
[D5.4 Report on congestion management in distribution networks with day-ahead dynamic grid tariffs](#)


**PMU Applications**

The increase of renewable generation sources in distribution grids creates more interactions between TSOs and DSOs. These interactions need to be monitored with measurement-based applications, and analyzed with models of the joint transmission and distribution system model.

The use of dynamic measurements (time series) from PMUs can be applied systematically to extract key information to be used in DMS functions and also to be sent to TSOs to be used in their operational functions. One crucial piece of information, which can be of immediate interest to exchange between DSOs and TSOs, is the equivalents of distribution network models. Using time-series from PMUs, equivalent models can be computed in near-real time which helps in understanding the strength and state of the distribution grid and consider the impact of these changes at TSO level.

**More information**

[D6.2 Distribution Network Dynamics Monitoring, Control, and Protection Solutions including their Interface to TSOs](#)
Commercial aggregator interactions

The aggregator interacts with other modules in two different time scales: day-ahead and real time:

- In the day-ahead time scale, the Commercial Aggregator interacts with the wholesale energy market to use demand and price-related data as input for its Optimal Planning Tool and trades SRP and CRP products in flexibility markets accordingly. Furthermore, the commercial aggregator provides the DER controls of its customers’ portfolio with the SRP incentives needed by their automation systems (Energy Management Systems) to comply with the SRP product specifications.
• In the real time scale, the commercial aggregator receives CRP activation requests from DSO (the Market Agent of the Tertiary Control) or any other qualified third party and sends CRP control set-points to the DER controls of the customers.

Benefits
Day-ahead and real time optimization and adjustments are incremental. The benefits of integrating these time scales according to the operation of commercial aggregator, DSO and TSO are:

• Real time optimisation is employed mainly for adjustments connected to truly unforeseeable occurrences. This reduces the need of real time decisions and operations, which are the most demanding.

• Foreseeable occurrences are anticipated and corrected based on historic knowledge and longer term forecasting through the day-ahead optimisation.

• Finally, the proposed operation merges technical and business knowledge and decisions, while maintaining the interests and competences well separated.

Limitations
DSOs will have to modify the way they operate by becoming more proactive. However, the implementation of technical solutions that permit this way of operation is limited by the lack of technical, economical and regulatory framework in several aspects, such as:

• Rules forbidding RES energy curtailment except for security issues so that the flexibility that these kinds of assets can provide is not utilized. DSOs should be capable of controlling the production, either by themselves or through third entities such as aggregators.

• Little/no incentives for smart grid solutions: DSOs are currently remunerated for reinforcing the network, so there is no immediate need for finding different solutions apart from reinforcements (i.e., smart grid solutions). In this sense, regulation linked to performance is a key element for the evolution of the smart grids.

It is required that regulatory authorities define a clear model which implements roles, rules, incentives and unbundling requirements for DSO and other stakeholders.

More information
D6.1 – Optimal scheduling tools for day-ahead operation and intraday adjustment, Part II: Commercial Aggregator concept
D6.1 Optimal scheduling tools for day-ahead operation and intraday adjustment - Part III: Commercial Aggregator tools and test results
D6.3 Emulation of the aggregator management and its interaction with the TSO-DSO
Demonstrations

Field demonstrators mainly focused on some specific use cases. The reason for this is that together they constitute two very important business cases:

- Congestion management business case, where:
  - a portion of the network is monitored by collecting data from smart meters and IEDs (monitoring use case),
  - its status is determined through a state estimation algorithm (state estimation use case),
  - pseudo-measurements are sent to the state estimator based on a forecast of load and production profiles (load and production forecast use case),
  - in case that a 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 Fault Location Isolation and Service Restoration, where IEDs are communicating based on a peer-to-peer paradigm in order to clear faults in the network and restore power to as many customers and as quickly as possible.

Examples of field and laboratory demonstrations

The following figures are examples of field and laboratory demonstration results in the form of selected graphs. More detailed and complete results are available in the deliverable of the overall final demonstration report.

![Active Power of 4 PV Units (Solar Eclipse, 20 March 2015)](image)

Figure 12. PV output monitoring in low voltage grid in Unareti demonstration site.
Figure 13. Net load forecasting of prosumers in Ostkraft demonstration. Low Voltage Load and Generation Forecaster (LVLGF).

Figure 14. State estimation of low voltage grids in Unareti demonstration.
Figure 15. Congestion management of low voltage grids in TUT laboratory demonstration.

Figure 16. Distributed FLISR. The picture shows GOOSE messages and operation commands that were registered in Unareti demonstration site.
Laboratory demonstrations

Demonstrations in IDE4L are shared among field and laboratory demonstrators. The latter exploit the Real Time Digital Simulators (RTDSs) to represent realistic testing condition and feed measurement devices and computation units with information of the power systems. The real time testing infrastructure allows you to understand how prompt the architecture in responding to line congestions or over/under voltages is. The monitoring chain, based on virtual and real IEDs connected to RTDS produces the necessary input for the control algorithm whose output is applied to the network simulation.

Benefits

Laboratory demonstrators enrich the field demonstration in the most powerful way, because the grid data and power profiles are exactly as the one in the fields. In addition, interesting scenarios, disturbances and congestions may be created in order to test the complete automation system and algorithms for power control and monitoring.

The RTDS laboratory creates an integration laboratory where individual developments are integrated and proved before field demonstrations. The aim of the simulations is to test interoperability of distribution automation and functionalities. This significantly reduces the time needed for setting up field demonstrations and provides necessary references for the results of field demonstrations. The integration laboratory tests have been essential to the development of...
interfaces and debugging of the algorithms to be deployed in the field. Without laboratory simulation in hardware and software-in-the-loop set up, it is not thinkable to thoroughly test devices, algorithms, applications and systems as was done in IDE4L.

**Limitations**

Virtual IEDs, based on standard computers and database and interface software, may work together or as alternatives to commercial IEDs to furnish SAUs with network information and to apply control actions on simulation environments in real time. The only components needed to apply the same approach to the field are sensors and transducers. In this way, advanced smart grid functionalities become more accessible for DSOs, and the same approach could be extended migrating the functionalities of the virtual IEDs to cloud services.

More information

D7.2 Overall Final Demonstration Report

**Conclusions and roadmap**

**Conclusions**

Based on three successful field and six laboratory demonstrations we may conclude that the proposed concepts, automation architecture and functionalities work as expected. The following paragraphs highlight the general conclusions of IDE4L project demonstrations.

**Basis for distributed grid management and interaction of business players**

The IDE4L project has successfully designed, implemented and demonstrated concepts of active network management, hierarchical and distributed automation architecture and commercial aggregator to provide flexibility services for grid management. Implementations of concepts have been validated by successful demonstrations in integration laboratories and field.
Efficient utilization of grid assets
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 power supply. The improvement of the quality of supply and the management of network outages are based on distributed FLISR, which significantly reduces the number of customers experiencing an outage and speed up supply restoration to other customers compared to traditional manual or partly automated solutions. Both the hosting capacity increment and the quality of supply enhancement will have a positive effect on social acceptance of the network infrastructure and the RESs.

More hosting capacity will help the integration of a larger share of RESs into medium and low voltage distribution grids, thus supporting Europe's 20-20-20 targets. Also, it may enable postponing new network reinforcements. Secondary and tertiary controllers of congestion management are the key components for the increment of distribution grid hosting capacity. The increment depends on the grid itself and the control possibilities of DERs and flexibility services. Planning tools developed in the project are able to estimate the hosting capacity increment in different conditions.

Scalability of automation solution
The hierarchical and distributed automation architecture designed and validated in the IDE4L project is based on existing devices, 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 IDE4L 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 total replacement of the existing infrastructure, which would not be feasible.

Data exchange between DSO and aggregator, merging information about DERs (validating flexibility actions) and controlling them (purchasing and activating flexibilities), will further extend ANM capabilities of DSO from distribution network to DERs and flexibility services provided by aggregators.

Replicability of solutions in other EU member states
The three DSOs partners of IDE4L represent urban and rural networks in different parts and countries of Europe. Demonstration grids also include relatively high penetration of RESs connected to low voltage grid. The same IDE4L automation system was implemented in all field demonstration sites. Results prove it effective in the different configurations (functionalities chosen by the DSO) and hardware implementations that were tested. Because the IDE4L solutions work in this variety of conditions, they are expected to be suitable for most of the EU.

However, network regulation and energy market rules are also different in each country. Whereas not all the developments may currently be deployed everywhere, the IDE4L demonstrations are not tailored to individual DSOs but rather represent general solutions, i.e. replication is already considered in the solutions.

Finally, the IDE4L concepts of active network management, automation and commercial aggregator have been influenced by all project partners and members of the advisory board, spanning all in all 12 EU member countries.
Benefits of proposed solutions

The solutions of IDE4L empower the DSOs to undertake the modernization of distribution grids based on proven technologies. They don’t have to devise themselves the right framework that is suitable for initial small scale deployment and that supports future expansions. IDE4L provides this framework, and the means to implement it, down to the individual algorithms and communications. In particular, IDE4L’s benefits include:

- The support to realizing the automation and modernization of distribution grids, thanks to a reference, validated concepts, architecture and functionalities.
- The availability of a solid base of critical monitoring and control algorithms, readily available and validated to work with the architecture, on top of which more can be built.
- Planning tools that include the automation as an asset and a way to evaluate technical and economical benefits of proposed automation solutions in addition to traditional grid reinforcement actions.
- The detailed schema to interface the commercial aggregator to validate market based flexibility services and to purchase flexibility services for active network management.
Utilization and development of standards

The IDE4L project has utilized international information model and interface standards (IEC61850, DLMS/COSEM (IEC 62056) and CIM (IEC 61970/61968)) for the design of the automation architecture and the implementation of devices and interfaces (FLISR IED, SAU and PMU) and all demonstrations. Most of the implementations are based on existing standards, only the implementation of distributed FLISR have required utilization of draft standards and have also provided feedback for the standardization working group. Concepts and implementations have been proved to be interoperable and scalable.

The interoperability has been achieved in IDE4L through:

1. Identification of interfaces and information exchange synthesized from the IDE4L use cases of advanced distribution automation concept for active distribution networks. The automation architecture was hence derived and defined based on the SGAM framework.

2. Implementation of interfaces and messaging has been realized based on above standards and off-the-shelf products. Pre-deployment interoperability of the automation system has been validated with hardware- and software-in-the-loop simulations and integration laboratory tests. Different installations of real time simulator RTDS, grid and DER emulators, real and...
emulated IEDs, prototype implementations of the IDE4L SAU have been used for the purpose. The same testing set ups, augmented to integrate full IDE4L functionalities, have been used to investigate scenarios which cannot be realize in the demonstrations.

The applications of active network management and the implementations of the IDE4L automation system have been demonstrated in three demonstration sites in Denmark (Ostkraft), Italy (Unareti) and Spain (Unión Fenosa Distribución). The automation system in the field demonstrations has been exactly the same as the one validated in the interoperability testing.

Roadmap

The roadmap to exploit IDE4L project outcomes has been divided into five viewpoints named knowledge and attitudes, grid codes and standards, market and grid regulation, flexibility market, and technology. Figure 18 represents how these viewpoints have been scheduled for design, development, demonstration and commercialization phases.

The IDE4L project has 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 are also required before a market for all technologies developed in IDE4L project really exists.

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

Very important aspect for the success of active network management in distribution grids is the modification of grid regulation to allow efficient utilization of DERs for grid management and to enable existence of flexibility market for DSO use. Otherwise DSOs continue developing their grids as passive infrastructure. The design, development and demonstration of regulation goes hand in hand with the schedule of flexibility market.

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 active network management in addition to the urgent needs of existing systems. The IDE4L project has utilized SGAM for automation architecture development and also provided the description of use cases to be used in the standardization work. 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 active distribution grid.

Probably the most challenging aspect of the viewpoints is the knowledge and attitude. 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 IDE4L outcomes and collecting the best practices from other demonstration projects is needed before utilizing new ideas as the best practice in a DSO.
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