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SC C6: Distribution Systems and Dispersed Generation
PS3: New roles and services of distribution systems for transmission system operation

**The Nice Grid project : Using Distributed Energy Resources
to Reduce Power Demand through Advanced Network Management**

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SUMMARY

Increasing penetration of distributed generation on the distribution network demands for a more flexible and efficient utilization of distributed energy resources. The development and deployment of Smart Grids technologies and solutions may provide solutions for significant changes in distribution operation within the near future. The Nice Grid project aims at implementing and testing a distributed energy resource management system, supporting hierarchical operation and control for a microgrid with high concentration of photovoltaic generators. The paper focuses on one use case of Load Reduction for TSO, from dispersed resources such as controllable loads and electrical storage units, which can be scheduled and operated through intermediaries, i.e. commercial aggregators.

The business process, the project geographical footprint, the various supported standards and the overall architecture of the system are detailed in the following sections, with a strong emphasis on the transaction mechanism that supports the coordination process. The issues and lessons from the first two years are also discussed.

KEYWORDS

Smart Grid project, Distributed Energy Resources, Local Transaction place, Load Shifting, PV integration on distribution network.

The Nice Grid project

Nice Grid is one of the six demonstration projects that are part of the GRID4EU initiative. GRID4EU is a joint FP7 project composed by 27 partners from 12 EU Member States, including six European DSOs. It corresponds to 6 large scale demonstration projects of advanced smart grid solutions with wide replication and scalability potential for Europe. Within this initiative, the local GRID4EU project in France, Nice Grid, aims at facilitating the integration and usage of distributed energy resources (DER) in a distribution network. The research project began in 2011, with a four-year duration [1]. The project is designed to test an innovative coordinated architecture for medium- and low-voltage distribution networks with high concentration of photovoltaic (PV) generators combined with smart end-users whose installation are capable of managing optimally their electrical needs. The operation modes tested are:

- Power demand reduction obtained by shifting several MW of load. This scenario would be typically triggered following an initial TSO request in order to mitigate a regional congestion or to contribute to the national power balance ;
- Management of a massive distributed PV generation and its impacts on the distribution grid regarding the maintenance of the voltage within the normative tolerance range around the nominal value ;
- Microgrid operation in islanded mode. The goal is to show that a specific network area can operate independently and can be disconnected from the electrical network. The main goal of this operation mode is to keep the lights on for customers. Two types of microgrid operation would be tested: scheduled islanding and unforeseen islanding [2].

This paper focuses on the first operation mode, i.e. the management of coordinated power demand reduction requests, initiated from the TSO, in order to solve critical grid conditions or to contribute to the control area power balance. This operation mode is presently under testing with the first realizations of load power reduction events, during the winter 2014. The pilot project is well underway and has already completed important parts of the first phases: design and specifications; recruitment of the participating customers, PV producers and local companies; installation of the first grid-connected storage unit for testing; development, testing and deployment of the first release (Demand Response use case) of the software applications for each party: forecast providers, DSO, TSO, aggregators. Another task within the realisation of the project is also the deployment of smart meters, which will be used to monitor the electricity consumption and generation at each Point of Common Coupling (PCC) on the public distribution network, within the whole Smart Grid demonstration area.

Experimentation location

The demonstrator is set up in the city of Carros, in the urban area of Nice, in the far South-East of France. Compared to the global French power system, this regional area is known as an electric peninsula, connected to the bulk power grid through a transmission corridor. In the district departments of Var and Alpes-Maritimes, the local generation represents only just ten percent of the consumption load. The area can hence be vulnerable, under load peaking conditions, to the risk of single contingency conditions or (N-1), on the transmission system. On summer, because of the Mediterranean weather conditions, the risk of forest fires is important also, so that events of disconnection of the aerial high-voltage lines may occur as well. Till 2010, one unique 400 kV line and one 225 kV line ensured the transmission of the energy from the neighbouring areas. Since then, the TSO has initiated network reinforcement programs in order to constitute a “safety net” with notably three additional 225 kV underground transmission lines [3]. In the future, replications of the advanced smart grid solutions such as developed within the Nice Grid project could also contribute to the strengthening of the reliability of the transmission flows.

Another characteristic of the Nice Grid project location is the quite important insertion rate of PV generation grid-connected at the distribution level (mostly at the low voltage level). The whole Nice Grid geographical area covers both the Carros industrial district and Carros residential district. The area is fed by several feeders linked to three primary substations. Five of these MV feeders, radially

operated, distribute the area that is concerned by the first winter scenario: power demand reduction from an initial TSO request. The residential districts that have been chosen for the summer experimentations are characterized by a high share of installed photovoltaic capacity, with mostly rooftop PV panels. The experimentation will include demand response from industrial load as well as residential load, residential batteries management and network batteries management.

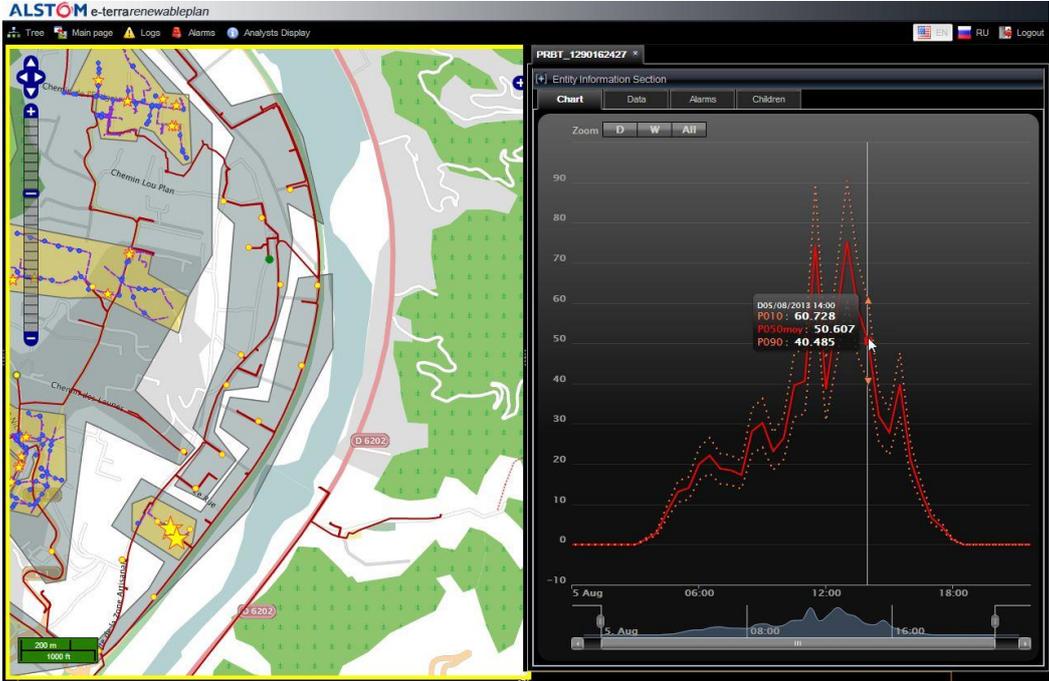


Figure 1: displays of the Nice Grid solar console (right: example of PV generation forecast schedule)

As shown in Figure 1, the Nice Grid solar console provides situation awareness for all the Renewable Assets within the different areas of Nice Grid. The solar console uses web browsers as a thin client. The application is configured to connect to a server which provides geospatial data, mainly extracted from periodical updates of GIS import files. Individual schedules are periodically sent via web services exposed to the forecasting applications and to the Network Energy Manager system, which orchestrates the daily workflows for the management of the Distributed Energy Resources (DER). The UI displays of the solar console are intended to be accessible from the Nice Grid showroom facilities, for various sorts of publics, for local authorities or for exhibition purposes. The solar console provides the possibility of an easy spatial and temporal navigation (past, current - and future, when day-ahead forecast schedules already imported).

Other features include the quality of the forecast, forecast blending and publication of the forecast high and low limits. The task of multiple forecast management and forecast aggregation is to be noted; the aggregation of the active power values can be done relatively to an administrative hierarchical tree or to the electrical topology of the distribution network. Due to the data confidentiality, information for each entity is anonymized and individual time series shall not be visible.

The Local Transaction Place

Operational paradigm in Nice Grid is based on mainly preventive action, i.e. scheduled operations on the distributed resources. While improved forecasting tools provide customized forecast load and generation time series for each individual end-user, it is therefore possible for the central supervisory intelligence, the DER management system, to process these inputs to determine a flexibility resource scheduling and ensure their dispatch in an optimal way, relatively to the needs of the network operators.

Another characteristic is the differentiation from the classical monitoring and control processes like in the traditional vertically integrated power system. The roles, stakeholders, responsibilities, business

models, within the tested Smart grids operations are quite different from those homogenous utility-based models of present power grids, mainly because of the distributed character of such systems involving new types of stakeholders and Distributed Energy Resources (DER): the commercial aggregators. Commercial aggregators are responsible for the aggregation and dispatching of the DERs that belong to their respective portfolios. Through a coordination of various dispatchable flexibility assets within the electrical installations of participating *prosumers*, it is hence possible for the aggregator to provide services as if the distributed assets were a single entity.

The technical infrastructure that is deployed in the project allows for local load management through the following actions: industrial demand response, residential batteries management, residential load shifting, network batteries charge and discharge. The Aggregators can manage various assets such as the water heating system of residential houses, the public lightning or manufacturing facilities, or small electrical batteries located in households. In the Nice Grid configuration, there is one aggregator per sector or kind of resources:

- One commercial aggregator for residential DERs (including residential batteries), also said “B2C aggregator”;
- One commercial aggregator for tertiary / industrial DERs, also said “B2B aggregator”;
- One aggregator for grid-connected low voltage network batteries, or Network Battery Aggregator (NBA).

The local transaction place provides a facilitation service between the network operators and the commercial aggregators, ensuring traceability and optimality of the transactions. The operator of the central flexibility transaction place is the Distribution System Operator, as the functionalities of the distributed management system require a complete and accurate view of the topology and the constraints of the network.

All the transactions between the DSO and the Aggregators are based on “flexibilities”, which are expressed as half-hourly time series of local variations of active power. Reactive power regulation is not considered here. DERs are seen as able to contribute to the provision of upward or downward variations of active power injections or withdrawals, from a reference baseline.

The main business process of the day-ahead scheduling of Load Reduction is a daily workflow framed through pre-defined gates of the transaction place. Each step of the workflow is allowed in its respective time window. The business process takes place as follows: the DSO and TSO express their requirements for the next day in terms of an active power upward or downward adjustment need and the localization of this need, as represented in Figure 2. These power requests are then converted to transaction commodities by mapping the related network areas to transaction areas, which are commonly known by all the stakeholders. Once the TSO/DSO power requests have been received and disaggregated by transaction areas, tenders are opened to inform the aggregators of the power needs. Based on their load forecast (residential and industrial), PV generation forecasts and the normal operation of their equipment (such as batteries), the aggregators agglomerate their potential flexibilities at the level of Transaction Areas and submit day-ahead flexibility offers per transaction area. The Network Energy Management system then conciliates requests and offers, while ensuring that no local network constraint is violated. In the Use Case of Load Reduction for TSO, the bids that are eligible and consistent with all the distribution constraints are aggregated and presented through a dedicated UI to TSO dispatchers, which can compare and select these sets of bids. Afterwards, the results of the selection by TSO and DSO are published to each aggregator. These transaction steps of the whole workflow span the day from 10 a.m. to 6 p.m. Each aggregator shall finally implement the selected schedule of power shifting, by disaggregating it on individual controls for the various resources of the concerned area the following day accordingly. After realization of the load reduction, performance evaluation should be also done by the means of post-hoc analysis based on the archived datasets of the relevant schedules of each daily exercise, within a data warehouse.

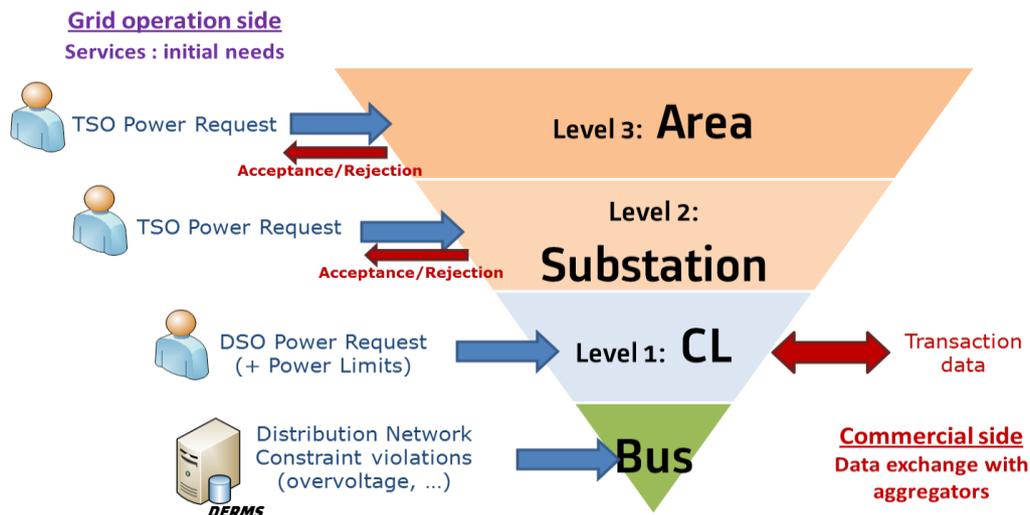


Figure 2: Multi-level coordination of various requests for flexibility

One major feature of the Network Energy Management is its multi-tier structure, with the handling of different aggregation levels, as shown in Figure 2 above. Transactions between the aggregators and the network operators (i.e. from the commercial side to the grid operation side) take place at the unique level that is defined by the DSO and that is called “Commercial Location” (CL). This transaction level corresponds to a part of the distribution network, delimiting rather a perimeter without recurrent internal congestion issues, and specifically defined for the purposes of the project. In the case of the first period of tests this winter, the simple zoning rule is one transaction area per MV feeder. These transaction areas are corresponding to an aggregation of homogeneous electrical nodes relatively to the considered ancillary service: the impact of a change in the power consumption at any node belonging to a transaction area should basically have a quite similar impact on the grid. Through the appropriate definition of the perimeter of the transaction areas, the multi-tier structure enables also vertical interactions between tiers that used to have limited exchanges due to their respective footprint and levels of responsibilities. For example, coordination between requirements from DSO and those from TSO is ensured following a set of priority rules that define the predominance of the lower levels on the upper levels: e.g., power reduction for TSO operation can be achieved on the whole area, while power demand increases can be operated as well very locally for the DSO in order to guarantee that the maximum limit of voltage is not exceeded. Flexibilities that have not been used for the DSO needs are freed, aggregated and exposed at the superior levels (‘Substation’ or ‘Area’) bound for the TSO. This hierarchical process guarantees that the use of any activated flexibility resource participation in a service for TSO has been firstly validated by DSO within the Network Energy Manager and is harmless for the quality of energy at the distribution level.

The timeline and the choice of the gates for the day-ahead process have been done by considering some time constraints originating in other systems, e.g. AMI for the provision of metering data of the day before. The future short-term intraday transaction processes for Nice Grid have not been definitely designed yet, but the same decisional architecture could be extended without major modification and applied for a shorter scheduling time horizon.

Mobilized resources

The DERs that can theoretically provide flexibility are dispatchable generators, Demand Response resources or energy storage units. The controllable devices used in the Nice Grid project consist of water boilers, electrical heating systems, batteries of various sizes, and more generally, any electrical load that can be piloted through a Time-Of-Use (TOU) signal. Extensions to public lighting facilities are also studied.

In the residential sector, electrical heating and water boilers are particularly interesting for Demand Response, because of their thermic inertia or the inertia of the housing: a load control can be done

in such a way that it is generally unperceived by the owner. In addition, it is a relatively large load for a typical French house and its management offers load increase functions.

In addition to direct load management through automatic device control, time of use tariffs and pricing signals (text messages) enable customer behaviour changes (customer – residential or tertiary - may decide by themselves to switch on or off appliances, to postpone or to anticipate some activities that consume energy).

Some houses will also be equipped with a battery system that can store energy from the network (i.e. when PV is producing) or supply house's load. For regulatory reasons, this battery system cannot be used to inject energy to the distribution grid. It is connected to the LV switchboard of the end-user, independently of the rooftop PV panels, which have a different coupling on the public distribution network. The initial objective was a total of 100 units of 48-V/ 4-kWh lithium-ion battery.

The other batteries are directly installed on the public distribution network and can be managed through the Network Battery Aggregator system, and locally by a Master Controller Unit, with a SCADA monitoring. These batteries include:

- Three 580-V 30-kW/106kWh lithium-ion batteries, connected on LV feeders;
- One 700-V 250-kW/560-kWh lithium-ion battery, connected on a LV feeder and able to run on micro-islanding mode;
- One 700-V 1,1-MW/560-kWh lithium-ion battery, connected on a dedicated MV feeder, next to the HV/MV main substation.

This last one is the first installed on the demonstration area. Studies are in progress for a proposal of additional use cases for this particular resource.

The locations for the 10-feet or 20-feet containers including the whole system (battery, BMS, inverter) have been carefully chosen in order to test the use of network batteries in the various use cases. The safety rules, notably regarding the fire risks or the minimal distance to the adjacent buildings, have drastically limited the possibilities of sites for implantation.

All these devices are controlled by the aggregators through their own information system. For implementation of the activated Demand Response plan, approaches can be based on AMI as a gateway, or not, following the devices that are aimed. The B2C aggregator sends demand response requests to Nice Grid participants following three distinct mechanisms:

- Energy box for project participants with battery (~100);
- Smart meter Linky for participants with controllable loads (~1000);
- Text message alert for all others.

Demand response requests via Linky consist in sending peak demand orders. These orders are the equivalent of load reduction or triggering requests which are 30 min to one-day long. They are sent by the aggregator to the smart metering system a day ahead or a few hours before activation. Peak demand signal is transmitted through the Local Meter Output and then translated by a communication device to manage the dedicated electrical devices (for instance electrical heating). Peak demand signal also drives dry contact state in order to delay or launch the heating cycle of the water boiler.

Demand response programmes will be successful and sustainable only with strong customer engagement. Commercial aggregators (in Nice Grid, the aggregator is also the energy supplier) play a key role to guarantee it. That can only be done if customers perceive an interest, and trust the relationship they have with their supplier. For them, “demand response”, “load shifting”, “aggregation” are terms without any meaning, especially in the residential area. Accepting a battery installation that will take a place in the garage or in the basement is not straightforward. For them, energy means usages, comfort, and... bill.

A key and critical piece in Nice Grid was around customer enrolment in the project. Specific offers have been designed, that push forward how they can benefit from the proposed schemes, in terms of possible bill reduction, of new opportunities (for instance, to run certain tasks in “solar off-peak period”), and also, in the fact that they will make a better use of their own solar production (for customers equipped with PV panels). In any case, customers should remain in control of what happens in their premises and can always escape from any automatic process. Impacts on comfort, if any, are clearly stated. Full transparency in terms of information is ensured: display with load consumption and

information of forthcoming off-peak or on-peak period, regular feedbacks and explanations on the bill, but also global results achieved by the experiment.

These assumptions were deliberate choices made in the project: demand response is not only a technical challenge; it is also a social challenge that relies on confidence, transparency and benefit for all stakeholders. Leaflets, meeting with customers, hotline were implemented, and very positively received.

Management System Architecture

The central component of the DER Management System, the Network Energy Manager, is deployed and run on the DSO's IT infrastructure and integrates with its legacy information system. This platform allows the DSOs to organize the day-ahead transaction process, which is going to be completed with a set of applications of distribution network constraints analysis. The diagram in the Figure 3 below presents the functional architecture of the three main information systems operated by the transaction participant (aggregator), the transaction operator and the distribution system operator. The Network Energy Manager is a customized instantiation/configuration of a more general software suite (Distributed Energy Resources Management System), which aims at handling Distributed Energy Resources in deregulated and regulated context. This software suite is built upon various components, which are not all used in the present Load Reduction operation mode.

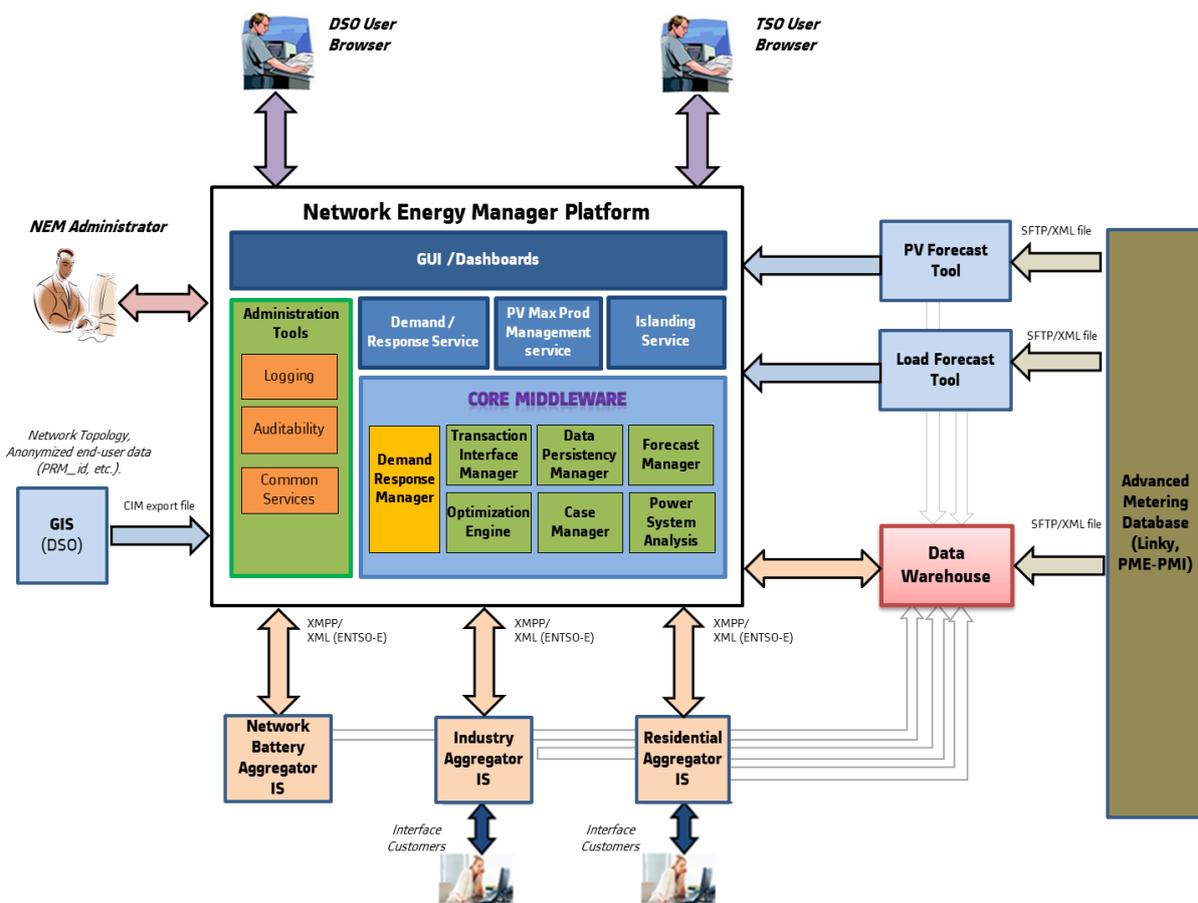


Figure 3: general architecture of the DER Management System

As represented by the

Figure 3, the Network Energy Manager component plays the role of mediation platform in a sense that it effectively:

- composes the different services provided by the components owned by the different actors;
- integrates the data collected from the different systems (forecasting tools, metering, etc.);

- ensures the implementation of the various Nice Grid operation modes on top of a composition of a set of core components;
- provides a set of per service and per stakeholder web GUI.

Additionally, it also provides some tools for the management of the platform (logging, auditability, etc.)

The whole Network Energy Management System is designed around common information model CIM standards and semantics, also for structuring data exchange with definition of CIM profile for each document. The interface definition is hence simplified, as CIM provides the necessary models, classes and relationships and fosters a common understanding. The XML document stream payloads are defined using XML schema. For the interface with the aggregators, the data model of the exchanged documents is designed to be consistent with the standard ENTSO-E business documents, and more precisely the documents related to Reserve Resource Process [4]: Planned Resource Schedule document, used to describe the power requirement; Reserve Bid document, to submit flexibility offers; Reserve Allocation Results document, to notify the bid reservation; Activation document, to notify the bid activation. The approach proposed in Nice Grid is similar to a tertiary reserve market in which the energy associated to the reserve bid is entirely called (not divisible bid). The implementation of the standard can support future evolution of the design for intraday or emergency processes, with distinct steps of reservation and activation, corresponding to both capacity and energy bidding. The use of standard like ENTSO-E based transaction documents facilitates the extension of market design and increases the interoperability of the whole system.

The sole external components that are not deployed in the secured DSO information system environment are the applications for the commercial and industrial B2B aggregator and the residential B2C aggregator. The commercial and industrial aggregator applications are deployed in the energy supplier information system.

These systems cover the following functions:

- Management of the DER registration and enrolments;
- Assessment of capacity of DER flexibilities, aggregation and provision of flexibility block bids in response to the published power needs;
- Dispatching of DER resources in response to the bid activations from the NEM platform;
- Provision of some Demand/Response related dashboards and performance evaluation.
- Supervision and configuration of the building communication devices (device management).

A first set of Linky smart meters have been deployed on the Carros demonstration area. The scope of work of the project Nice Grid does not have a focus on smart metering technologies and experimentation; however, this complete deployment with an astute configuration should provide improved information regarding electricity consumption and production, and even regarding voltage quality. A change of the registration frequency to 10 minutes is studied. As mentioned above, Smart Metering technology is evaluated as an enabler for support of smart DER operations, while it is used to send and receive load control information by the means of a critical peak price signal.

Other issues: forecasting tools, battery aggregation

The research and development on PV forecasts was focused on the aspects reported below, and for each one of them it is possible to identify key learning during the first two years of the project.

- Calculation of probabilistic forecasts
- Calculation of highest allowable production

Probabilistic forecasts represent the state of the art for photovoltaic production forecasts and provide information not only on the expected amount of PV production at a certain time, but also on its probability. They are particularly useful in decision making, since they add a layer of additional information. For example they can prevent decisions to be taken on the basis of unlikely extremely conservative assumptions or, on the other hand, they can be used to highlight the risk associated with seemingly reasonable assumptions. Anyway, although the technology behind the production of PV probabilistic forecasts is being developed, its integration into standard decision making processes must yet be accepted.

In order to facilitate the integration of forecasts into the system, it was decided to enrich the probabilistic forecasts with a prediction of the maximum allowable production at any given time of the day. The difficulty of this task lies in the lack of knowledge of important parameters characterising PV plant production such as surface, inclination and orientation. For this it has been proposed a machine learning approach able to identify both the maximum allowable production and the PV plant characteristics from the analysis of PV power production historical data. The methodology developed has provided good results, although complex plants with multiple orientations represent a complex and still open challenge.

Finally it must be noted how the unavailability of some confidential PV production data may represent a barrier to the production of reliable and accurate PV production forecasts.

The research and development on the Network Batteries Aggregator is still ongoing but two issues have arisen as worthy of further studies and analysis:

- The importance of the update frequency
- The regulatory framework for network batteries

From a technical point of view it was shown that a considerable improvement in the performances of the NBA can be achieved by increasing the update frequency of the NEM. This is because the availability of newer and more precise forecasts allows the NBA to reschedule non useful activities before that they have been performed. This has a double advantage: it reduces the operation cost for the network operator and reduces the utilisation of the batteries, increasing their life. In the demonstration this observation is applied in a two-step process, where flexibility offers are allocated each day for the day ahead but their application is confirmed only on the morning of each day.

Another observation arisen during the development of the project is on the regulatory framework for network batteries. Usually storages are operated by a third party respect to the distribution system operator who in general is not supposed to trade in electricity. Furthermore batteries present considerable losses in the charge and discharge phases that would increase the losses of the distribution network.

Lessons learnt during the first steps of the project

The design phase of the Nice Grid project has brought several lessons. It is fundamental to apply well defined roles and responsibilities of all actors to anticipate the resolution of conflict of interests between the actors. For instance, DSO assets such as network batteries should not be privileged (the fact that, in Nice Grid, network batteries belong to the DSO is not prefiguring any market design preference). The local transaction place must be operated by the DSO to select in a non-discriminatory manner the power reduction offers while avoiding any grid constraint violation. Introducing a gate-based workflow will facilitate the operation of the Network Energy Manager, but also the interaction with the dispatchers through the dedicated UI. The use of large transaction areas would facilitate the aggregator tasks. Indeed, large transaction areas translate for aggregators into larger portfolios of resources, with a higher diversity factor and a lower correlation. The aggregators can therefore improve their forecasts performance, mitigate the uncertainties, and reduce the risk costs. This is expected to benefit indirectly the DSO, thanks to more cost-effective offers submitted through the local transaction place.

The multi-tier structure associated to the definition of a common level for the flexibility transactions could offer a good trade-off between complexity and technical constraints consideration. This approach settles conflicts between concurrent ancillary services. Moreover, roles of the actors and respective access to information are hence compartmentalized, between TSO, DSO and aggregators. The mapping between technical side and commercial side is operated by the unique share of the reference codes of the grid interconnection points. Network operators do not access the individual distributed resource schedules. Similarly, TSO accesses only aggregated flexibility schedules relatively to aggregation levels consistent with its perimeter: area, HV/MV substation.

Extensibility to other services and other resources has been prepared: the Load Reduction operation mode may be completed with intraday or emergency workflows, with a shorter time horizon. The challenges would be the minimal duration for the preparation of the flexibility resources and the time responses of the communication channels to the final device for residential resources.

The ambitious objectives of the project made necessary the development of new concepts in order to answer the needs of a highly supervised, flexible and ICT based future distribution network. Focus on energy-centric services and related business and data models, covers only a part of the issues identified and solved. The demonstration, implying an active participation of numerous end-users, also required deeper insights in the commercial, societal, juridical and regulatory constraints, which have been assessed and handled. Realisation achievements and the first field test results this winter should contribute to the assessment of the different Nice Grid design choices.

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