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E-LOBSTER

Electric losses balancing through integrated storage and power electronics towards increased synergy between railways and electricity distribution networks

Deliverable D3.1
Report on the current operating standard

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Executive Summary

The E-LOBSTER project is exploring a Rail to Grid (R2G) management system based on a smart soft open point that operates as energy interface between the power distribution grid and the power supply of the rail network. The proposed system allows active control of the energy distribution to the various users and suppliers within the grid and railway systems to ensure a reduction of power losses and a more efficient use of local power generation and energy storage.

To achieve these goals, it must be ensured that the E-LOBSTER infrastructure can fully integrate with current existing grid infrastructure. European energy network legislation contains numerous rules and processes outlined in various grid codes and standards to ensure a safe and reliable network. Beyond just applying on a technical level, these regulations are crucial to every aspect of the project's implementation. Including technical requirements and thresholds for system components, as well as rules regarding the installation of the network in parallel with existing distribution arrangements. This knowledge search has identified three key aspects of legislature and standardisation important to the development of E-LOBSTER.

Firstly, the standards and regulations concerning the physical integration of E-LOBSTER to the wider national and European grid infrastructure. This concerns standards related to component thresholds, required technologies, and other similar polices. While standards that can be directly translated to a project like E-LOBSTER may not exist, future standards are proposed for smart grid infrastructures. In the proposed future guidelines for smart grid standardisation there is a strong focus on robust control infrastructure and secure data transfer across the network. Focusing on these aspects for E-LOBSTER may ensure regulatory barriers during implementation are kept to minimum.

Regulations concerning the energy storage component of the project must also be considered. This concerns both the integration of energy storage systems with the railway overhead power supply network but also the wider grid as well. These consider not only for batteries, but also for emerging storage technologies as well. Industry developments such as changes to embedded generator and the reduction of 'red-band tariffs' will prove impactful to economic viability of E-LOBSTERS energy storage systems. Closely following developments within the Energy Storage sector may prove beneficial to the development of E-LOBSTER, itself containing many energy storage elements.

Finally, there must be consideration for the legislation relating to the installation and operation of E-LOBSTER. This concerns the contractual agreements with DSO's, network operators and other actors that need to happen to ensure the project is operable. There are various electricity distribution models throughout the continent, and so plans for implementation will vary, but there are various EU mandated codes that outline the process of connection to European power networks. The European Union is proposing a move to a common 'Energy Union', with a prioritisation on modern and secure information and control systems with transparency of data, as well as a move towards renewable energy sources. E-LOBSTER fits in with both of these aims, so it is worth looking at new policies and incentives in this area to see if these can enhance the projects economic viability.

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1 Introduction

The E-LOBSTER project aims to provide a Rail to Grid (R2G) management system that uses a new smart soft open point to actively control the flow of energy through the overhead railway network and the power distribution grid.[1] The proposed system allows not only the recuperation of the braking energy from the train on energy storage devices, but also the possibility of supplying back this energy to another part of the distribution network not normally connected to the traction power supply.

The main goals of the E-LOBSTER project are:

- To reduce electricity losses within the overhead system
- To ensure that the grid retains stability in areas with a large supply from renewables
- To accommodate the needs of new energy actors such as EVs, electrical storage devices and prosumers.

To achieve these goals, the project must ensure that the E-LOBSTER infrastructure can fully integrate with currently existing grid infrastructure. The European Members States electricity grid network contains numerous rules and standards outlined in its various grid and distribution codes to ensure a safe and reliable network. Beyond just applying on a technical level, these regulations are crucial to every aspect of the project implementation. From requirements and thresholds of the components themselves to rules regarding the installation of the network in parallel with existing distributors.

In terms of adhering with current legislature, the E-LOBSTER system proposes a unique challenge. The current infrastructure of the grid means that there are not sufficient relevant regulations, so instead this knowledge search will draw from existing and upcoming industry standards and regulations to derive a prospective framework for which the project can be developed around.

There are three main issues that this knowledge search will address.

- The standards and regulations concerning the **physical integration** of E-LOBSTER to the wider national and European grid infrastructure. This concerns standards related to component thresholds, required technologies, and other similar polices. The main question for this section will be "Is the currently envisioned E-LOBSTER project technologically viable?"
- The standards and regulations concerning the **energy storage component** of the project. This concerns both the integration of energy storage systems with the overhead network and also the wider grid as well. This not only concerns traditional storage methods such as batteries, but also emerging storage solutions for surplus energy like Electric Vehicles. The main question for this section will be "Is incorporating energy storage systems viable for the currently envisioned E-LOBSTER project?"
- The standards and regulations concerning the **installation and distribution** of E-LOBSTER. This concerns the contractual agreements with DSO's, network operators and other actors that need to happen to ensure the project is operable. The main question for this section will be "Is the currently envisioned E-LOBSTER project economically and logistically viable?"

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[1] E-LOBSTER - *Electric LOsses Balancing through integrated STorage and power Electronics towards increased synergy between Railways and electricity distribution networks (2018)*. Cordis website

In the technology roadmap "European railway energy roadmap: towards 2030" the European Rail Research Advisory Council stated the importance of developing energy storage and battery technologies for future rail infrastructure.[2] In this context, the E-LOBSTER outcomes will have a relevant impact.

RES Legal provides an important repository of the available opportunities for connecting renewal energy sources (RES).[3]

[2] Cheron, C., Walter, M., Sandor, J. and Wiebe, E., 2012. *ERRAC Roadmap. Towards 2030: energy, noise and vibration European railway roadmaps*. Procedia-Social and Behavioral Sciences, 48, pp.2221-2229.
[3] http://www.res-legal.eu/home/

1.1 The Railway (Train) to Grid System

With reference to the railway electrification network, E-LOBSTER proposes an adaptation of the current electrification infrastructure. Conventional systems have been implemented around the world for decades and have various uses, with many permutations throughout Europe. Overhead networks in the UK take the form of a 25 kV AC system for freight and passenger rail [4]. Germany and Austria use a 15 kV 16.7 Hz AC network. The other common systems in Europe for mainline railways are 1.5 kV DC and 3 kV DC. Tramways and metro systems often operate at 600 - 750 V, although there are many line specific systems. The power supply for the Madrid Metro is a 600 V DC overhead system.

A 'Railway to Grid' system differs from standard overhead rail infrastructure in the fact that it is designed to allow **bidirectional transfer of energy**. Not just drawing power from the grid to power the electric rails, but also transferring electrical energy around the overhead rail network and even supplying stored energy back to the grid.

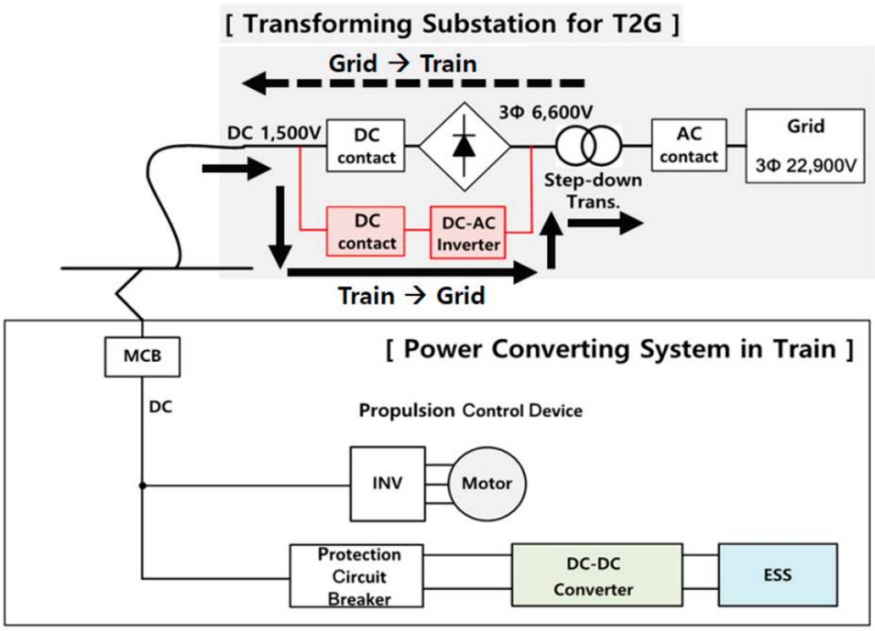

Figure 1 : An example of a proposed railway to grid system from South Korea

The method of installation for Train (Railway) to Grid systems is drawn from existing grid-tied electrical systems, such as **Vehicle to Grid (V2G)** systems. A Vehicle to Grid system refers to the interface between Electric Vehicles (EV's) and the National Grid, where energy is drawn from the grid as the EV charges, but in addition to this, energy can be supplied from the EV back to the grid as well. [5]

While Vehicle to Grid is based on the concept of a freely moving vehicle periodically connecting to the main grid to charge up, a 'Train to Grid' system is using the existing overhead electrical network with the network itself interfacing with the wider grid. Therefore, it is important to note that not only can a Railway to Grid system be abstracted to an energy storage system in the context of its relationship to the wider grid railway; but the range of operations and actors within the railway to grid sub-system

[4] Nyberg. F and Pollard. R (2015). [Network Rail: A Guide to Overhead Electrification](), Alan Baxter.
[5] Cleveland, Cutler J.; Morris, Christopher (2006). *Dictionary of Energy*. Amsterdam: Elsevier. p. 473. ISBN 0-08-044578-0.

also lend comparisons to microgrids, which are self-contained electricity grids that operate independently from the wider distribution network.

There are various examples of railway to grid-based projects under development:

- In South Korea, the **Korea Railroad Research Institute** is developing a Train to Grid system for a wireless railway vehicle concept currently in development. This T2G system uses large Energy Storage Systems (ESS) to transfer power back to the grid while the wireless trains are at standby. They claim that this method can end up reducing overall energy consumption by 0.74% [6].
- In the US, the **ARES** (Advanced Rail Energy Storage) project in California is using rail infrastructure to provide an alternative source for energy storage. An OLE powered train directly connected to the grid is placed on an elevated railway, drawing power and later being let down the elevations and supplying the regenerative power generated back to the grid. Its main purpose is to provide supplementary power to the network during blackouts or outages to increase network responsiveness [7].
- Another example of a railway to grid-based project is **Hesop**, a rail-based energy recovery system developed by **Alstom**. Designed to harness energy lost through train braking and supply it to the line or even the wider grid itself. Alstom have sold 128 Hesop substations to date for various projects around the world. Including metro systems in Milan, Dubai, and Panama, and tramway networks in Sydney. The system has been trialled in the Cloudesley Road underground station, and further rollout is planned along the underground network.[8]

[6] Go, H.-S. et al., (2018). *Reduction of Electricity Prices Using the Train to Grid (T2G) System in Urban Railway. Energies*, 11(3), p.501.
[7] Aresnorthamerica.com. (2018). *Energy Storage - Grid Scale Energy Storage - Ares North America.* [online]
[8] English, C. (2016). *Alstoms multi-award winning energy recovery substation in commercial service in London Underground*. [online] Alstom.

1.2 The Proposed E-LOBSTER Installation

An E-LOBSTER demonstrator installation will be connected at a substation within the Madrid Metro network between the railway and a grid supply.

The proposed arrangement of E-LOBSTER at substations will allow multidirectional distribution of electricity between sites, local battery storage and the public grid through a smart soft open point based on a **Back to Back DC** converter with integrated battery storage. Further information on the detailed connection proposals are set out in other Public E-LOBSTER deliverables (See D2.1, D2.2, D2.4)

In a typical DC overhead line electrification-based system, substations draw energy from a connection to the public grid and supplies electricity to the contact line of the OLE network via a step-down transformer/rectifier to convert the incoming AC supply to DC. If implemented on a wide scale, E-LOBSTER architecture differs in two key ways, the substations within the network can be connected within an array; and there is a bi-directional flow of current between each substation to substation connection, each substation to OLE connection, and each substation to grid connection.

For further information on E- LOBSTER substation configuration, see deliverable D4.1

Regenerative energy is captured as the train brakes and is stored in energy storage systems (ESS) around the network. This energy can be drawn by the network to be supplied to the overhead lines or fed back to the grid.

2 Integration of E-LOBSTER with Grid

2.1 The Smart Grid

In approaching the core topic of this knowledge search, an analysis of the ability of the E-LOBSTER system to integrate with grid infrastructure, the current state of grid infrastructure needs to be investigated.

The Railway to Grid mechanism behind the E-LOBSTER project relies on the bidirectional distribution of electrical power to and from the grid. However, existing grid infrastructure currently only facilitates conventional one-way distribution. As problems with outages and blackouts, as well as difficulties with implementing renewable energy sources like solar and wind, continue to grow with increasing user demand, a need for a more flexible and responsive grid has led to investments into **smart grid** technologies.

There is no universal definition of 'smart grids' since this is a business term rather than a technical term. Smart grids are generally defined as network infrastructures that use various technologies and systems to facilitate active monitoring of electricity distribution from the grid to users, and from users to the grid, with great emphasis on renewable energy generation and large-scale energy storage. This is typically through the both the implementation of smart meters, devices that monitor power consumption for the various types of consumers in the grid and adapting transmission systems to allow bidirectional energy transfer.

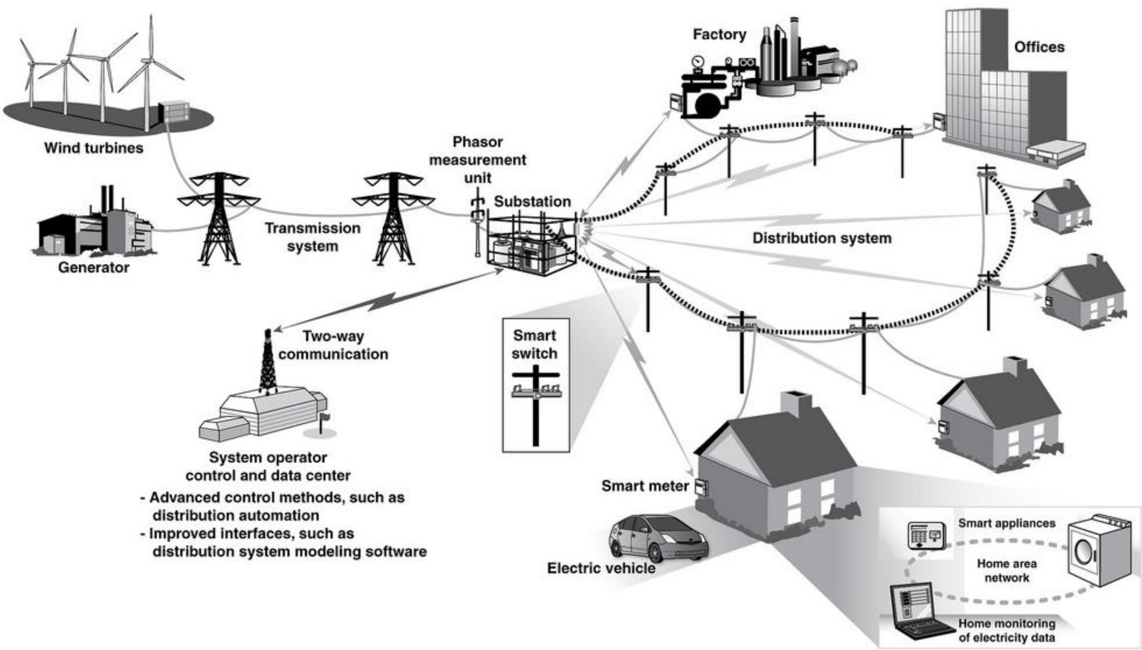

Figure 2: A Typical Smart Grid Network (*U.S GAO, 2011)*

Smart grids, in comparison to traditional infrastructure, aim to improve the efficiency of energy transfer around the network by operating in a decentralised fashion. Typical users of these systems also supply excess energy back into the network, while energy storage devices like batteries draw from the grid and then can supply excess power back to the grid. The ideal smart system would move away from a typical set-up of a centralised power source supplying power to various parties, but instead would consist of multiple parities intermittently drawing and supplying electricity to the grid through renewables or energy harvesting, ensuring consistent supply even during outages and blackouts.

To ensure proposed control and transmission components of E-LOBSTER can sufficiently operate while connected to the grid, research into traditional standards alone is not enough. Instead, further studies must be undertaken into the standards for smart grids. Standards related to smart grid infrastructure could be thought of as analogous to the standards required for the E-LOBSTER system itself. The proposed E-LOBSTER network consists of an array of independent but connected traditional transformer/rectifier substations, sources it's energy mainly from regenerative braking and local generation of renewable sources, storing it in an ESS and has connections to the power distribution network. The flow of power is multidirectional, and much like in a smart grid, appropriate standards are required to ensure that the project is viable.

2.2 Development of EU Smart Grids

Smart grid initiatives are still in their infancy. The European Union has proposed that 80% of homes should have smart meters installed by 2020 [9]. However, there are still regulatory barriers which may impede the move to a fully smart system.

To tackle these, the Smart Grid task force was set up in 2009 by the European Commission, aiming to facilitate the EU's plan for smart grid implementation by laying out a set of new European Standards. Expert group 1 of this task force, responsible for smart grid standards, published a mandate in 2009 laying out a roadmap for the publication of initial smart grid standards by 2012. The task force identified 6 high level services that smart grids should prioritise.

- Enabling new user integration with the smart grid
- Ensuring day to day efficiency
- Ensuring network security, system control and quality of supply
- Ensuring robust network investment planning
- Improving customer service and market functionality
- Ensuring stronger engagement with customers

In 2011 a working group consisting of members from the European Committee for Standardization (CEN), the European Committee for Electrotechnical Standardization (CENELEC), and the European Telecommunications Standards Institute (ETSI) was formed [10]. In 2014 the **CENELEC set of Smart Grid standards (SGCG/M490/G)** [11] was published, laying out a prospective framework for future smart grid legislation and standardisation. This report primarily concerns the interface between users and the grid.

[9] https://www.euractiv.com/section/energy/news/smart-meters-not-needed-after-all-for-european-power-grid/

[10] Standardization Mandate to European Standardisation Organisations (ESOs) to support European Smart Grid deployment

[11] CEN-CENELEC-ETSI Smart Grid Coordination Group, (2014). SGCG/M490/G Smart Grid Set of Standards [online]. Brussels: Publisher. [Date viewed]. Available from: DOI or URL

2.3 EU Smart Grid Standards

This section will consist of an analysis of the set of standards laid out in the **CENELEC set of Smart Grid standards (SGCG/M490/G)** document.

This paper envisages a smart grid as a set of sub-systems responsible for power generation, transmission, distribution, monitoring and storage. These sub-systems are representative of how an ideal smart grid system will function. We can look to these systems and their functionalities to draw parallels with the various functionalities of the E-LOBSTER system and then from this, draw a group of appropriate standards from this document.

An important factor identified for smart grid implementation its ability to operate where various users of the network, from traditional suppliers to home users to batteries, being able to frequently exchange information with one another and actively act on said information. As a result of this, **information management** is integral to smart grid infrastructure.

SGCG/M490/G is a comprehensive mapping of thousands of potential standards in relation to smart grids interfaces and thus has a wide scope, covering functionalities on a device and component level all the way to outlining standards for business operation. There are various smart grid functionalities described are in scope for E-LOBSTER grid integration and interrogating the recommended standards will prove useful.

CENELEC sets its proposed standards for smart grids around a framework called the **Smart Grid Architecture Model (SGAM)**. This model consists of five interoperability layers representing business protocols, functionality, Information protocols, communication protocols and basic connectivity protocols. These layers are superimposed over a 'Smart Grid Layer', which maps out the electrical processes (generation, transmission, etc.) involved with the levels of management, referred to as 'zones' in a 2-D plane. Together these two concepts form a three-dimensional model of a smart grid to which various standards can be applied.

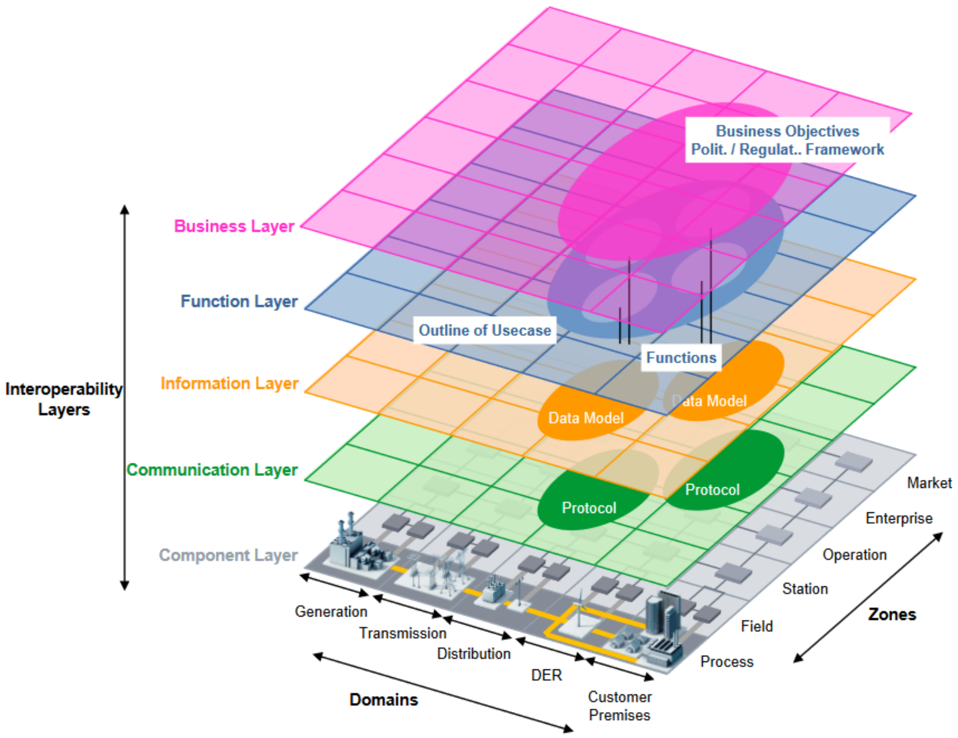

Figure 3: The Three-Dimensional Smart Grid Model *(CEN-CENELEC, 2014)*

The SGAM proposes these sub-systems interacting with each other on three layers:

- The **component layer** concerns the physical connection between various devices within each system.
- The **information layer** is representative of the IT and informational systems within the system that regulate component operation and system monitoring.
- The **communication layer** represents how the various data related the system are distributed between various parties.

To derive a list of appropriate E-LOBSTER standards for the grid based on the CENELEC set of smart grids we must consider the Railway to Grid interface bidirectionally: The transmission of power from the electrical grid to the OLE system, and the transmission of power from the OLE system back into the grid via the smart soft open point. The appropriate standards in relation to integration with the grid therefore will be drawn from the transmission section of this standards list. We can also deduce that standards cantered around the **component layer** are most appropriate for this section. Regulations enforced in different member states below.

2.4 Case Study: Smart Grid Standards in Italy

This section provides an analysis of the legislation in force in Italy for the regulation of Smart Grids. The regulatory framework related to the integration of widespread generation in Italy can be grouped into different thematic areas:

- Connection to electrical networks
- Access and use of the network
- Electricity measurement methodologies for the sale of the electricity produced and exchange on site
- Promoting the development of network infrastructures
- Information flows and database management
- Incentive schemes applicable to particular forms of electricity production

The regulatory discipline of Closed Distribution Systems (SDC) is regulated by European Directive 2009/72/EC[12] (13 July 2009) concerning "common rules for the internal market in electricity" in which networks are defined as plant configurations including a various subjects that share a network and allows the optimization of energy supply or requires specific technical, safety or management standards.

The variations of the technical standards for connection to medium and low voltage networks have been recently published (norms CEI 0-16 and 0-21) as well as the resolutions that will govern the use of storage systems.

The experimental approach for Smart Grid interventions and utility-oriented storage systems will need to move to a more structural and dedicated regulation.

[12] https://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX%3A32009L0072

2.4.1 Application of the CEI Variants 0-21 and 0-16 of the resolution AEEGSI 642/14

The AEEGSI 642/2014 resolution approves the updates of the CEI 0-16 and 0-21 connection rules published by CEI on December 2014 and dictates its application timeframe. The CEI 0-16 standard, together with the new variations, indicates the connection rules and the tests on storage systems related to medium voltage. The CEI 0-21 standard, together with the new variations, indicates the connection rules and the tests for low voltage. The section related to the tests has been included in CEI 0-21-V1-2017. In the list below, the main requirements that storage systems must meet are summarized:

- Follow the capability curves;
- Active power regulation
- Active power limitation for voltage values close to 110% of the nominal value;
- Over-frequency operating condition by absorbing active power and interrupting any discharge cycle;
- Operation in sub-frequency by supplying active power and interrupting the charging cycle;
- Participation to the tension control

The technical requirements defined by the variations to the CEI 0-16 and CEI 0-21 standards will need to be used in Italy for all the systems with connection requests submitted to the Authorities starting from November 21, 2014.

The connection of storage systems, both in medium and low voltage, is only possible by providing substitutive declaration of notary deed according to the Italian Presidential Decree n. 445/00: this is to give the necessary time to suppliers and laboratories to carry out the tests defined in the annexes of the Rules. For medium voltage connection requests, according to the annex N. Bis of the CEI 0-16, test reports will have to be compulsory declared to the Authority.

In the above mentioned variations, the delay in the activation of the active power over frequency transients limitations on the grid has been indicated, as well as the automatic supply/use of reactive power on the basis of a defined curve; this is applied to all inverters, even for the ones that will be installed on photovoltaic systems without any storage. The obligation to provide such delay is however only applicable for systems whose connection request is later than 1st September 2015.

2.4.2 CEI 0-16 V1 of 2014-12

Reference technical rules for the connection of active and passive consumers to the HV and MV electrical networks of Distribution Company. This Variation V1 to the Standard CEI 0-16: 2014-09 (consolidated version of the Standard CEI 0-16: 2012-12, Corrigenda: 2013-05 and Variant V1: 2013-12) mainly concerns the requirements applicable to electricity storage systems that are part of production facilities.

The purpose of this Variation is to provide guidelines for the insertion of storage systems into the generation plants connected to the HV and MV networks of the Distributors. It also includes the tests necessary for such storage systems to fit the needs of network service security to which they are connected.

2.4.3 CEI 0-16 V3 of 07-2017

This Variant V3 to Standard CEI 0-16 integrates Annexes C and D with the provisions concerning the modalities for carrying out the checks and functional tests in the field, both of first activation and periodic, for the General Protection System (SPG), whether it is integrated or not. In the definition of an accumulation system the exclusion of static compensators without accumulation is made explicit. Furthermore, the normative references to be adopted for the measurement systems are correctly specified and some editorial modifications are inserted.

2.4.4 CEI 0-21;V1 2014-12

These are reference technical rules for the connection of active and passive users to the LV electrical utilities. This Variation V1 to the Standard CEI 0-21: 2014-09 (consolidated version of the Standard CEI 0-21: 2012-06 and its Variations V1: 2012-12 and V2: 2013-12) mainly concerns the requirements applicable to electricity storage systems that are part of production facilities.

The purpose of this Variation is to provide guidelines for the insertion of storage systems into the generation plants connected to the LV networks of the Distributors. It also includes the necessary tests necessary for such storage systems to fit the needs of network service security to which they are connected.

2.4.5 CEI 0-21 of 07-2017

This Variant to the CEI 0-21 Standard introduces some simplifications for the connection of plants with a size inferior to 800 W of power. In the definition of an accumulation system the exclusion of static compensators without accumulation is made explicit. Furthermore, the normative references to be adopted for measurement systems are correctly specified and some editorial changes are included.

2.4.6 ANIE Energy: the market of storage systems is starting

The AEEGSI Resolution 574/2014 defines the rules for the connection, the performance characteristics and the areas of application. Resolution 574/2014 /R/EEL, clearly defines the rules for connection to the medium and low voltage electricity grid, the performance characteristics and areas of application of the storage systems both applied to energy production plants and in a stand-alone configuration, giving a way to a market and certainty to novel applications in Italy. The provision was eagerly awaited by the national energy storage industry, which had invested in R and D and technical-commercial development for several years., and will now move forward with distributed generation, photovoltaic installations and self-production, for residential, commercial and industrial areas.

2.4.7 360/2015/R/EEL of 16 July 2015.

Further provisions on the installation and use of storage systems as well as on the application of the CEI 0-16 and CEI 0-21 standards came with resolution no. 642/2014/R/EEL of 18 December 2014, subsequently amended by resolution.360/2015/R/EEL of 16 July 2015. In April 2015, the Energy Italian Services Operator (GSE) published the "Technical Rules for the implementation of the provisions on the integration of electricity storage systems in the [Italian] national electricity system". This document, revised in June 2017, structures the methods for managing the storage systems integrated with the electricity production plants managed by the GSE.

Compared to the first edition, the contents of the current version of the Technical Regulations incorporate the most recent regulatory provisions, including updates of the CEI 0-16 and CEI 0-21 standards made by the Italian Electro Technical Committee. The Technical Rules illustrate:

- The reference regulatory and regulatory context;
- The grid connection diagrams of the storage systems as defined by the IEC;
- The requirements to be met for the installation of integrated storage systems in production plants powered by renewable sources, which access incentives or guarantees of origin or, as part of the dedicated withdrawal, the minimum guaranteed prices;
- The requirements for the maintenance of incentives or benefits already recognized for production plants powered by renewable sources in cases where storage systems are installed;
- The methods for managing communications relating to the installation of integrated storage systems in production plants managed by the GSE;
- The algorithms used by the GSE for the quantification of the electricity produced or fed into the grid and the methods of disbursement, either on account or in balance, of the incentives or benefits recognized to the production plants, following the installation of accumulation.

2.4.8 Energy efficiency

Nowadays, it is more appropriate to consider a user who is also a producer of electricity at the same time (a "prosumer" system, a consumer who is also a producer). The international evolutions of the **CEI 64-8/8** Standard, already underway on these aspects. This standard indicates the measures and recommendations for the design of a low voltage electrical system from the point of view of energy efficiency in order to obtain the best service with the lowest consumption of electricity. It is applied to new installations and to the modification of existing low voltage installations including local generation and the accumulation of electricity.

2.4.9 Electrical Vehicles

The regulations concerning the power supply of electric vehicles are contained in section 722 of Standard **CEI 64-8: 2012-06** (introduced with variant V1 of July 2013), where the type of circuits necessary to power vehicles are dealt with both for charging and for protection in the event of electricity flowing from electric vehicles to the private and public power supply network.

CEI 64-8 requires that all connection points to be protected individually with a differential having a rated differential current of no more than 30 mA, capable of interrupting all active conductors, including the neutral. The differential device that protects the connection point must, be, in general, at least of type A.

In the case of three-phase power supply, the adoption of a protection sensitive to the continuous earth fault currents is also prescribed by installing, for example, type B differential devices. Each connection point must be protected by its own overcurrent protection device.

2.5 Transmission and Distribution

The core technology behind the E-LOBSTER project is the smart soft open point that enables a multi-directional transmission of power between the railway network and the power distribution grid using a dedicated back-to-back power converter. This is key to the system's core functionality.

Therefore, standards highlighted below are key in delivery of E-LOBSTER.

- **IEC TR 62543:2011+AMD1:2013+AMD2:2017** - High-voltage direct current (HVDC) power transmission using voltage sourced converters (VSC). This standard gives general guidance on the subject of voltage-sourced converters used for transmission of power by high voltage direct current (HVDC). It describes converters that are not only voltage-sourced (containing a capacitive energy storage medium and where the polarity of DC voltage remains fixed) but also self-commutated, using semiconductor devices which can both be turned on and turned off by control action. The scope includes 2-level and 3-level converters with pulse-width modulation (PWM), along with multi-level converters, but excludes 2-level and 3-level converters operated without PWM, in square-wave output mode. HVDC power transmission using voltage sourced converters is known as "VSC transmission". The various types of circuit that can be used for VSC transmission are described in the report, along with their principal operational characteristics and typical applications. The overall aim is to provide a guide for purchasers to assist with the task of specifying a VSC transmission scheme. Line-commutated and current-sourced converters are specifically excluded from this report. This technical report cancels and replaces IEC/PAS 62543:2008 (Ed.1) which was published by IEC and CIGRÉ jointly and combined with engineering experience.
- **IEC 62751-1:2014+AMD1:2018** – Power losses in voltage sourced converter (VSC) valves for high-voltage direct current (HVDC) systems - Part 1: General requirements. This standard sets out the general principles for calculating the power losses in the converter valves of a voltage sourced converter (VSC) for high-voltage direct current (HVDC) applications, independent of the converter topology. Several clauses in the standard can also be used for calculating the power losses in the dynamic braking valves (where used) and as guidance for calculating the power losses of the valves for a STATCOM (static synchronous compensator) installation
- **EN 50549-1** Requirements for generating plants to be connected in parallel with distribution networks. Connection to a LV distribution network. Generating plants up to and including Type B - This standard specifies the technical requirements for the protection functions and the operational capabilities for generating plants, intended to operate in parallel with LV distribution networks. For practical reasons this document refers to the responsible party where requirements have to be defined by an actor other than the DSO e.g. TSO, member state, regulatory authorities according to the legal framework. Typically, the DSO will inform the producer about these requirements. The requirements of this European Standard apply, irrespective of the kind of energy source and presence of loads in the producer's network, to generating plants, generating modules, electrical machinery and electronic equipment that meet all of the following conditions:
  - Converting any energy source into AC electricity;
  - Generating modules capacity of type B or smaller according to COMMISSION REGULATION (EU) 2016/631 while considering national implementation for the decision regarding power limits between A and B types and B and C types;
  - Connected to and operated in parallel with an AC LV distribution network.
- **EN 50549-2** Requirements for generating plants to be connected in parallel with distribution networks. Connection to a MV distribution network. Generating plants up to and including Type B - This standard describes and specifies the main characteristics of the voltage at a network user's supply terminals in public low voltage, medium and high voltage AC electricity networks under

normal operating conditions. This standard describes the limits or values within which the voltage characteristics can be expected to remain at any supply terminal in public European electricity networks and does not describe the average situation usually experienced by an individual network user.

2.5.1 Information transfer across the substation network

Smart Grid systems are autonomous systems with a variety of differing users acting as both consumers and suppliers. In this decentralised system, various control technologies and systems are used to monitor the performance of the network, regulate the distribution of energy between all connected users, regulate the generation of energy within ER's, regulate the storage of energy within ESS's, and various other tasks. Once again, this need for standards related to information transfer can be extrapolated for the E-LOBSTER project.

Significant improvements in networking technologies like switched Ethernet and TCP/IP, as well as the increase in computing power at a lower cost, have led to demand for an overhaul in how automation systems are standardised.

- **IEC 61850** was designed as a new standard that is appropriate for more modern informational systems. The IEC 61850 standard is actually an extensive set of standards defining the required parameters for the various electronic and control devices present in a network of electrical substations in order for all of these devices to communicate with one another. **IEC-61850-90** and **IEC-61850-80** contain numerous subsections detailing various data models and programming language requirements for system functionality.

  In a broad sense IEC 61850 works by abstracting the various data types and processes that occur within a desired automatous system and mapping out these abstracted objects and items. This allows this standard to be repurposed for not just smart grids as stated in the report, but for the E-LOBSTER. This standard will likely prove useful as of the extent of automation required within E-LOBSTER substations is more fully known.

  IEC 61850 has already been implemented at all traction substations on GWML 25kV AC electrification. Any further implementation of the standard would be for the idiosyncratic mechanical elements of E-LOBSTER, related to the multidirectional transfer of electricity as a unique functionality of this substation network.

2.5.2 Control and Regulation Equipment

For ideal smart grid operation, there must be active monitoring of electricity transfer amongst the various users of the network. Therefore, various control instruments and equipment need to be installed and maintained.

Automation systems are required in substations to protect, monitor and control equipment within the substations. Automation of the substation network is a core functionality of E-LOBSTER network operation, so in this knowledge search we are interpreting these standards as analogous to the substation network in the proposed E-LOBSTER architecture.

- **IEC 62589**, Railway applications - Fixed installations - Harmonisation of the rated values for converter groups and tests on converter groups - provides requirements for some type tests, which are significant only when made on the entire converter group. Provides also a basic relationship between compatible ratings of traction transformer and converter(s), in order to provide minimum requirements for the choice of their ratings. Moreover, gives the minimum values to be considered in order to choose switching devices with characteristics suitable for the converter group(s) involved.

- **IEC 62590**, Railway applications - Fixed installations - Electronic power converters for substations - specifies the requirements for the performance of all fixed installations electronic power converters, using controllable and/or non-controllable electronic valves, intended for traction power supply. The devices can be controlled by means of current, voltage or light. Non-bistable devices are assumed to be operated in the switched mode.
- **IEC 62277-1**, High-voltage switchgear and controlgear - Part 1: Common specifications for alternating current switchgear and controlgear - this standard applies to AC switchgear and controlgear designed for indoor and/or outdoor installation and for operation at service frequencies up to and including 60 Hz and having rated voltages above 1000 V. This document applies to all high-voltage switchgear and controlgear except as otherwise specified in the relevant IEC standards for the particular type of switchgear and controlgear.
- **EN 50549-1** and **EN50549-2** listed earlier, concern the hardware requirements in switchgear in order to form a fully formed picture of required switchgear parameters for E-LOBSTER.
- **EN 62689** is the standard for Current and Voltage sensors or detectors. Moreover, in the case of E-LOBSTER, concerns the equipment automating the substations of the network, as well as feeder operation. This operation requires the usage of fault detectors, pole or ground mounted switches, disconnectors, and various circuit breakers, in order to control the current flow between substations. These components must be able to handle high voltages (from the high voltage AC grid) and medium voltages (within the back to back mechanism). This standard is a rundown on common use cases and fault occurrences for these components, how they are used within a grid system and how to repair and maintain them.

2.5.3 Electromagnetic Compatibility

Electromagnetic Compatibility, (EMC), is defined as the ability of electronic components within network to interact with each other and operate desirably with minimal interference and impairing of functions. This is of special importance for electrical transmission systems, which contains many components operating in the electromagnetic plane with varying parameters. Poor EMC could lead to equipment damage and a failure in the system. For smart grids (and by implication, E-LOBSTER) the diversity of users and suppliers within a decentralised system means that it is important to establish a set of standards for EMC throughout the system.

- Electromagnetic Compatibility is defined in the **EN 61000** series of standards[13]. This standard set covers **general safety concepts (61000-1)**, **testing (61000-4)**, and **installation guidelines (61000-5)**. EN61000-6 contains generic standards relating to Electromagnetic Compatibility [14].

- For E-Lobster application, **IEC 62236**, which applies to emission and immunity aspects of EMC for electrical and electronic apparatus and systems intended for use in railway fixed installations for power supply will be complied with.

2.5.4 Power Quality

Power Quality is defined as the voltage, current, and frequency characteristics exhibited by a point in a specific point in a power system. In the context of smart grids, power quality usually refers to the

[13] CENELEC 2018, *Electromagnetic Compatibility*, EN 61000, viewed 30th October 2018, retrieved from British Standards Online.
[14] *Structure of IEC 61000* (2018), IEC

regulations that network operators need to adhere to, for example the IEC TR 61000-3 contains planning standards the operators frequently use for engineering methodology.

- **EN 50160** lists the characteristics of electricity supplied by public electricity networks and is often used by the industry to gauge power quality requirements for their systems. In smart grids however, the diverse range of energy generators and suppliers within smart grids means that power quality can be more severely impacted than traditional grids. This problem also applies for E-LOBSTER, itself as a system containing a diverse amount of energy users (overhead lines for trains, wider grid) and suppliers (energy storage systems, regenerative systems on train, wider grid).
- Standard **TR 50422** is a guide to the application of EN 50160, outlining the voltage characteristics of supply terminals. For low, medium, and high voltage systems. Edits have been proposed in order to make this standard more suitable, and a revised version (**prTR 50422 Ed2**) is currently under development.

2.5.5 Cybersecurity

Efficient flow of power within a smart grid infrastructure will require a high degree of data sharing between different parties. Therefore, proper protocols on Cybersecurity are of vital importance. This is also true of the E-LOBSTER project.

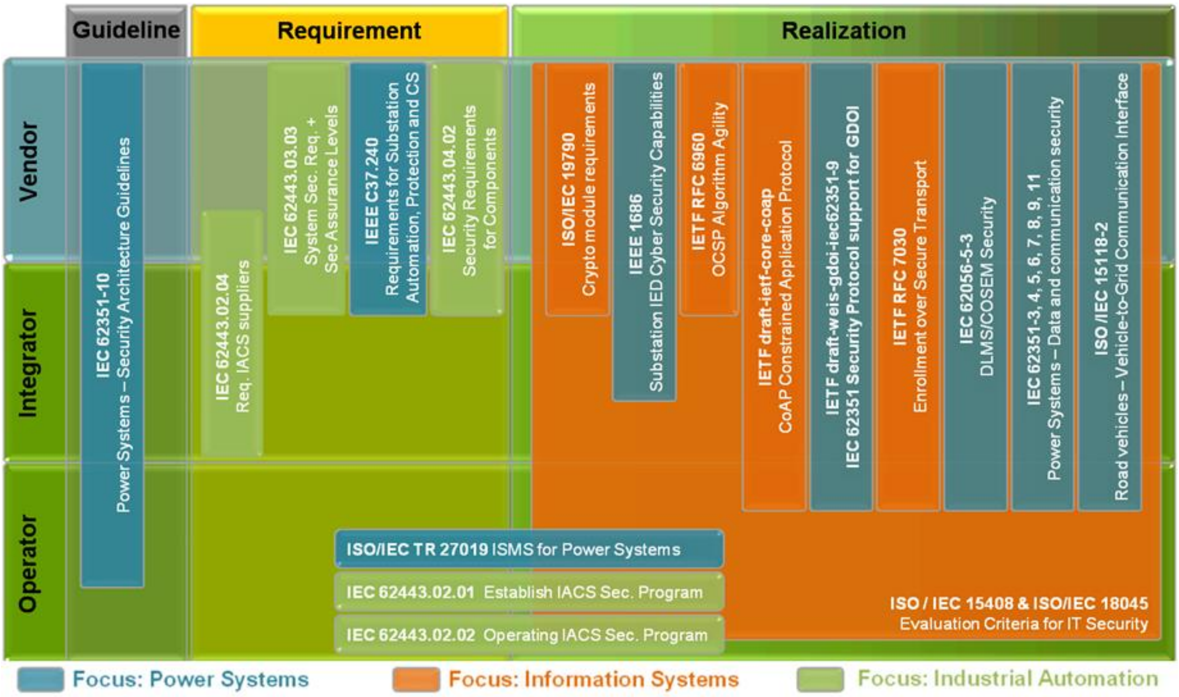

Figure 4: Security Standard Applicability Needs Reference. (CEN-CENLEC, 2014)

Informational transfer in smart grids is a multifaceted process. The decentralised nature of the system means that large amounts of data is required to be exchanged not only for control and monitoring purposes on a device level, but of constant maintenance of efficient power flow between devices in the network. This information must be available and interpretable by all users and any disruption to this information flow would severely damage the grids functionality.

Within SGIS there is a specialised team dedicated to compiling a set of cybersecurity standards for smart grids. The **IEC 62351** series of standards, for example, were highlighted by this group as a key standard regarding cybersecurity. These standards provide an overview of the security systems and practices required related to the previously mentioned IEC 60870 (covered in IEC-62351-5) and IEC 61860 (covered in IEC-62351-6) standards, including encryption, and authentication via digital signatures.

3 Energy Storage

3.1 Introduction to Energy Storage

A key aspect of the E-LOBSTER project is its capacity to actively regulate the distribution of electricity around the network via the usage of batteries and similar energy storage devices. By storing power in and drawing power from these devices, the aim is to provide a more efficient overhead network for the rail system, where energy is only used when needed and excess generated energy can still be re-supplied back into the overhead system or back to the grid.

As an example, to date there is an **estimated 3 GW of network scale storage capacity operational in the UK**, and in 2016 various Enhanced Frequency Response (EFR) and Capacity Market (CM) auctions indicated 489MW of storage being approved for development [15].

Numerous factors have contributed to the sudden emergence of energy storage systems within grid infrastructures, the main enabler being the rise of smart grid-based systems. The rise in technological development, government interest and regulatory upheaval over the past few years means that Energy Storage systems are proving more viable.

3.2 Legislative Issues and Trends related with Energy Storage

In the pursuit of a set of appropriate standards and policies for this aspect of the project, a problem arises. As an example, within UK, in the grid code, the list of regulations that the National Grid sets for the connection and development of the grid, 'Energy Storage' is not defined. This means there is no precedent for the installation and usage of these energy storage systems with the wider grid. Further aspects about policies across EU level will be explored in deliverable D3.2.

In the article "Energy Storage - The Next Wave" [16], REGEN outlines the current status of energy storage technologies and their role within the wider energy marketplace. The report predicts a new wave of energy storage projects to be commissioned from 2020, stating an expansion in the domestic storage market and an increase in demand for grid generators as factors. These new systems are predicted to be based on co-location and 'behind the meter' models of distribution, methods that reduce the reliance on purchasing energy from utilities.

It is clear that through looking at the current energy storage market, various legislative roadblocks related to the E-LOBSTER project emerge. Within UK, as an example, the EPSRC funded **Realising Energy Storage Technologies in Low-carbon Energy Systems (RESTLESS)** briefing paper **'Regulatory Barriers to Energy Storage Deployment: the UK perspective'** [17] outlines aspects of current policy that would prove detrimental to the increased growth of the large-scale energy storage market.

For the E-LOBSTER application, the standard applicable for energy storage system will be **IEC 62924:2017** – Railway applications - Fixed installations - Stationary energy storage system for DC traction systems

[15] Connolly, M. (2017). *Energy Storage: The Next Wave.* Amsterdam: Regen [online]

[16] Connolly, M. (2017). *Energy Storage: The Next Wave.* Amsterdam: Regen [online]

[17] Castagneto-Gissey, G. and Dodds, P.E., (2016). *Regulatory Challenges to Energy Storage Deployment*, Birmingham, RESTLESS.

4 E-LOBSTER Installation and Distribution

4.1 Issues and Current Situation

The E-LOBSTER project, being a large scale, self-sufficient network consisting of potentially hundreds of substations spread out over miles of land, creates unique challenges in implementation. For any new large-scale electrical distribution project, various construction and installation factors must be taken into account.

E-LOBSTER draws power from and supplies power back to the grid, so its role within the wider energy market is ambiguous.

The E-LOBSTER project will feasibly be deployed in areas where overhead rail electrification networks and grid transmission infrastructure intersect, this can either manifest itself in traditional rail or in smaller scale systems like metro or tram systems. Considerations may need to be taken into account regarding substation location, size and scale, meaning there must be negotiations with the DSOs to ensure proper interfacing and a bidirectional transfer of energy.

In line with the goals of the E-LOBSTER project applying across Europe, research into grid companies across the continent will prove helpful to further project development, there are over 2000 DSO's throughout the EU. For multipurpose usage throughout Europe, the project itself needs to be considered as feasible in a large range of markets. There are a variety of Europe-wide policies relating to the energy market, and these policies will need to be taken into account in regard to the scope, and broader functions of the E-LOBSTER project. An analysis of the policies at EU level will be reported in D3.2 released by the E-LOBSTER consortium at the end of August 2019.

This section of the Knowledge Search examines standards within both the UK and Europe regarding the installation and connection of a new system, both in terms of generators and users. In this case, the E-LOBSTER project is considered as a new large-scale generator/supplier and customer device that is currently being developed for grid connection. Appropriate standards and polices will be drawn from Installation and generation policies, required licences, and through looking at the wider transmission market.

For the E-LOBSTER application, the following standards will apply:

EN IEC 62909-1 - Bi-directional grid connected power converters. General requirements

EN 50438 - Requirements For Micro-Generating Plants To Be Connected In Parallel With Public Low-Voltage Distribution Networks.

With respect to the the demonstration site of the project (Metro de Madrid), the following will additionally apply:

MT 3.53.01:2016 - Condiciones Técnicas de la Instalatión de Producción Electrica Conectada a la Red de Iberdrola Distribución Eléctrica, S.A.U. (Technical Conditions of the Instalation of Electrical Production Connected to the Network of Iberdrola Distribución Eléctrica, S.A.U.)

ROYAL DECREE 1669/2011 - Regulating grid connection of small capacity electricity production plants

4.2 Project Installation Legislation and Standards

The E-LOBSTER project will feasibly be deployed in areas where rail electrification networks and grid transmission infrastructure intersect; this can either manifest itself in traditional rail or in smaller scale systems like metro or tram systems. Considerations may need to be taken into account regarding substation location, size and scale, cost of components, and more.

4.2.1 Understanding the European Energy Market

For multipurpose usage throughout Europe, the project itself needs to be considered feasible in a large range of markets across the continent. In order to compile a list of appropriate grid connection policies, the state of the European energy market needs to be understood.

Further work on the E-LOBSTER project will most likely need to take these infrastructural challenges in order to truly emerge as a system that can be installed across the continent. In addition, meeting these regulatory challenges will indicate the feasibility of E-LOBSTER as a project that be integrated with the current European grid.

4.2.1.1 Overview of the European Energy Market

Throughout Europe the structure of the energy market and various operators in the market varies. The principle of company ownership of a distribution network is not uniformly applicable. In France and Portugal distribution companies operate with concessions contracts for the various municipalities. Whereas in Germany and Austria, DSOs' hold a leasing contract with a parent group. Regional taxation and municipal operation policies create different operating conditions for distributors, in areas like Sweden, Austria and Finland the cost is negligible, but they are significant in places like France and Belgium. [18]

The table below outlines the varying frequencies of DSOs within the markets of various European countries.

Country	Number of DSOs and Concentration
Austria	About 15 DSOs. Largest delivers approximately 15% of consumption
Belgium	30 operators of different size. The largest contributes about 10% of distributed electricity.
Denmark	107 distribution network companies. The largest group delivers energy to a third of customers
Finland	89 operators. The largest represents about 15% of delivered energy.
France	Approximately 150 DSOs but the largest equates to 95% of consumption
Germany	About 800 operators but 4 major groups. The largest represents approximately 25% of consumption.
Ireland	A single DSO delivers 100 % of consumption.

[18] Chanel. P, (2008). *Overview of Electricity Distribution in Europe*, Capgemini

Italy	The largest operator accounts for 85% of consumption. 182 DSOs account for the remaining 15%
The Netherlands	7 major DSOs are directly connected to the transmission network.
Portugal	The largest delivers almost 100% of total consumption.
Spain	About 300 operators registered in 2006 with 5 major DSOs. The largest delivers approximately 40% of total consumption.
Sweden	180 DSOs which are mostly owned by major groups.
United Kingdom	14 DSOs of similar size. Three of the largest supply 31% of consumption.

4.2.1.2 Moving towards a European Energy Union

Work has been undertaken in recent years to create a more integrated European energy market. The Energy Union Framework Strategy outlines various goals and objectives that the European energy market needs to meet in order to unify markets across the continent with secure and sustainable energy supply.

There has been significant interest in the regulation of data and information related to transmission and distribution networks, and the distribution of said information. This links in not only with the discussions about smart grid mentioned earlier in the document, but also a desire to create a transparent and flexible network for consumers.

Although this may seem out of scope for this project, it is important to consider E-LOBSTER's place in the wider grid, and these initiatives will ultimately influence policies that will ultimately affect the implementation of the project around Europe. A consideration towards the various sources of information and data distributed throughout the E-LOBSTER network, and more importantly between the network to wider grid bidirectional connection.

4.2.1.3 European Grid Connection Standards

The European Commission has proposed a series of regulations related to **HVDC (High Voltage DC) systems** as outlined in **Commission Regulation 2016/1447** [19]. The document lays out requirements for:

- **Frequency Range Capability** - The system must be able to operate between a range of frequencies outlined in the document *(Articles 11 - 16)*
- **Active Power Control** - The system should be able to effectively mitigate loses of active power injection, the value of maximum losses being defined in an agreement between the HVDC operator and the relevant authorities *(Article 17)*.
- **Reactive Power Capability** - The system must be able to operate at maximum leading and lagging reactive power for at least 1 hour, and be able to operate reliably within the operation parameters set in the document *(Articles 20 - 22)*
- **Fault Ride Through Capability** - The system should be able to maintain operation in the event of both active power transient faults *(Articles 25 - 27)*

[19] *Commission Regulation (EU) 2016/1447 of 26 August 2016 establishing a network code on requirements for grid connection of high voltage direct current systems and direct current-connected power park modules.*

- **Control Capabilities** - synchronised converter stations may not deviate from synced voltage by over 5% of an agreed value *(Articles 28 - 31)*
- **Protection/Restoration Capabilities** – There must be sufficient protective equipment and schemes within the system, with prioritisation of protection according to the specifications within the document. The system must also contain black start capabilities *(Articles 34-37)*

European Commission Regulation **2016/631** for the **network code on requirements for grid connection of generators** [20] is also a helpful document for defining how E-LOBSTER can function within European infrastructure. The document outlines requirements and competencies that new systems need to show in order to connect to the wider grid. This document has a broader structure compared to 2016/1447, focusing on systems connecting to the grid in a more general sense. Within the document there are detailed profiles for appropriate frequency response, power capability, and fault capabilities.

European Commission **2016/1388** for the **network code on demand connection** [21] is also recommended as a complimentary document, these regulations focus on large renewable power generation plants, within the scope of appropriate knowledge or this project.

These documents can help provide a range of appropriate parameters for the behaviour of the E-LOBSTER network and its connection with the wider grid, with this, more informed decisions about components, design and the appropriate scale of the final network concept can be made.

[20] *Commission Regulation (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators*
[21] *Commission Regulation (EU) 2016/1388 of 17 August 2016 establishing a Network Code on Demand Connection.*

5 Conclusion

Within the wider European energy market there is movement towards an 'Energy Union'. A unified, sustainable, and secure energy market. With recent and future policy developments prioritising data and informational standardisation, incentivising renewable energy development, and decentralised 'smart grid' infrastructures. This creates opportunities for the E-LOBSTER project.

E-LOBSTER, as a concept, represents a new type of electric infrastructure. Not only an advancement in overhead line based rail systems, but also a new form of grid connected system that would be a crucial element in the transition to decentralised smart grids systems in Europe.

A robust set of standards for smart grids in the EU is being developed and analysing these emerging standards may prove useful to the development of this project. Current enquires into the standards for smart grids emphasize a need for a robust control system and information distribution systems meaning control components, data protocols, and cybersecurity. There is also consideration for DC components and circuitry required in DC systems.

The development of potential proposals of standard relevant with respect to E-LOBSTER will be based upon the already established highlighted in the Appendices 6.1 and 6.2. These standards will provide some of the core requirements for the E-LOBSTER application to comply with when integrating it within the railway environment.

6 Appendices

6.1 Table of Identified Key Standards and Policies For E-LOBSTER

Standard/Policy Code	Standard/Policy Title	Organisation	Application for E-LOBSTER
IEC TR 62543:2011+AMD1:2013+AMD2:2017	High voltage direct current (HVDC) using voltage sourced converters (VSC)	International Electrotechnical Commission	General guidance on the subject of voltage-sourced converters used for transmission of power by high voltage direct current (HVDC)
IEC TR 62978:2017		International Electrotechnical Commission	HVDC installations - Guidelines on asset management
IEC TS 62578:2015		International Electrotechnical Commission	Power electronics systems and equipment
IEC 62590:2010	Railway applications - Fixed installations - Electronic power converters for substations	International Electrotechnical Commission	Provides requirements for the performance of all fixed installations.
IEC 62589:2010	Railway applications - Fixed installations - Harmonisation of the rated values for converter groups and tests on converter groups	International Electrotechnical Commission	Provides requirements for some type tests which are significant only when made on the entire converter group
IEC 62924	Railway applications - Fixed installations - Stationary energy storage system for DC traction system	International Electrotechnical Commission	Specifies the requirements and test methods for a stationary energy storage system to be introduced as a trackside installation and used in a power supply network of a DC electrified railway.

IEC 62236	Railway applications - Electromagnetic compatibility	International Electrotechnical Commission	Applies to emission and immunity aspects of EMC for electrical and electronic apparatus and systems intended for use in railway fixed installations for power supply
CLC TS 50549-1	Requirements for generating plants to be connected in parallel with distribution networks	European Commission	Bidirectional connection with wider grid (E-LOBSTER can be seen as a generator when supplying energy to the grid)
IEC 61850	Power Utility Automation	International Electrotechnical Commission	General Application
IEC 61850-7-1:2011	Communication networks and systems for power utility automation - Part 7-1: Basic communication structure - Principles and models	International Electrotechnical Commission	Communications structure
IEC 62271	High-voltage switchgear and control gear	International Electrotechnical Commission	Components for E-LOBSTER substations
IEC 62689	Current and voltage sensors or detectors, to be used for fault passage indication purposes	International Electrotechnical Commission	Components for E-LOBSTER substations
IEC 62909-1	Bi-directional grid connected power converters. General requirements	International Electrotechnical Commission	Specifies general aspects of bi-directional grid-connected power converters (GCPC), consisting of a grid-side inverter with two or more types of DC-port interfaces on the application side with system voltages not exceeding 1 000 V AC or 1 500 V DC.
EN 61000	Electromagnetic Capability (EMC)	International Electrotechnical Commission	General Application
IEC 60850 / EN50163	Railway applications – Supply voltages of traction systems	International Electrotechnical Commission	Specifies the main characteristics of the supply voltages of traction systems, such as traction fixed installations, including auxiliary devices fed by the contact line, and rolling stock

IEC 62497-1:2010+AMD1:2013 CSV / EN50124-1	Railway applications - Insulation coordination - Part 1: Basic requirements - Clearances and creepage distances for all electrical and electronic equipment	International Electrotechnical Commission	Deals with insulation coordination in railways. It applies to equipment for use in signalling, rolling stock and fixed installations up to 2 000 m above sea level.
IEC 61992 (all parts)	Railway applications - Fixed installations- DC switchgear	International Electrotechnical Commission	DC Switchgear standards
IEC 62128 (EN 50122) – All parts	Railway applications - Fixed installations - Electrical safety, earthing and the return circuit	International Electrotechnical Commission	Protective provisions, DC stray currents
IEC 62498-2	Railway applications - Environmental conditions for equipment	International Electrotechnical Commission	Environmental influences of fixed electrical installations
IEC 62313	Railway applications - Power supply and rolling stock - Technical criteria for the coordination between power supply (substation) and rolling stock	International Electrotechnical Commission	Interaction between power supply and rolling stock
EN 50160	Voltage characteristics of electricity supplied by public distribution systems	CEN / CENELEC	General Application
EN 50438 (Withdrawn)	Requirements for Micro-Generating Plants To Be Connected In Parallel With Public Low-Voltage Distribution Networks	CEN / CENELEC	

TR 50422	Guide for the application of the European Standard EN 50160	European Commission	General Application
IEC 62351	Power systems management and associated information exchange - Data and communications security	International Electrotechnical Commission	Informational management and control systems for E-LOBSTER
MT 3.53.01:2016	Condiciones Técnicas de la Instalatión de Producción Electrica Conectada a la Red de Iberdrola Distribución Eléctrica, S.A.U. (Technical Conditions of the Installation of Electrical Production Connected to the Network of Iberdrola Distribución Eléctrica, S.A.U.)	Metro Metro – Iberdrola agreement	E-Lobster application on Madrid Metro
ROYAL DECREE 1669/2011	Regulating grid connection of small capacity electricity production plants		E-Lobster application on Madrid Metro
GC0096	Energy Storage	National Grid	Energy Storage Devices for E-LOBSTER (Technical)
CMP264/CMP265	Proposals to change electricity transmission charging arrangements for Embedded Generators	Ofgem	Energy Storage Devices for E-LOBSTER (Economic)
DCP228	Revenue Matching in the Common Distribution Charging Methodology (CDCM)	Ofgem	Energy Storage Devices for E-LOBSTER (Economic)

Commission Regulation 2016/1447	Network Code on High Voltage Direct Current Connections	European Commission	Bidirectional connection with wider grid
Commission Regulation 2016/1388	Network Code on Demand Connection	European Commission	Bidirectional connection with wider grid
Commission Regulation 2016/631	Network code on requirements for grid connection of generators	European Commission	Bidirectional connection with wider grid
BCA	Bilateral Connection Agreement	Ofgem	Required documentation for grid connection
CONSAG	Construction Agreement	Ofgem	Required documentation for grid connection
Generation License	Generation License	Ofgem	Required documentation for grid connection

6.2 Other Standards

Organisation	Standard Title	Standard Description
CEN / CENELEC	BS EN 61508-1:2010	Functional safety of electrical/electronic/programmable electronic safety related systems – general requirements
CEN / CENELEC	BS EN 50270:2015	Electromagnetic compatibility – electrical apparatus for the detection and measurement of combustible gases, toxic gases or oxygen (applicable systems with embedded batteries)
IEC	IEC 62040-1:2017	UPS – Part 1: Safety requirements (this may be greatly applicable to E-Lobster and may move to the previous section)
CEN / CENELEC	EN 50065-2-3	Signalling on low-voltage electrical installations in the frequency range 3 kHz to 148,5 kHz - Part 2-3: Immunity requirements for mains communications equipment and systems operating in the range of frequencies 3 kHz to 95 kHz and intended for use by electricity suppliers and distributors
CEN / CENELEC	EN 50065-7	Signalling on low-voltage electrical installations in the frequency range 3 kHz to 148,5 kHz - Part 7: Equipment impedance
CEN / CENELEC	EN 55011	Industrial, scientific and medical equipment - Radio-frequency disturbance characteristics - Limits and methods of measurement

CEN / CENELEC	EN 55022	Information technology equipment - Radio disturbance characteristics - Limits and methods of measurement
CEN / CENELEC	EN 55024	Information technology equipment - Immunity characteristics - Limits and methods of measurement
CEN / CENELEC	EN 55032	Electromagnetic compatibility of multimedia equipment - Emission requirements
CEN / CENELEC	EN 61851 (all parts)	Electric vehicle conductive charging system
CEN / CENELEC	EN 61851-1	Electric vehicle conductive charging system - Part 1: General requirements
CEN / CENELEC	EN 61851-21	Electric vehicles conductive charging system - Part 21: Electric vehicle requirements for conductive connection to an a.c./d.c. supply
CEN / CENELEC	EN 61851-22	Electric vehicle conductive charging system - Part 22: AC electric vehicle charging station
CEN / CENELEC	EN 61851-23	Electric vehicle conductive charging system - Part 23
CEN / CENELEC	EN 61869	Instrument transformers
CEN / CENELEC	EN 61980 (all parts)	Electric equipment for the supply of energy to electric road vehicles using an inductive coupling
IEC	IEC 61981	On board electric power equipment for electric road vehicles
CEN / CENELEC	EN 61982 (all parts)	Secondary batteries for the propulsion of electric road vehicles
CEN / CENELEC	EN 62056 (all parts)	Electricity metering data exchange - The DLSM/COSEM suite
IEC	IEC 62056-1-0	Electricity metering - Data exchange for meter reading, tariff and load control - Glossary of terms - Part 1: Terms related to data exchange with metering equipment using DLMS/COSEM
CEN / CENELEC	EN 62196	Plugs, socket-outlets, vehicle couplers and vehicle inlets - Conductive charging of electric vehicles
CEN / CENELEC	EN 62443	Industrial communication networks – Network and system security
CEN / CENELEC	EN 50438	Requirements for the connection of micro-generators in parallel with public low-voltage distribution networks
CEN / CENELEC	EN 55035	Electromagnetic Compatibility of Multimedia equipment - Immunity Requirements
CEN / CENELEC	EN 50633	Protection principles for AC and DC electric traction systems
CEN / CENELEC	CLC TR 50579	Electricity metering equipment - Severity levels, immunity requirements and test methods for conducted disturbances in the frequency range 2 - 150 kHz
IEC	IEC 60255	Measuring relays and protection equipment
IEC	IEC 60700-1	Ed.1.2, Thyristor valves for high voltage direct current (HVDC) power transmission - Part 1: Electrical testing
IEC	IEC 61194	Programmable controllers

IEC	IEC 61954	Power electronics for electrical transmission and distribution systems - Testing of thyristor valves for static VAR compensators
IEC	IEC 62282	Fuel cell technologies
IEC	IEC 62443-3-3	Industrial communication networks - Network and system security - Part 3-3: System security requirements and security levels
IEC	IEC 62786	Smart Grid User Interface: Demand Side Energy Sources Interconnection with the Grid
CEN / CENELEC	EN 60364-4-41	Selection and erection of electrical equipment - Isolation, switching and control
CEN / CENELEC	EN 60364-5-53	Selection and erection of electrical equipment - Isolation, switching and control
CEN / CENELEC	EN 60364-5-55	Selection and erection of electrical equipment - Other equipment - Clause 551: Low-voltage generating set
CEN / CENELEC	EN 60364-7-722	Requirements for special installations or locations - Supply of Electrical Vehicle
IEC	IEC 60783	Wiring and connectors for electric road vehicles
IEC	IEC 60786	Controllers for electric road vehicles
IEC	IEC 61894	Preferred sizes and voltages of battery monoblocs for electric vehicle applications
CEN / CENELEC	EN 60364 (all parts)	Electrical installations of buildings
IEC	IEC 62749	(TS) Characteristics of electricity at supply terminals of public networks: power quality assessment
IEC	IEC 62751-1:2014+AMD1:2018 CSV	Power losses in voltage sourced converter (VSC) valves for high-voltage direct current (HVDC) systems - Part 1: General requirements
IEC	IEC 62477-1	Safety requirements for power electronic converter systems and equipment
ENA	ER G59/3-4	Engineering recommendation for the connection of generating plants to the distribution systems of licenced distribution network operators.