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Assessment of ICT-based Architectures for the integration of EVs in Smart Grids

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Abstract

The involvement of Information and Communication Technology (ICTs) systems in the evolution of distribution networks towards smart grid approaches is critical. The use of ICTs in the electrical system is already a fact, mainly in transmission but also at energy distribution level. It is expected that this dependency will increase in the future and, among other functionalities, it will help integrate distributed energy resources (DER), including electric vehicles (EVs), into network operation.
Both remote communications and automated actions will be a characteristic of smart grids design, permitting higher levels of control and visibility in distribution networks. In general, smart grid features and processes in the fields of distribution automation, advanced metering, DER integration and customer empowering will condition the availability of services.
DER system involvement in network operation processes is one of the main tools for flexibility enhancement in smart grids and the principal scope of this study. The services that could most suitably be provided by EVs to the network have been analysed through use case descriptions, involving: frequency regulation, load balancing, voltage regulation/reactive power provision, peak shaving, load profile flattening and renewable energy system (RES) integration.
As result of the study, general ICT system requirements, including a network architecture, are proposed for the provision of advanced network services by EVs and other demand resources in smart grid environments.

Keywords: communication, smart grid, load management

1 Introduction

The evolution of distribution networks towards smart grids pursues lower environmental impact through optimized processes (higher efficiency) and the deployment of cleaner energy production technologies.
To achieve this, the system must transit from a passive to an active network, requiring remote and automated control systems, extensive monitoring, and the integration of distributed energy resources (DER), together with updated operation and planning processes.
In this framework, the involvement of Information and Communication Technology (ICT) systems is critical to limit the negative impact of the penetration of electric vehicles (EVs) in the system through network services provision.
This paper introduces the following issues:

- A framework of smart grids features, defined through ICTs and smart components.
- An analysis of the main services that could be provided by EVs and other DER.
- An ICT system proposal, permitting the integration of DER in the smart grid system.

The study is based on the outcomes from EU research project PlanGridEV task 3.3 [1].

2 Smart grid features

The processes that make distribution networks smarter can be classified into the four categories introduced below. An overview of smart grid

components related to each of them is also presented:

[1] **Distribution automation**: it deals with network devices and strategies linked to network operation. Most common components:

- Automated voltage regulators and capacitor regulators for voltage and reactive power control.
- Automated and remotely controlled switches, circuit breakers, etc. allowing reconfiguration and power restoration.
- Automated and adaptive protection systems to facilitate fault clearance and power restoration under different grid conditions. Microprocessor based relays and reclosers.
- Network sensors to measure line loading, voltage level, fault data...
- Energy metering equipment in distribution networks.
- Secondary substation automation, control or monitoring systems.
- Automatic sectionalizing and restoration programmes in substations.
- Power electronic systems: distribution FACTS (Flexible Alternating Current Transmission System), short circuit current limiters, phasor measurement units (PMU, which are more suitable for transmission networks)...
- Energy management systems (EMS) for local energy networks (part of the distribution system).
- Remote terminal units (RTU).
- Direct load control systems (not integrated with AMI).
- Equipment for asset conditioning monitoring.
- Back office system applications: Distribution Management System (DMS), Outage Management System (OMS), Supervisory Control and Data Acquisition (SCADA), Geographic Information System (GIS), work management system, data analysis software, advanced data acquisition system...
- Back office hardware.
- Communication networks for SCADA, network asset control from substations, between control centres, etc.

[2] Advanced metering infrastructure (AMI) and **automatic meter reading (AMR):** smart meter related features and technologies. Main devices:

- Smart meter: in addition to energy measurement, it can be used to control load (through built-in relays), for time of use tariff implementation, voltage detection, power limitation, etc.
- Meter data management (MDM) system.
- Communication networks: home area networks (HAN); between meters and concentrator (Neighbourhood Area Network, NAN); and between concentrator and head-end system (Wide Area Network, WAN).

[3] DER integration: integration of distributed generation, storage and demand management resources, including EVs, in the distribution network operation. Related components:

- Distributed generation installed in distribution systems.
- Storage installation in distribution systems.
- Demand management systems: from control centres or virtual power plant systems to customer energy management systems (CEMS).
- Communication networks for DER control: from control centres to the DER plant management systems, from the DER plant control to the devices.
- Energy data management (EDM) systems.

[4] Customer empowering: devices and strategies that can induce customers to change their energy consumption habits. Systems might be owned either by distribution system operators, retailers or by customers themselves:

- Customer information system (CIS), Customer Relationship Management (CRM) including care and billing systems (retailers).
- Web portal for information sharing.
- In-home displays.
- Grid ready appliances and devices, including EVs and EV supply equipment (EVSE).
- Distributed generation installed in customer premises.

Summing up, the provision of smart grid functionalities will rely on two main components, which will be present in all four points above:

- **ICT**s permit the exchange of information between actors and components for the development of actions such as monitoring and control.
- **Smart systems**, including intelligent electronic devices (IED), i.e. devices with processing, storage and communication capacities. Located at both ends of communication links, they can run smart algorithms, permitting automated actions and

local control (providing a fallback when communications are not available).

Both remote communications and automated actions will be relevant and characteristic of smart grids design, permitting higher levels of control and visibility in distribution networks.

3 Services for smart grids

A service classification is presented below as starting point to focus on the services that EVs, and DER in general, could provide to the electricity network:

- **Network ancillary services provision**: frequency and voltage regulation, load balancing and deviation management, reactive power provision, intertrips (automatic disconnection of generation or demand when a specific event occurs).
- **Network sustainability improvement**: grid extension postponement (peak shaving, load profile flattening...), DER integration (Renewable Energy Sources, EV supplying electricity to the grid, storage...).
- **Power quality services**: phase balancing, harmonic and flicker reduction, voltage dip compensation.
- **Aggregation**: distributed load and generation.

Here, we target at services that require ICTs for their implementation, therefore, some of the previous are **discarded** for further analysis:

- Power quality services are mainly related to features achieved during the design phase of both devices and systems, resulting in ride through capabilities, harmonic filtering, phase switching, etc.
- Frequency primary regulation and intertrips services can be provided through the use of locally installed frequency sensitive protections. These services are normally linked to connection agreements and with no compensation scheme behind.

In addition to this, the aggregator could provide any of the above listed services and, for that reason, the aggregation is not considered as a separated service (it is an administrative service that permits the distribution system operator (DSO), or any other party, not to deal directly with a high number of small flexibility providers).

Summing up, in the following subchapters, we will focus on network ancillary services and on services addressing network sustainability improvement. After a general explanation of the service, a use case is proposed. These use cases intend to show different strategies (direct and indirect control, time of use tariffs...), which are not specific of the service where they are proposed, i.e., they could be used in other services as well.

Emergency mechanisms requiring the unilateral intervention of system operators are not considered here, since no service is provided by a third party. This is the case when it is not possible to use market mechanisms to face load/generation deviations and, e.g., some loads must be curtailed.

3.1 Frequency regulation

Frequency is a parameter of the global electricity system and, therefore, its regulation is managed by the transmission system operator (TSO). It is controlled at different time scales, normally resulting in three **types of services**, which may adopt different denominations depending on the market:

- Primary regulation, frequency response, frequency control demand management, etc.: immediate and automatic response (in few seconds). Built-in frequency sensitive protections are required within devices (normally generators). As already commented, as it does not require ICTs, so it is left out of the study.
- Secondary regulation, fast reserve, etc.: service activation within 30 seconds to 2 minutes, to be maintained during few minutes (around 15).
- Tertiary regulation, reserve, etc.: response within minutes to be maintained during few hours (minimum 2, normally).

Each service can be mandatory or optional depending on the provider characteristics. It can be contracted, depending on the case, through bilateral contracts, periodic tenders (annual, seasonal, monthly, daily) or connection agreements (subscription conditions). Service activation could be directly or indirectly controlled by the system operator.

Normally, eligible parties need to meet certain features, e.g. to have a minimum size (few megawatts order), and to qualify as service provider. Generators are the main actors offering frequency regulation but, currently, some systems (e.g. UK) do also permit the participation of demand.

Tertiary frequency regulation relies on big capacities and requires long supply periods from providers. In order to meet these requirements, huge aggregation capacity is required. Coming to

EVs, apart from the small capacity of each of them, it is feasible that some will disconnect or discharge to unacceptable levels within the service time frame and, as result, others would have to replace them, in order to keep the aggregated capacity firm. For this reason, we consider that EVs will not be able to provide this service in the short- to medium term.

Secondary regulation faces the same big capacity aggregation challenge together with the fast response requirement, but shorter operation times are requested. In consequence, it is deemed a more realistic service for EVs and small loads in general. However, some regulatory barriers must be overcome:

- Aggregation is still necessary and, therefore, the aggregation role should be defined by the legislation and should be eligible to participate in ancillary markets.
- Demand should be also accepted as flexibility source, which today it is not the case yet in many European countries.

From the technical point of view, some challenges do also exist. All providers must qualify as fast reserve suppliers and it is normally required that they pass some tests, in order to have the certainty that they will meet the required technical and operational specifications. Response time is a challenge for EV participation in such schemes when both EMSP and charging service operators (CSO) are involved in the communications. For example, in the Spanish secondary frequency reserve service, direct communication (direct control) is required between production units and the AGC (Automatic Generation Control) system. This would leave out EVs as providers. To avoid this, new rules could be proposed where service providers' time response features would be assessed via test.

A **use case** is proposed aiming at the allocation and activation of the secondary frequency regulation service. These are its main features:

- During the generation programme definition process in the day-ahead wholesale market, secondary frequency regulation reserves are settled.
- The TSO requests a regulation band for each area and market period in the following day.
- Service providers offer their capacity increase and decrease capabilities together with a price (€/MW).
- The TSO allocates the service considering capacity requirements and minimum costs for each of the periods.
- If secondary regulation is effectively needed, a central control system calculates up or down deviations and sends control signals to allocated generators in an area, through an area control centre, which forwards the settings to the involved production or demand units. This is performed automatically thanks to the AGC systems.

Other characteristics of the design of the service are also out of the scope since they do not have any influence on the ICT architecture, e.g. mandatory/optional, eligible parties, etc.

3.2 Load balancing

Load balancing, deviation management and imbalance reduction are terms with similar meanings but with specific characteristics depending on the market.

We consider here the following definition for the load balancing service: when balance deviations between two intra-day electricity markets are expected to surpass certain capacity that may endanger system tertiary regulation reserves, a tender is called to re-programme the following market periods until the next intra-day market. The units already programmed for those market periods and authorized to provide this service can participate in the tender.

Traditionally, only production and pumping storage plants are eligible for this market.

A **use case** is proposed to cover the allocation and activation of the load balancing service:

- The service is called via tender when tertiary regulation reserves are under risk due to deviations in the generation programme. DER aggregators are eligible.
- Once called, providers have minutes (e.g. 30) to place their bids, specifying type (generation, consumption or demand reduction), maximum energy (MWh), maximum energy variation (MWh/h), and price of the offered energy (€/MWh).
- Tender results are communicated to assigned service providers. The programme for the next periods is modified and published accordingly; service providers modify their schedule to meet the new agreements.

3.3 Voltage regulation/reactive power

In the transmission system, voltage regulation is related to reactive power control, which can be provided by generators above certain capacity, transmission system operators (through capacitor banks, reactances, transformers with regulation, line topology changes...), consumers connected to the transmission network and distribution system operators. The latter will use all voltage control mechanisms available within their management area to meet TSOs requirements at transmission/distribution boundary nodes.

Normally, certain reactive power generation/absorption margins are mandatory and with no remuneration for service providers. We could think of a voltage droop characteristic required by regulation to EVs to meet these obligations. However, capacity above obligatory limits is also possible and assigned providers get monetary compensation for the service.

Because voltage regulation is a local issue (related to a particular point in the network), service providers are assessed on yearly basis depending on their features. Voltage settings are defined daily during the technical restriction assessment of the daily generation programme coming out of the wholesale market sessions. The system operator will set daily, for each service provider, the reactive power limits for each programme slot in the next day. Participants receive remuneration both for the available capacity and the effectively absorbed/generated energy.

Traditionally, the voltage control service is linked to transmission systems but distribution system operators need both to control voltage in their systems and meet the requirements set by the TSO. Following the example of the TSO, DSOs could leverage the capabilities for voltage control of final consumers and generators connected to the distribution system, in addition to the resources linked to their infrastructure (capacitors, tap changers, storage, etc.). It must be considered that the lower the voltage level, the more voltage control is dependent on active power, since networks become more reactive and less inductive. Therefore, active power consumption and generation management could also be deployed for voltage control.

Due to the local characteristic of voltage, aggregation should consider the location of service providers.

The following **use case** is proposed:

- The DSO issues a load/generation schedule to respond to voltage profile requirements on day-ahead notice (it could also be chosen other time frame) for all the periods of the wholesale market. Controllable generators (e.g. CHP), storage and loads are eligible to help control the voltage at the connection point.
- Apart from the mandatory voltage control range, an optional band is offered to aggregators (and individual end-users) willing to provide the service. The service provider should be remunerated by offering this extra capacity for voltage regulation.

The procedure is similar to a non-specific day-ahead load/generation schedule definition, the difference is the final objective of the control: peak shaving, voltage control, etc.

3.4 Peak shaving

The peak shaving service aims at postponing network capacity investments in the distribution system through on peak load reduction. It can be achieved through different strategies:

- Day-ahead operation: tariff design (fixed or variable time of use) or load/generation schedule definition (indirect control).
- Real time operation: through direct and indirect control mechanisms, or tariffs design (such as critical peak pricing or real time tariffs).

The service provision assignment can be carried out via market structures (to be implemented at distribution system level), specific bilateral contracts or in the frame of electricity supply contracts.

Even if demand peaks are normally forecasted day-ahead, unexpected situations may arise in the network, as it actually occurs in the transmission system (solved there by frequency regulation and load balancing): DER generation forecast change, topology change due to fault in the network or asset failure (e.g. transformer), etc. To face these occasions, a **use case** is proposed where a direct control is performed by the DSO in order to avoid severe load curtailment (not as emergency management but as kind of intraday, hours-ahead or quasi real time strategy):

- Event response characteristics are agreed between DSOs and aggregators, and between aggregators and flexibility providers, through bilateral contracts, where the conditions of the service are specified: flexible capacity, number of curtailments or load reductions in a day/week/year, remuneration scheme, penalization for not fulfilling the requested action, etc.
- The DSO sends load management indirect control actions to flexibility providers: demand reduction or generation increase.
- Aggregators provide the service by managing the flexibility of their customer portfolio.

3.5 Load profile flattening

Somehow related to peak shaving, the main focus of this service is set on load profile flattening and, therefore, on system efficiency improvement through losses reduction. The most suitable tool to achieve this objective is the use of time of use energy tariffs linked to subscription contracts, since the success depends, to a wide extent, on energy customers' habits modification.

The positive aspect of tariffs is that ICT requirements are limited and, as consequence, the impact of investment on the DSO side is reduced compared to other services provision. On the contrary, the main drawback is that customer involvement and response is more difficult to obtain and predict. Therefore, relevant efforts should be paid to increase customer awareness, including campaigns, in-home displays, building/home energy management systems, etc. In addition, demand forecast and related deviation correction measures, as well as tariff design, become increasingly important.

Simple tariffs, e.g. fixed steps and prices, might involve some problems. For example, lower price during night time might shift the peak to the period right after the tariff switch time instead of reducing it. In order to avoid this, a smart control is necessary at higher level (aggregator, DSO...).

Another aspect to be considered is the different demand / generation balance casuistry that can take place in a distribution network. If high PV capacity is installed in a network, generation can be higher than demand during mid-day hours in summer time, leading to low energy prices; however, in wintertime, on a cloudy day, demand can be much higher than generation. Even if seasonal tariffs may be used, fixed time of use tariffs might not be the most efficient strategy for load curve flattening.

A common problem of time of use tariffs in most European countries today is that the limited energy price difference between periods is not appealing enough for customers to change their habits. In more stressed systems (e.g., in some USA states), price volatility is higher, which makes it possible for end-users to benefit from this type of tariffs (this is common for most demand response strategies today).

Both day-ahead and real time prices (including critical peak price) can be communicated using information protocols permitting such type of data structures, via multi-point messages (e-mail, for example) or through the publication of the data in a web site.

The proposed **use case** considers the following:

- The DSO establishes network fee prices, in response to expected network conditions. It informs about this fact in its web site and sends messages to energy service providers (retailer, EMSP, DER aggregators). Price profiles might be different depending on the network and demand characteristics.
- Service providers communicate new prices to end-customers through smart devices able to optimize local demand and generation. DER aggregators use the new prices to re-schedule their production units if necessary.
- DSOs are able to limit power demand by controlling smart meter settings, this assures a maximum demand limit for each period.

The level of automation available in customers' premises will impact on demand response ratios, especially if prices are very variable from one day to the other. Smart algorithms are able to avoid peak shifts instead of real profile flattening.

Summing up, no real service is provided by end-users to DSOs and, therefore, the figure of the demand aggregator role is not needed. However, the consumers' habit modification certainly provides a service to the system as a whole and, as a consequence, to the society by means of environmental benefits.

3.6 RES integration

Load management can increase the integration of sustainable energy from fluctuating renewable energy sources (RES) in the system. The excess of energy during off-load periods may require the curtailment of energy production to avoid operation risks, therefore the increase of EV consumption at this time may help integrate fluctuating RES.

This poses similarities, in terms of architecture, with the described peak shaving use case, however the objectives of the strategy differ: while peak shaving seeks to avoid risk during on-peak periods through remand reduction, RES integration in based on demand increase at off-peaks to permit a higher production of renewables.

Energy storage at distribution level (in customer premises, including EVs with vehicle to grid capabilities, secondary or primary substations) increases the operation flexibility of the system, making it easier to shift energy consumption between periods and profit from non-controllable generation.

The following **use case** is proposed:

- When deviations from forecasts occur, the DSO issues control signals and demand schedules (normally demand increase) on short notice (hours ahead) for the following periods of the day.

- Small size demand is controlled through aggregators (conventional customers and EV customers). The DSO manages the available storage connected to its network.

4 ICT system requirements

The start point to define ICT systems within a smart grid is to select the strategies that will be deployed within a planning period of time, in order to achieve targeted features and services provision.

Once smart grid strategies have been planned, the ICT networks and backend systems associated to them should be defined. In general terms, ICT systems will have to meet the following general features:

- ICT systems should be scalable to face the growth of demand and the increasing number of controllable and smart devices in distribution networks.
- The design should optimize data exchange requirements, in order to avoid oversizing the communication channel and the computational power.
- In order to achieve interoperable solutions and higher levels of competence, standardized and widely used protocols should be introduced in ICT network design.
- Security aspects should be introduced from the early stages in ICT network design. The criticality of the functionality and the impact on technical aspects, such as latency and volume of data, should be considered.
- Optimum communication technologies should be chosen in accordance to end-to-end coverage, size and frequency of information exchange, latency, data flow direction and security/reliability requirements.

4.1 ICT architecture proposal

An ICT architecture is proposed based on:

- The smart grid services analysed above.
- The main characteristics of communication technologies and information protocols [2][3][4][5][6][7].
- The SGAM (Smart Grid Architecture Model) layer approach and the identification of smart grid set of standards performed by the CEN-CENELEC-ETSI Smart Grid Coordination Group (following Mandate 490) [8].

This architecture, see figure 1, permits to develop all the use cases proposed in the previous chapter. It shows the communication links between smart grid components, which can be related to different actor roles, and it makes reference to suitable standards for each connection, when available.

The figure is complemented with additional information in the following subchapters (the abbreviations not explained in the paper, before or after the figure, are all included in a legend).

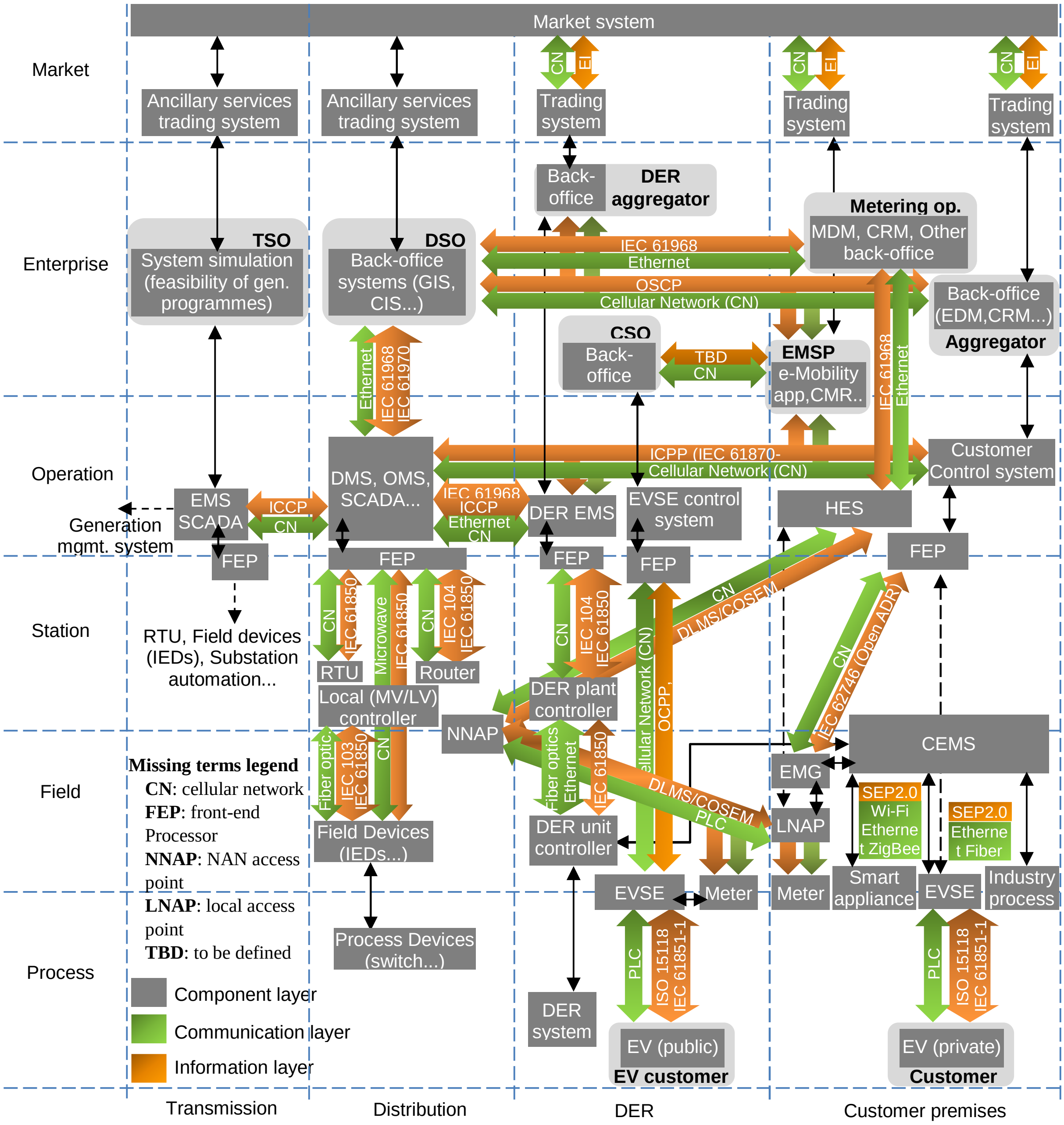

Figure 1: ICT architecture proposal

4.2 Distribution automation

It is mainly represented at the Distribution domain in the previous figure, even if distribution operations do involve all other domains (transmission, DER and customer premises).

Several processes fall within this field but, because of its direct impact on power quality and reliability, protection remains the most critical application for the distribution service provision in smart grids. Two aspects are relevant when dealing with ICTs in this field:

- *Monitoring*: it permits to achieve awareness about network operation conditions.
- *Response to faults*: it is an automated process due to the fast response required.

Fault clearing related applications require very fast transmission of signals, with total times of half cycle, i.e. 10 ms [9]. These latency requirements can be only offered by few communication technologies such as fiber optics, Ethernet and high performance microwave [10]. These networks are Local Area Networks (LANs) in substations or other sites with local control systems. They are normally private.

Other processes do not require such tight response times, for example [9]:

- *Slow automatic interactions*: such as normal state information (SCADA system, for example) or less time critical automation messages (e.g. network reconfiguration actions), in the order of 100ms. These actions can be performed using technologies such as LTE (cellular mobile technology) and WiMAX.
- *Operators commands*: involving reading and changing of set points, presentation of system data, normal event handling, etc., in the order of 1 second. Possible communication technologies: PLC (Power Line Carrier) communication, wireless mesh or 3G.
- *Information used for post-mortem analysis or off-line statistics:* this is the less time-critical data in distribution automation, because it is never involved in real time operation processes. All most common communication technologies are suitable to carry out these low latency functionalities.

4.3 AMI

Remote meter reading and configuration are common tasks that will have to be performed in all smart grid environments in the future. Message size for one meter reading (just meter data) can be around 100 bytes, so network requirements for data retrieval depend on the number of meters per concentrator, and on the latency, which could go from few seconds for on-demand meter reading, to thousands of seconds for data reading for monthly billing.

AMI and AMR architectures are normally based on a data concentrator connected with smart meters in a neighbouring area network (NAN) via PLC technology. This concentrator is linked to a head end system (HES) collecting all demand data through a WAN technology, e.g. cellular mobile technology.

The HES is then connected to a metering data management (MDM) system at the DSO or metering operator company, through a CIM (Common Information Model) based protocol. This MDM system feeds all the applications requiring metering related data.

Coming back to figure 1, both distribution and customer domains are involved in this case.

4.4 EVs and DER control for ancillary services provision

In the proposed ICT layout, all DER are characterised by similar architectures, located both in DER and customer domains, and based on:

- A central control system at the operation zone.
- A plant or local control (station and field zones).
- A unit or device control.
- A process device.

DER control is linked to both operation and ancillary services provision.

Ancillary service characteristics condition the networks used to fulfil them. Activation times may vary from the fast response required to provide secondary frequency regulation (around 30 seconds), to day-ahead communications.

Differences between control functionality implementations can go further. Regulation, market and business model characteristics define the actors involved in the transmission, where the load and generation control could be direct or indirect, through aggregators or straight between DSOs and end-users. This has direct impact on response times.

In many cases, the communication between actors is not standardised, and this might represent interoperability problems. In general terms, when the different roles (DSO, aggregator, EMSP, CSO...) are played by independent parties, WAN public communications will be used, for example, cellular mobile networks (CN), from GPRS to Advanced LTE, depending on the data rate requirements of the services. In this case, the total end-to-end transmission time depends more on data processing within back-end systems, that on the pure communication, coding and decoding interval. Therefore, in order to make a certain service provider eligible, system operators may request to certify that an end-to-end communication meets service performance requirements.

After the communication between actors is performed, an intra-company communication might be required. If communications are performed by a party (e.g. DSO) and they do not involve any additional players, the proposed data protocols are those related to Common Information Model (CIM), for the exchange of information between different applications (IEC 61968 and IEC 61970). In this case, the communication network characteristics might be the following:

- **LAN**: Ethernet, PLC... depending on the available infrastructure and data rate requirements. Fiber optics represents normally the most expensive solution and it will be used only when high transmission speeds are required or when electromagnetic interferences may affect transmitted signals (polluted environments).

- **WAN**: cellular mobile networks are an option for data transmission. The suitability of using a public or installing a private network should be assessed. Public networks might not guarantee a quality of service, unless the operator is able to provide a Service Level Agreement (SLA), but require no own infrastructure. Virtual Private Networks (VPN) can also be stablished, they cannot make online connections completely anonymous but they can increase privacy and security through the use of tunnelling protocols. On the contrary, private networks permit full control and access for licensed spectrums, but the infrastructure and band acquisition involves high investment, and underutilization is always a risk. Unlicensed spectrums are free but they can suffer from unpredictable interference and saturation situations. Other WAN technology solutions are microwave, WiMAX and, if required coverage is not too high, wireless mesh networks (based on Wi-Fi, Zigbee...).

When service provision is based on market mechanisms, market operators do normally set communication requirements. However, standardisation efforts are being performed at European level also in this field (OASIS EMIX, EneryInterop - EI -, IEC 62325).

Normally, the provision of services, such as those mentioned above, does not require specific ICT solutions and, therefore, the same networks dedicated to distribution automation or AMI can be used if appropriately sized.

4.5 Security and reliability

Security and reliability aspects affect transversally the whole ICT architecture.

Security is critical in smart grids because it can affect both network reliability and privacy issues. Smart grids are especially vulnerable due to the large number of components, insecure communication protocols, lack of awareness, old equipment legacy, etc. Problems may arise from technical risks but not only, e.g. human failures, organised crime, natural catastrophes, etc.

In order to face security, an assessment of risks should be carried out during the ICT system design steps. The most critical points should be identified by taking into account the threats, vulnerability and impact of each risk. Once identified, priorities should be assigned and appropriate measures should be chosen, implemented and maintained, in accordance to cost/benefit considerations.

Merging different security approaches involves additional risk and, to avoid problems stemming from this, at European level the harmonisation of security requirements is being pursued through the selection of existing standards and the identification of gaps.

Security affects the **reliability** of distribution networks, which are expected to be more and more dependent on ICT performance. However, the impact of ICT failures under different system conditions should be further studied and methodologies to perform such evaluations should be performed [11][12].

The reliability of a network can be calculated by the reliability of its components and its topology (series, parallel or mesh). Generally speaking, the existence of alternative paths to transmit data from one point to another increases reliability and, therefore, system redundancy or mesh topologies, permitting the nodes to select dynamically the best paths in accordance to the availability of connections, present better reliability levels, at least theoretically.

As already mentioned, reliability in electrical networks is much related to protection systems, and the misoperation of the latter is cause for disturbances. Therefore, the design of protection systems should be accurate to respond to network characteristics. Distribution smart grids may bear different demand/generation conditions including energy flow direction change and, because this may affect protection settings, it may be required to install adaptive protections in certain points of the network.

Other strategies to improve ICT system reliability are, the already mentioned, use of redundancy, e.g. of hardware, data, software...; the development of reliability databases to provide historical information and improve design; the reduction of wrong signal reception, for example, through data conditioning; the increase of the reliability of less reliable components; etc.

Regarding data privacy, tasks like data encryption and signing increase the transmission time and the volume of messages. Therefore, the impact of security tasks should also be considered in connection with latency and computational capability requirements (e.g. smart meters, communications...).

4.6 ICT overall system

Summing up the previous requirements, DSOs will configure their smart grids through three different networks, covering distribution automation, AMI, DER control and customer empowering functionalities. However, these networks can be shared up to some extent. The proposed solution is the following:

- One common ICT infrastructure for AMI, non-critical distribution automation, DER control and customer empowering: the final solution should be scalable, built upon standard solutions when available, hierarchical according to the presented ICT architecture, with accurate coordination, and considering security and reliability aspects from the design phase. Public networks could be used for less critical information exchange and Service Level Agreement options could be chosen for communications requiring intermediate resiliency.
- Critical distribution automation ICT infrastructure: these networks are normally local area networks in charge of connecting control systems with intelligent field devices through fast and reliable technologies such as fiber optics. Security risks should be carefully assessed and managed, and reliability improvement strategies should be deployed. Private networks are recommended.

5 Conclusions

New strategies for network operation will be achieved through the increased flexibility of processes, the higher control and automation of network assets and the participation of the distributed energy resources (DER), including the end-users of energy.

The use of ICTs in the electrical system will increase with the evolution towards smart grids. Apart from the interaction between actors, most smart grid strategies will depend on ICT systems, e.g. remote control, monitoring, etc. Technical solutions already exist to overcome the new challenges. The communication means are ever faster and able to transmit higher amounts of data, information protocols permit an intelligent communication with demand and network assets, data mining processes allow a better management of big amounts of data, etc. However, still certain improvements are required to enhance the efficiency of ICT deployment in smart grids:

- Interoperability of solutions should be improved to obtain more effective implementations and more competitive markets. The existing gaps in standardised communication solutions between actors (e.g., between DSO and aggregators) should be overcome. This is a target already pursued at European and international levels through initiatives as that of the Smart Grid Coordination Group and the COTEVOS EU funded R&D project [13]. Still, there is a long way to go.
- New smart grid deployments will coexist with legacy systems and they should be coordinated. The life cycle of new technologies, including firmware and software application upgrades, should also be carefully studied and deployed.
- Security aspects should be included in ICT design. The high number of devices, the use of wireless communication technologies, the protocols not inherently secure, legacy systems, the intersection between different security boundaries, etc. should be taken into account. Risk assessment should be conducted to identify vulnerabilities, and actions should be taken to overcome potential problems.
- The impact of ICT reliability on smart grid reliability should be further studied, through the creation of event databases, post-mortem analysis, and assessment methodology development.

In this context, market and regulation are also relevant aspects that need further development in order to foster the electricity system evolution towards smart grids:

- The inclusion of lower size customers in wholesale and ancillary services markets would increase the availability of flexibility for system operators and, therefore, it might have a positive impact on system operation costs. Their small size makes it advisable to aggregate resources in order to obtain capacities with real impact on network management. The participation of the aggregators and other new actors should be fostered by regulatory improvements and feasible business model opportunities.
- The cost of implementing new operational strategies should be lower than business as usual network expansion. In regulated environments, as that of energy transmission and distribution, this would provide a benefit to the whole society, resulting in lower tariffs for customers and lower investments required

in the energy system. However, involved parties, system operators in one side and service providers (end users and aggregators) in the other, should also benefit from using more efficient and sustainable procedures and from offering a service, respectively.

- New smart grid operation strategies should be included as remuneration concepts. ICT systems improving distribution network management and DER participation in operation procedures should be considered eligible network investments, in the same way as new lines or substations are considered today.
- Regulation should guarantee high levels of competitiveness in energy markets.

All three aspects, i.e. technical, market and regulatory, are critical to permit the deployment of ICT based strategies. This deployment should always look for the optimum solution implementation, targeting always sustainability. Therefore, apart from technical and cost aspects, social impact should also be taken into account in the global assessment of solutions.

As result of this analysis, a general ICT architecture has been proposed to permit new strategies for distribution network operation, with the involvement of distributed energy resources (DER) as service providers. It results impossible to define a unique solution addressing all casuistry, but the main technical aspects to be considered have been revised and some regulatory barriers have been identified.

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