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E-LOBSTER

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

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Proposal for new Standards covering the existing gaps

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Terms and abbreviations

Abbreviation	Description
AC	Alternating Current
ACSI	Abstract Communications Service Interface
ATO	Automatic Train Operation
ATS	Abstract Test Suite
AVC	Automatic Voltage Control Schemes
BESS	Battery Energy Storage System
BS	British Standard
CCSE	Communication Controller of Supply Equipment
CLC	European Committee for Electrotechnical Standardization
CMS	Cryptographic Message Syntax
COSEM	Companion Specification for Energy Metering
DC	Direct Current
DER	Distributed Power Resources
DLMS	Device Language Message Specification
DSO	Distribution System Operator
EEA	European Economic Area
EMC	Electromagnetic Compatibility
EMO	Electricity Market Operator
EN	European Normative
ERTMS	European Railway Traffic Management System
EST	Enrollment Over Secure Transport
EV	Electric Vehicle
EVCC	Communication Controller of an Electrical Vehicle
GMCR	Ground Mounted Conductor Rail
GSM-R	The Global Systems for Mobile communications – Railway
HAS	Harmonised Approach
HEMP	High-Altitude Nuclear Electromagnetic Impulse
HLC	High-Level Communication
HSR	High Speed Railway
HVAC	Heating, Ventilation and Air Conditioning
HVDC	High Voltage Direct Current System
IACS	Industrial Automation and Control Systems
IEC	International Electrotechnical Commission
IED	Intelligent Electronic Devices
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IM	Infrastructure Manager
ISMS	Information Security Management Systems
ISO	International Standardization Organization
IT	Information Technologies
LCTs	Low Carbon Technologies
MMS	Manufacturing Message Specification
NSM	Network and system management
NWI	New Work Item
O&M	Operation and Maintenance

OCL	Overhead Catenary Line System
OCSP	Online Certificate Status Protocol
RES	Renewable Energy Source
RFC	Request for Comments
RSGs	Rail Supply Groups
RTPSS	Rail Traction Power System
RTU	Remote Terminal Units
RU	Railway Undertaking
SCADA	Supervisory Control and Data Acquisition
SCSM	Specific Communication Service Mapping
SECC	Supply Equipment Communication Controller
SiC	Silicon Carbide
sSOP	Smart Soft Open Point
SUT	System Under Test
T2G	Train to Grid
TCP/IP	Transmission Control Protocol/Internet Protocol
THD	Total Harmonic Distortion
TSO	Transmission System Operator
UNE	Una Norma Española
UPS	Uninterrupted Power Supplies

Executive Summary

The overall scope of the H2020 E-LOBSTER project is to propose an innovative Railway to Grid Management system which, combined with advanced power electronics and storage technologies (the smart Soft Open Point and the electric storage developed in the framework of the project), will be able to reduce electricity losses both in the power distribution and in the railway distribution networks. In particular, the system will be able to make the best use of the available energy on both the grids by increasing their mutual synergies and maximizing the consumption of local RES production through electric energy storages and, at the same time, by creating synergy with charging stations for electric vehicles.

Considering this big picture of the proposed system, it is important to build a strong base that support the project in terms of standardization. Moreover, due to the wide range of technologies that ELOBSTER gathers in order to achieve synergies between different systems and, therefore, becoming a disruptive concept, this deliverable aims to cluster standards from different sectors that do not often work together in the same facility. Consequently, the first sections show the main standards that apply to railways, transmission and distribution networks, power electronics, ESS, and the information that flows between all the elements that form the ELOBSTER system.

This deliverable will analyse, firstly, the train to grid and smart grid systems, their requirements and their technical challenges. Then, the fields above enumerated (railways, distributions grids…) are analysed from the perspective of standardization, what allows to gather all the standards that may be applied to this use. These sections aimed to give a brief sample, if possible, of conceivable gaps that might arise when those standards are applied to E-LOBSTER. Finally, and linked to the previous idea, the last two sections aim to develop, first, a guide for the E-LOBSTER marketability and guidelines for a potential new standard that will consider new issues concerning the new system.

It is rather important to notice the technical complexity of settling the standards for a system that it is still in research progress and that is likely to differ from the first sketches after some pilot demonstrator tests. Nonetheless, this study sets a standard framework that enables to build the system with enough safety and quality requirements and that may even be useful to foster new standards for new problems that may arise.

At present we are not aware of any gaps related to the existing standards. For the demonstrator is based in Metro De Madrid, Spain, specific Spanish standard have been investigated. During the replication activities, in the final phase of the project, a specific analysis of some specific national standards could be needed.

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1 Introduction

The main objective of the E-LOBSTER project is to develop and demonstrate an innovative, economically viable and easily replicable Railway Electric Transport Grid Inter-Connection System, up to TRL 6 in the relevant environment (the metro of Madrid connected to a local power distribution network with a high penetration of RES). The system will be able to establish mutual synergies between power distribution networks, electrified urban transport networks (metro, trams, light railways etc.) and charging stations for electric vehicles.

In particular, E-LOBSTER is demonstrating tools and technologies, software and hardware to assess the source of losses of both the networks (transport and electricity distribution networks) prioritising techniques for their minimisation via a coordinated control of the power supply for electrified transport and recharge stations for electric cars. At the same time, specific objective is the maximisation of the local consumption of Renewable Energy Sources (RES) production thanks to the use of Electrical Energy Storage (EES) and advanced power electronics devices.

In its concept, the E-LOBSTER project is proposing an innovative Railway to Grid Management system which, combined with advanced power electronics, will be able to reduce electricity losses in both the power distribution network and the railway distribution network. The system will be able to make the best use of the available energy on both grids by increasing their mutual synergies, and maximizing the consumption of local Renewable Energy Sources (RES) production through electric energy storages.

In this deliverable, an analysis of the gaps in standardisation of railway applications connected to E-LOBSTER topics will be performed and, if needed, potential proposals for new standards to cover these gaps and unlock the existing barriers will be suggested. The analysis will reach, not only the rail systems, but also the part of the electrical system involved in the E-LOBSTER concept. Moreover, and as part of the approach of the E-LOBSTER, a standard analysis as a guidance for the marketability of the project is included (for the future Installation and Distribution). Finally, guidelines for developing a potential standard for the E-LOBSTER are also included.

1.1 The Train to Grid System

The power supply to the railway (and trains) comes normally from the DSO Grid points. Railways tend to get their power through Overhead Contact Line System (OCL) or Ground Mounted Conductor Rail (GMCR), which is in turn supplied from the DSO through railway distribution network. Overhead networks in the UK and France take the form of a 25 kV AC system for passenger and freight railways. Germany, Austria and Switzerland use a 15 kV 16.7 Hz AC network for the mainlines. 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 fed through OCL (i.e. the Metro de Madrid facilities operate at 1500 V DC using a rigid OCL in line 12) although there are many line specific systems. In several countries, such as Germany, UK, France, etc. GMCR systems are used for metro services.

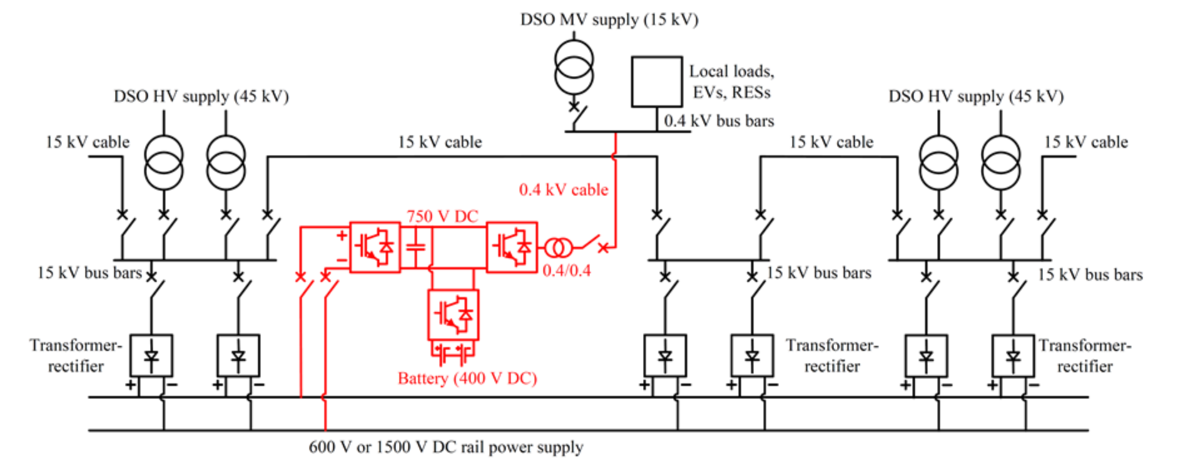

Figure 1: Typical configuration of E-LOBSTER

A 'Train to Grid' (T2G) system differs from standard electrification 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 electrification network and even supplying stored energy back to the grid.

Typical configuration for E-LOBSTER is shown in Figure 1: . In this configuration, the power converter is connected to the railway electrification system on the rail power supply, to the railway substation local AC auxiliary system and to the energy storage system. Actually, the main components of the innovative E-LOBSTER system are the sSOP (smart Soft Open Point which is based on modular AC/AC back-to-back power converters), the Electrical Storage System (EES) and the R+G Management system that should enable the effective and efficient management of the energy flows.

It is possible to perform the following primary power flow functions:

- Railway traction network supports the local grid during periods of large loads and no trains.
- Battery supports the local grid during periods of large loads, but the railway is in use.
- Railway traction network recharges the battery when there is no significant load on the local grid and no trains or when a train is braking.
- The local grid recharges the battery when there is no significant load or there is availability of energy generation from renewable energy sources.

The reverse power flow from the railway (train) to the grid (a bi-directional transfer of energy) gives the E-LOBSTER the advantage of supporting a weak grid system and thereby minimising losses or alternatively supplying the grid with energy that can be reused elsewhere. Currently, according to several studies[1][2], regenerative braking on a metro system could recuperate around 5%-15% energy, some of which would otherwise be lost if it cannot be utilised, by the railway itself.

1.2 Fundamental requirements and application challenges

Railways have an enormous potential in the implementation of smart management, considering their advantages of being permanently connected to the electricity grid and interacting with it.

Trains can exploit these advantages of permanent connection that certainly will exempt them from losses due to recharge time and the inconvenience of moving heavy energy storage systems.

Requirements and challenges of smart management development can be identified from the technical point of view, but also, they can be related to standardisation and regulatory framework, social environment, etc. Several challenges need to be considered for the development and introduction of a railway smart grid.

1.2.1 Standardisation and regulatory framework

The development of smart grids, especially in the railway domain, requires a legal and regulatory basis that sets the right incentives and clearly defines the roles of different power system actors, the interactions between them and enables a smooth communication between all its components.

Developing standards for railway smart grids is important for ensuring that the technologies delivered are compatible and interoperable with the remainder of the system. It is expected that any safety critical aspect of the railway smart grids would be governed by regulations and the aspects relating to interoperability would meet published standards. Therefore, standardisation will be necessary for monitoring and control devices, communications system (including protocols), electromagnetic compatibility, cybersecurity, data collection, storage and sharing.

In terms of adhering with current legislation, the E-LOBSTER system proposes a unique challenge. In this deliverable, an analysis of the gaps in standardisation of railway applications relevant with respect to E-LOBSTER will be performed and, if needed, potential proposals for new standards to cover these gaps and unlock the existing barriers will be suggested.

1.2.2 Technical challenges

Considering the possible technical challenges generated by the instruction of smart management of railway systems, i.e. use of smart grids inside the railway domain, the following main items can be identified: nature of the traction demand, optimisation of train driving, complexity, interfacing new

[1] Andersson, E. (2000): Improved energy efficiency in future rail traffic. Proceedings of the UIC Energy Efficiency Conference, Paris, 2000
Moninger, F.; W. Gunselmann (1998): Einflüsse des elektrischen Versorgungssystems auf den Energieverbrauch elektrischer Bahnen. Not published, 1998.
Khodaparastan, Mahdiyeh & Mohamed, Ahmed & Brandauer, Werner. (2019). Recuperation of Regenerative Braking Energy in Electric Rail Transit Systems. IEEE Transactions on Intelligent Transportation Systems. PP. 1-17. 10.1109/TITS.2018.2886809.
[2] E-LOBSTER Deliverable D1.4 Report on DC bus – DC rail connection feasibility (Confidential)

equipment, communications (efficiency and reliability), security and cybersecurity, electromagnetic compatibility, distributed generation, data management. Some of the above mentioned, such as cybersecurity and information sharing, require not only technical solutions, but also good planning and management.

1.2.2.1 Nature of the traction demand

One of the most important drivers and challenges of railway smart grids implementation is the nature of the traction demand. There is a wide range of railway traction power supply systems in existence across the world. These systems operate at different voltages, use different transmission methods and require different conversion equipment. Rail Traction Power Systems (RTPS) are either powered by DC or AC supplies. Typically, intra-city rail services are powered by DC via third rail or OCL (overhead contact line), whereas inter-city and HSR (high speed railway) are powered by AC supplies exclusively using OCL. Although 25kV 50 or 60Hz AC is considered as the world standard for main line railways and HSR, at least two other AC systems exist, 11 kV 25Hz and 15 kV 16 2/3 Hz. These are non-standard legacy systems, which were developed at low frequency to deal with the limitations of early traction motors. Although these issues have since been overcome, such systems are unlikely to be replaced because of the expense and disruption of changing the railway and, in some cases, power supply infrastructure. For example, in Austria, Switzerland and parts of Germany, there are dedicated plants which supply power at 16 2/3 Hz via a single-phase power distribution network for the railway.

Other than the exceptions mentioned above, in most cases both DC and AC supplies for rail are taken from the public power supply network, which provides a high voltage AC supply. In a DC network, three-phase duplicated input transformers step down this voltage to tens of kilovolts AC for input to substations along the line. Within the substation, this voltage is reduced again before being rectified to the correct DC voltage for the third rail or OCL. In an AC network, no intermediary transformer is required. Instead, the substations feed directly from the grid and reduce this voltage to 25 kV for OCL, using a single phase. To balance the load on the grid, different substations draw from different phases.

1.2.2.2 Optimisation of train driving complexity

Optimizing the train driving in a short time is a major challenge that the application of railway smart grids has to address. In general, the main objective of the smart train driving can be different: minimizing the energy consumption, adapting the train consumption to the capacity of the infrastructure in a specific area, and reducing the cost of the electricity.

These goals are usually tackled with the use of Automatic Train Operation (ATO) systems which is becoming widespread in the railway network. This kind of system helps the driver make the most efficient decisions in order to reduce the energy devoted to traction, improving the timetable and, therefore, the use of the available rolling stock.

1.2.2.3 Interfacing new equipment

One of the first issues to overcome is achieving monitoring and controllability capability for the wide range of devices used in railway power supplies, which operate using different voltages, current types (AC or DC) and software. There is typically a limited set of controllable devices including switches, transformer tap changes and converters, nonetheless, further controllability is expected in the future. Despite railway power systems generally already have integrated supervisory control and data acquisition (SCADA) systems that allow for surveillance, data collection and control, they are not necessarily useful for RSGs (Rail Supply Groups). Traditional SCADA systems evolved over time without standard specifications, leading to several different architectures that are proprietary in nature. Realising the need for interoperability, rail is now moving towards distributed and networked SCADA systems with standardised protocols, but many legacy systems are still in service. For older systems, interfacing sensors and communications to meet smart grid requirements may prove challenging, particularly when hardware replacements or software reconfiguration tools are obsolete and expertise and knowhow is lacking. Rather than designing bespoke smart grid interfaces for each different type of equipment, even if it may be feasible as many use standard components, it may be necessary to completely renew current systems with smart grid interoperability in mind. This would require standardisation across systems and the assurance that these would not become obsolete in 5–10 years' time. With new systems that are currently being installed, it may be possible to use the in-built monitoring capabilities for smart grid purposes.

As well as SCADA for example, the European Railway Traffic Management System (ERTMS) has been designed with monitoring capability for faults and failures, speed monitoring, communications monitoring for the Global Systems for Mobile communications – Railway (GSM-R) and health monitoring of the system with remote access for technicians for interoperable railways.

1.2.2.4 Developing communications in terms of efficiency and reliability

The communication links within the smart grid are essential for achieving its functionality. They must be bi-directional, allowing individual components to report their condition to the management system, and for the management system to take control and perform any necessary actions. They are required to provide a guaranteed quality of service, transmit in 'real-time', have sufficient bandwidth for future connections, be scalable, and be secure from cyber-security threats. A number of communications systems, such as wireless, optical and wireline, have previously been used in smart grids and for most applications, the choice of technology largely depends on the network requirements (amount of data, sampling rates, etc.) and the distribution of elements in terms of distance.

One of the difficulties for railway communication is ensuring reliable and consistent connections with equipment on-board trains, whilst these trains are moving across the network and through a range of environments. Necessarily, these communication systems have to be wireless, which means that tunnels, deep-cuttings and remote areas can create problems. There are a number of radio-based technologies currently deployed, with GSM-R representing one of the newest technologies for connecting drivers and signallers.

1.2.2.5 Security and cybersecurity

Security, and more specifically cyber-security, is a challenging issue since the on-going smart grid systems are facing increasing vulnerabilities as more and more automation, remote monitoring/controlling and supervision entities are interconnected.

The main goal is to be secure from cybersecurity threats when interfacing smart grid equipment with rail systems security vulnerabilities; this issue should be evaluated and properly mitigated. The fact that SCADA and railway energy management systems are now being interconnected and integrated with external systems creates new possibilities and threats in cybersecurity. Cybersecurity in smart grids is important for ensuring the confidentiality and fidelity of information, and the availability of power supply assets. Cyber-attacks could lead to power outages and infrastructure damage, compromise safety, affect operations and maintenance or impact the energy market.

Given the importance of cybersecurity for both smart grids and railways, it is essential that railway smart grids are protected and secure from threats targeting the power supply, railway, or both. Therefore, when interfacing smart grid equipment with rail systems security vulnerabilities should be evaluated and mitigated.

Cybersecurity standards that build upon current railway and smart grid best practice should be developed.

1.2.2.6 Electromagnetic compatibility

The EU directive requires that ''*Manufacturers of equipment intended to be connected to networks should construct such equipment in a way that prevents networks from suffering unacceptable degradation of service when used under normal operating conditions*[3]''. Any smart grid equipment installed, therefore, must take EMC into account and ensure that its performance will not cause electromagnetic interference that could have adverse effects on the network. Failure to reasonably control electromagnetic interferences in the railway smart grids could compromise safety.

The railway electromagnetic environment is generally considered to generate severe problems not presented in other sectors. Transient electromagnetic fields can be produced by train movements. Rolling stock electromagnetic emissions can also disturb wireless communications in a number of frequency bands. Therefore, for railway smart grids standardisation and measures to deal with specific railway electromagnetic interferences issues shall be taken into account.

1.2.2.7 Distribution network and distributed generation

The railway specific technical difficulties related to distributed generation are not solely due to the differences in power supplies and distribution above introduced; even when powered using the same type of supply, the demand varies depending on the service or route sections, is subject to large fluctuations due to daily peaks, and experiences smaller fluctuations due to driving style, delays, loading and regenerative-braking exchange. Due to all these factors, the power requirement at each substation differs.

This kind of systems approach would need to be taken for the implementation of smart grid to determine the number, sizing, location and type of distributed energy resources (solar, wind, etc.) to integrate into the RTPS, with the added complexity of considering the current power supplied by existing technologies (including trains), the likely future demand, and the limitations of the environment.

[3] Directive 1999/5/EC on radio equipment and telecommunications terminal equipment and the mutual recognition of their conformity

1.2.2.8 Data management

Another important challenge in smart grids is relevant to data management and data processing; in order to manage the generation, distribution, transmission and consumption of energy, data must be collected from multiple assets and used to make decisions in real time. The scale and complexity of the data for applications of smart grid makes it difficult to deal with in terms of transportation, storage, and transformation to useful outputs.

These issues are complicated considering the rail environment, because of railway smart grids would need to access and analyse data that belong to multiple stakeholders, both from the railway and power distribution sectors; moreover, open data coming from different sources (e.g. arrival and departure times, delays, etc.) are usually in different formats, and this makes their utilisation difficult.

1.3 E-LOBSTER in railway energy management concept

Considering the E-LOBSTER concept within the railway energy management, there are two main issues regarding smart management of railway network:

- Firstly, railways are formed by different subsystems: operation, infrastructure and rolling stock that should perfectly assemble to assure their correct functioning.
- Secondly, and in a similar way, smart management of railway network implies several technologies combination, which increases the difficulty of its implementation.

In terms of railway operation, smart management systems offer new business opportunities and also add new technical and organisational problems to be tackled. These concepts will be analysed more in detail in section 3.1, within the integration of E-LOBSTER with the grid.

2 Standardization of railway applications

In this chapter, an overview of potentially relevant railway application standards with respect to E-LOBSTER is briefly reported. The application of these standards focuses on technical aspects of the system, covering the characteristics and electrical requirements of fixed installations, parameters of the traction network, environmental requirements, and electromagnetic compatibility.

This section must be considered as a part of the whole analysis of the system, together with chapters 3, 4 and 5 where the analysis is further developed by particularly focusing on the integration of E-LOBSTER within the power grid (chapter 3), the energy storage (chapter 4) and the converters/sSOP (chapter 5) and by identifying potential gaps with respect to the existing standards.

In this context, it is worth to underline that when it comes to detecting lack of definition in standardisation of components, it is difficult to determine the extension to which these standards could be adjusted to the implementation of an innovative product. As it is the case of E-LOBSTER, existing standards and regulations may cover certain aspects by an approximation to the systems in use. Nevertheless, as the object of E-LOBSTER deals with an innovative product in development, this approximation becomes complex implying that more information is required from the final system application to recognize its position within standardization, so the identification or development of specific standards should be considered. Therefore, although a complete gap analysis is no feasible at this stage, an in-depth analysis of the potential relevant standards and gaps has been carried out in the next chapters, whereas, after having investigated in chapter 6 some marketability aspects, in chapter 7, how a standard based on the E-LOBSTER system could be drafted using the CENELEC process is illustrated. **The need of this proposal of standard will be confirmed only at the end of the project when several loose ends will be clarified after the installation of the system in the demonstrator based in metro of Madrid and the successful completion of the demonstration activities**.

By coming back to the scope of this chapter, a brief overview of the railway standards covering the characteristics and electrical requirements of fixed installations, parameters of the traction network, environmental requirements, and electromagnetic compatibility is provided in the following table.

Table 1: Railway standards

Standard reference	Topic	Analysis
EN 50119:2020	- **Fixed installations.** - **Electric traction overhead contact lines**	Deals with requirements and tests for projects with overhead contact lines to supply current to the traction units. Not applicable to systems with conductor rails (GMCR) next to running rails.
EN 50121-1:2017	**Electromagnetic compatibility**	It includes a set of standards about electromagnetic compatibility, specifying in them the electromagnetic behaviour in railway systems, radio frequency emission limits, requirements for the emission of rolling stock,

		immunity, and emission of equipment, signalling and fixed power installations. Due to the aspects that it covers, related to the EN61000, its study may be of interest.
EN 50122-1:2011	**Fixed installations. Electrical safety, earthing, and return circuit.**	It includes in its three parts the protection measures against electric shocks, against stray currents of traction systems and the interaction between direct and alternating systems; reason why its consideration for the implantation of the system is considered important.
EN 50123-1:2003	- **Fixed installations.** - **DC switchgear**	It copes with different connection devices, automatic switches, grounding and disconnectors, all the necessary in the DC network of the railway system, and their requirements.
EN 50125-2:2002	- **Environmental conditions for equipment.** - **Part 2: Fixed electrical installations**	Standard of special interest for the consideration of the environmental conditions under which the equipment of the electrical installation of the system will be found and the requirements that must be met to withstand them.
EN 50149:2012	- **Fixed electrical installations.** - **Electric traction.** - **Copper and copper alloy grooved contact wires**	Applicable for overhead lines. Defines the characteristics of copper and copper alloy wires.
EN 50152-3-1:2017	- **Fixed installations.** - **Particular requirements for alternating current switchgear**	It deals with the different connection devices of the alternating current network: automatic and earthing switches, transformers, measurement devices, control and protection of the traction network and their requirements.
EN 50163:2004	**Supply voltages of traction systems**	The main characteristics of the supply voltage of the traction network are specified: fixed installations, auxiliary devices and rolling stock.
EN 50327:2003	- **Fixed installations.** - **Harmonisation of the rated values for converter**	It offers test criteria and values for the choice of transformers and converters in the traction network.

	groups and tests on converter groups.	
EN 50328:2003	- **Fixed installations.** - **Electronic power converters for substations**	It copes with the requirements for the operation of the converters of the fixed installation for the power supply of the traction network.
EN 50329:2003	- **Fixed installations.** - **Traction transformers**	It defines the characteristics of the transformers used for the power supply of the traction system, in DC and AC; in addition to the auxiliary equipment.
EN 50345:2009	- **Fixed installations.** - **Electric traction.** - **Insulating synthetic rope assemblies for support of overhead contact lines**	Applicable to overhead lines. Define the characteristics of synthetic cables.
EN 50526-1:2012	- **Fixed installations.** - **D.C. surge arresters and voltage limiting devices**	About protection measures in the DC network: lightning rods and limiting devices. Part 3 of this standard is a guide for the application of these systems.
EN 50533:2011	**Three-phase train line voltage characteristics**	It establishes the characteristics of the three-phase train network that supplies power from the auxiliary power conversion system to the auxiliary loads. It applies to passenger trains towed by locomotives and electric and diesel automotive elements.
EN 50633:2016	- **Fixed installations.** - **Protection principles for AC and DC electric traction systems**	About the protection criteria of the traction network. It establishes the requirements, principles, and minimum functionalities of protection systems, as well as the principles for conformity assessment.
EN 62621:2016 A1:2016	- **Fixed installations.** - **Electric traction.**	It establishes the characteristics of composite insulators for electrical traction power networks, in overhead line systems, for nominal voltages of 1000V in AC and 1500V in DC.

	- **Specific requirements for composite insulators used for overhead contact airline systems**	

3 Integration of E-LOBSTER with power Grid

The integration of E-LOBSTER with the power grid involves the implementation of smart grids within the rail network. The use of this kind of technology changes several aspects of the different parts of the railway systems.

This section aims to summarise these changes in order to introduce those challenges that standardisation must tackle by means of new standards and requirements.

3.1 E-LOBSTER at railway energy management system level

The results of installing smart management solutions in railway networks set a series of changes within the railway facility itself, with which the range of possible business will experiment a considerable expansion, as it is developed in section 3.4.

This section aims to describe briefly how these changes affect the railway network considering three main aspects: infrastructure, rolling stock, and operation.

3.1.1 Infrastructure

Given that smart management solutions is mainly supported by smart grids and considering that those are installed within the power grid, infrastructure elements are regarded to play a rather important role regarding energy efficiency.

The implementation of smart technologies will not completely avoid losses, nonetheless, it will generate the possibility that the total energy balance could be nearly neutral. Hence, the actions that are introduced in order to increase the energy efficiency, or reduce losses are the following:

- Regulating substation transformers
- Reducing the losses in rheostatic braking
- Disconnecting some substations at off peak times
- Reversible power-supply substations
- Energy storage devices that can be integrated at different levels (generation level, transmission level, distribution level, customer level)
- The use of reversible converters
- Power factor correction in order to increase the reactive power
- Voltage regulation to achieve a constant power load
- Automatic voltage control schemes (AVC)
- Harmonic compensation
- The use of smart meters.

3.1.2 Rolling stock

Regarding the framework of the rolling stock, the application of the smart grid concept, originally developed for electric networks with distributed power generation, is gaining growing attention[4]. This approach enables efficient management of all the energy sources in the network by taking into account the actual demand. Actually in this context, the power from renewable sources from regenerative braking or from the public grid can be either used to match the demanded power of the system, or stored for later use shaving peak consumptions, determining in this way relevant cost savings[5].

Furthermore, ancillary systems in railways are other parts where smart management of energy implementation could improve their efficiency. Within these, apart from converters, transformers, rectifiers, etc. the HVAC systems might need smart management technologies in order to increase the efficiency due to the large amount of data that would be necessary to reach a conclusion about reducing energy losses.

3.1.3 Railway operation

Apart from the technical discussion about the introduction of smart management in railway networks, the opinion and thoughts of stakeholders (administrators, operators, universities, technology centres, and manufacturers) about the topic are an important subject to consider. Besides the discussion that was tackled in different E-LOBSTER deliverables (e.g. D6.4 “First Stakeholders’ vision document”), without repeating the same ideas about the concept of the sSOP (Smart Soft open Point) in E-LOBSTER, the idea of the stakeholders is that increasing energy efficiency is not only about reducing energy losses, but also recovering as much energy from the installation as possible. That is why energy storage systems increase their importance within the project as a method to enable the exploitation of all the energy that cannot be reused.

Therefore, the challenges that arise in this project considering smart infrastructure may be summarised:

- Electricity produced by the infrastructure itself, a micro generation of renewable energy close to where it will be consumed (technical buildings, auxiliary facilities, etc.)
- Penetration of storage systems - as it has been previously indicated, these add flexibility to the functioning of the system as a whole. It should be noted that storage systems offer advantages beyond energy savings. They improve the electrical stability of the system smoothing out the substation charge curve or for example providing power to the train at points on the line where sub-voltage problems are experienced.

As previously mentioned, the design of new line layouts (or improvements to existing ones) should incorporate energy related factors that have not been taken into consideration yet. In order to achieve this, it is necessary to develop the existing knowledge of energy consumption of different types of train

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[4] “Electricity Supply using SMART grid technologies coupled with increasing the residence and variety of supply resources (e.g. main grid, local renewables, recovered, etc..) can be applied not only to traction systems, but also for road usage and stations.e RAIL 2030- Research and Innovation priorities. ERRAC. 2019.

[5] A.E. Díez, I.C. Díez, J.A. Lopera, A. Bohorquez, E. Velandia, A. Albarracin, M. Restrepo, Trolleybuses in smart grids as effective strategy to reduce greenhouse emissions, In: IEEE International Electric Vehicle Conference – IEVC 2012, Greenville, USA; 2012.

on each line section as this will allow understanding of the problem, and to adapt the existing models to meet these specific needs. This presents several challenges, such as defining and developing efficiency indicators to evaluate the level of efficiency of each section of line.

Flexibility, which is also a way to reach higher energy efficiency, could be provided by four sources[3], flexible generation, interconnection, demand side response and electricity storage, as follows.

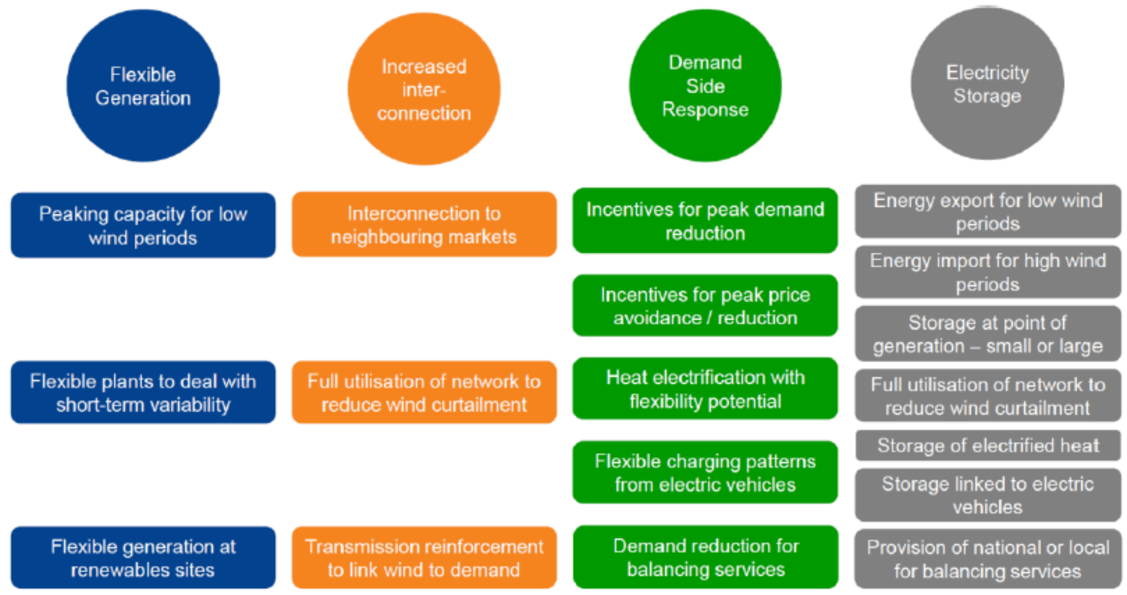

Figure 2: Sources of flexibility[6]

Smart grids use innovative products and services together with intelligent monitoring, control, communication, and self-healing technologies in order to:

- To improve the ease of connection and operation of generators of all sizes and technologies.
- To allow electricity consumers to play a part in optimizing the operation of the system.
- To provide consumers with greater information and options for choice of supply.
- To reduce significantly the environmental impact of the whole electricity supply system.
- To maintain or even improve the existing high levels of system reliability, quality and security of supply.
- To maintain and improve the existing services efficiently.
- To foster market integration towards a European integrated market.

3.2 Integration of E-LOBSTER components in energy management

The introduction of E-LOBSTER implies the need for the components within the energy management system to be connected with the E-LOBSTER using the concept of "smart management".

[6] Smarter Network Storage-LCNF-Interim-Report-Regulatory Legal Framework, 2015

Regarding the business side, smart management integration into the system means the expansion of the very same railway system, taking into consideration that new actors come into play (management of EV, renewables, energy storage systems, etc.), and, therefore, the entry of new potential business fields, like energy purchasing and integrated transport systems.

On the side of new technical and organisational issues, the creation of timetables and the calculation of headways considering new inputs, like the energy that is recovered from train braking and its reinjection into the grid or into energy storage systems.

Two elements are considered over the rest in terms of importance: the introduction of EVs and new renewable energy sources.

3.2.1 Electrical Vehicles within the energy management system

The introduction of EV within the energy management system implies interesting possibilities in terms of energy synergies that come from the interaction railway-EV in order to reduce the total consumption of energy.

The use of EVs within the system framework is partially supported by new directives like Directive (EU) 2019/944 presenting this system as a path to reach the goals set by European roadmaps towards energy and transport sustainability. Some point that reinforce this concept are[7]:

- *"[…] the need for the decarbonisation of the transport sector and the reduction of its emissions, especially in urban areas, and highlights the important role that electromobility can play in contributing to those objectives* […] *they should ensure the effective deployment of publicly accessible and private recharging points for electric vehicles and should ensure the efficient integration of vehicle charging into the system*."
- […] *and shall set out the planned investments for the next five-to-ten years, with particular emphasis on the main distribution infrastructure which is required in order to connect new generation capacity and new loads, including recharging points for electric vehicles* […]

Regarding railway current energy technologies, the use of residual energy that can be recovered from braking may be transferred through the overhead conductor, so that it is possible to directly use or to store it. This electrical power is likely to be used as power source of another facility or mode of transport. From this concept, the idea to reuse energy braking from railways sets an important support to EV, whose battery charge is considered one of the main problems regarding the currently available charge points.

The integration of E-LOBSTER, therefore, makes possible the use of the surplus energy that comes from the train regenerative braking to charge the EVs, and the use of the batteries of EVs to stabilise the energy balance within the energy network, easing the energy flow management.

[7] Directive 2019/944

3.2.2 Renewable Energy Sources within the energy management system

The use of RESs responds to the necessity of searching and finding new energy sources that allow to accomplish the European stances towards a clear energy generation. The integration of RES like solar panels, as it may be consulted in the diagrams of the E-LOBSTER functioning - Figure 1: - makes the energy balance more stable between demand and supply and will be used as an example of the straight use of these kind of energy sources within the considered network.

3.3 Actors and roles in smart grids

The introduction of E-LOBSTER and smart grids in railway facilities will cause the development of several architectures and information exchanges structures that allow new ways of interaction between the involved agents (IM, RU, EMO, TSO, DSO, etc.).

The services that the installation of E-LOBSTER may provide are the following:

- Electrical railway system operation systems: These services aim to optimise the energy flows (trains consumption/regeneration, infrastructure consumption, ESS charge/discharge, DES production, etc.). The entity supplying this operation control services (normally the IM) should be paid for providing these services, either by means of a fixed term (that should be established in the network statement) or using a distribution mechanism of the achieved savings.
- Execution of control actions: These services consist of executing the instructions received from a REM to enhance the operation (for example, to reduce power peaks, to reduce losses, etc.) and are provided to all the agents involved in the operation (RUs, IMs, etc.). The agents that follow these instructions should be paid according to a distribution mechanism of the achieved savings.
- Energy procurement services: In order to minimize the volatility of energy prices, a practical solution is to manage a portfolio of supply alternatives, combining long term contracts and participation in the spot markets. An algorithm helps to determine the best way of combining the available contracts with the participation in the spot markets to optimize the price of the energy.

The following are considerations regarding smart grids and its implementation:

- The adoption of smart grid solutions has achieved savings of 11% of the total energy consumption under traffic congestion situation[8] and 15% of the power peaks. The electricity bill can be reduced by 5.54% thanks to this reduction in peaks[9].
- The optimisation of the energy procurement is advisable, not only because of the average energy price reduction it can achieve, but also because of the risk management strategies that can be followed to reduce the exposure to the volatilities of spot market prices and the energy demand.
- To allow a proper optimization of the operation, the train power profiles must be predictable for all the trains (those equipped with smart grid technologies and those which are not) and their allocated power at each substation (which is dynamic) should not be exceeded (unless the control system authorize it).

[8] E-LOBSTER D1.8 “Smart Management of Railway Networks” Pg.41
[9] EU FP7 Project “MERLIN (2015)”. GA – 314125

- In order to provide the appropriate financial viability, a mechanism for distributing the economic savings that can be achieved by the smart grid has to be detailed, including both the “mark-up” to be paid to the IM and the payments to the RUs.

3.4 Constraints of E-LOBSTER compliance against EU Smart Grid Standards

The aim of this section is to tackle the possible gaps that may appear regarding the compliance of standards of smart grid and the elements that work within their framework considering the functioning of E-LOBSTER.

Therefore, the following analysis will consider all the aspects that are regarded to be problematic considering the actual installation and functioning of E-LOBSTER under real circumstances.

3.4.1 Standard application: Types of standards

As this deliverable discusses many standards that have different sources and ranges of application, for this reason, it is worth making a prior clarification on the different types of standards that may be found, as well as the area in which they can be applied:

Table 2: Types of standards

Acronym	Description	Application range
IEC	Acronym of "International Electrotechnical Commission", the global organization for the preparation and publication of international standards for all technologies related to electricity and electronics (electrotechnology).	Its application range is **international.**
CLC	Acronym for CENELEC, the European Committee for Electrotechnical Standardization which is responsible for standardization in the field of electrotechnical engineering. It is mainly focused at European level, nevertheless it is also a reference at global level, as they work with the IEC.	Thus, although this organization is of international reference, its application range is **European.**
EN	Acronym for "European Normative" which are European standards that are explained, created, and used by experts from different member states, for a mixed industrial or technological sector.	Its application range is **European**.
UNE	Acronym for "*Una Norma Española*", A Spanish Standard, which is a united group of technological standards founded by the technical standardization committees (CTN). It is a non-profit association, legally recognized in Spain as a national standardization body.	Its application range is **Spanish national level**.

ISO	They are a set of universally applicable regulations and provisions. ISO is an acronym for the International Standardization Organization. They are applicable to different types of organizations, providing them a set of certifications regarding whether they meet the level of requirement that are set out in those standards. Organizations that comply with ISO standards will obtain a certification that supports them considering their customers.	They application range is **worldwide.**
IEEE	It is an acronym for "Institute of Electrical and Electronics Engineers". IEEE is a global association of engineers dedicated to standardization and development in technical areas.	Its scope is **worldwide.**
IETF	Acronym for "Internet Engineering Task Force". It is an open international organization for standardization, whose objective is to ensure that the architecture of the Internet and the smooth operation of the Internet.	It was created in the United States, however today its application range is **worldwide.**
RFC	It is an acronym for "Request For Comments", and they are a group of documents that serve as reference for the Internet community that describe, specify, and assist in the implementation, standardization, and discussion of most standards, technologies, and protocols related to the Internet and networks in general.	Its scope is **worldwide.**

3.4.2 Transmission & Distribution

The standards applied to the electrical transmission and distribution are discussed in this section:

- Behavior of high voltage systems with steady state in DC current.
- Definition of HVDC systems.
- Specific operating guides for a distribution network.
- Protection and operational capabilities related to distribution lines.

3.4.2.1 IEC/TR 60919-1. Performance of high voltage systems (HVDCs) with line-commutated converters. Part 1: Steady-state conditions

This part of the standard provides a general guide to the steady-states behavior of high voltage systems in DC current. It focuses on the steady state behavior of two High Voltage Direct Current (HVDC) terminals using a 12-pulse rectifier, not on HVDC multi-terminal transmission systems.

Topics related to:

- Types of HVDC systems.
- Power, current, and voltage ranges.
- The capacity of the equipment.
- The concept of reactive power.
- Associated Control Systems.

- Other concepts related to the mentioned aspects.

Auxiliary power source storage items are also mentioned, specifically regarding those uninterrupted power supplies (UPS).

It is considered to be applicable to provide information of the types of connections between HVDC terminals, as well as different topics about these terminals, considering their possible integration with storage equipment and power management.

3.4.2.2 IEC 61803. Determination of power losses in high-voltage direct current (HVDC) converter stations

It provides information and environmental parameters related to the use of HVDC, as well as calculations of converter losses. It does not refer to battery transmission.

This standard is considered to be important from the point of view of the network and power distribution, since supply systems need an estimation of losses and where they occur, considering those produced by the very same conversion and the auxiliaries when feeding the converter.

3.4.2.3 CLC/TS 50549-1. Requirements for generating plants to be connected in parallel with distribution networks – Part 1: Connection to a LV distribution network – Generating plants up to and including type B

The purpose of this technical specification is to provide a technical guide regarding the requirements for generation plants that operate in **parallel to** a distribution **network.** It applies to all types of generation plants, electrical machinery, and electronic equipment, regardless of the primary power source used and the nature of the loads, provided that they are connected to **low voltage** and current values higher **than 16 A per phase,** and planned to operate in parallel with the distribution network under nominal conditions.

This standard describes:

- Connection schemes.
- Switch options.
- Nominal operating range.
- Immunity to variations.
- Active response to variation in frequency.
- Response to voltage variations.

And other concepts related to the mentioned aspects. The connectivity requirements it defines are highlighted from this standard.

The selection and evaluation of the connection point, evaluation of the power and impact system, connection assessment, the operation of power islands of generating plants where it does not affect the distribution network, personnel safety requirements or, above all, **train units powering power back to the grid** is not covered. It is advisable to limit its use to connectivity issues between electrical distribution networks.

3.4.2.4 EN 50549-2. Requirements for generating plants to be connected in parallel with distribution networks. Part 2: Connecting to an MV distribution network. Generating plants up to and including type B

This standard specifies the requirements for correct conditions of protection and operability in generation plants intended to operate in parallel to distribution lines. The application of this standard is independent of the type of power source and loads.

These requirements describe:

- Connection schemes.
- Switch options.
- Nominal operating range.
- Immunity from interference.
- Active response to variation in frequency.
- Response to voltage variations.
- Other concepts related to the mentioned aspects.

The battery systems response to compensate frequency fluctuations is also mentioned.

This standard focuses on parallel-connected generation plants, but not so much on the characteristics that the instruments connected must meet.

3.4.3 Information transfer across the substation network

This section will analyze all the regulations concerning communication systems and networks for the connection and implementation of the system within a smart grid. The architecture and requirements related to data transfer in communication networks will be considered analyzing some parts of IEC 61850 on substation automation. This pursues to define a data model within a structure that uses a common language for substation description (SCL) and is modeled by using Logical Nodes.

The importance of this section lies in the communication of electronic instruments (IEDs) that track the substation.

The study focuses on the following topics:

- Power generation and electricity facilities.
- Power networks of power companies.
- Substations and feeding equipment.

3.4.3.1 IEC 61850. Communication networks and systems for power utility automation

Part 3. General requirements.

The general requirements are mostly related to construction, design, and environmental conditions for communication and automation tools, as well as power plant systems and substations.

Part 4. System and project management.

It applies to projects related to power automation processes, such as power supply to railway substations. It is also useful for systems with communication between intelligent electronics, as it could occur between a power plant substation and its associated systems.

Part 5. Communication requirements for functions and device models.

This part of the regulation applies to electrical grid automation systems, standardization of communication between intelligent electronic devices (IEDs), and the definition of system requirements. These requirements include information of battery data, nodes, and monitoring measures.

Part 6. Configuration description language for communication in power utility automation related to IEDs

Descriptive configuration of the language for communications in IEDs-related substations. It provides a cross-SCL substation language for the configuration of IEDs of electrical substations used, in this case to track systems and power distribution between network equipment.

Part 7-1. Basic communication structure. Principles and models.

This part of the standard provides a description of the architecture for communication between electrical grid automation systems, including:

- Protection systems.
- Transformers.
- Substation Hosts.

To do this, modeling methods and communication principles are presented, focusing on providing conceptual assistance to understand:

- Basics of modeling and description of automated power, network, and substations.
- Device functions for automation.
- Communication systems for interoperability.

It also provides explanations and requirements in relation to other sections of IEC 61850.

Part 7-2. Basic information and communication structure – Abstract communication service interface (ACSI)

This standard applies to ACSI communication for utility automation, offering interfaces for communication between client and remote server and for the distribution of system-wide event distribution between remote devices and applications.

Direct battery information is not provided, although it is considered of interest to understand the language to be implemented between devices for the communication of network equipment.

Part 7-3. Basic communication structure - Common data classes

This document is part of a set of specifications that detail the communication architecture of layered substations. This architecture has been chosen to provide abstract definitions of classes and services so that the specifications are independent of specific object and protocol stacks.

The constructed attribute classes and common data classes related to applications of electrical grid automation systems in substations are specified here.

This standard refers only to common data classes, part of the basic communication structure; it is therefore of interest to the implementation of the network communications system.

Part 7-4. Basic communication structure – Compatible logical node classes and data object classes

This standard specifies the information model of the devices of the automation system of the electricity grid and those related to the functions of the substations

The name of the supported nodes, and the names of the data objects for the communication of IEDs is specified, so battery node information is included within the node classes section.

Part 7-420. Basic communication structure - Distributed energy resources logical nodes

This compendium on standards discusses the connectivity modes of DERs, Distribution Energy Resources.

DERs are distributed power-resourced systems interconnected with power electrical systems around the world. Regarding the E-LOBSTER study, the application of this standard is interesting considering that the system will be interconnected to the Smart Grid to different electrical elements of the railway substation.

This standard arises from the need to provide an international standard that defines the communication and control of the different interfaces for all DER devices.

In particular, this standard develops a study of the information models that can be used for the exchange of information with DER. A standard communication model is established that uses the existing nodes defined in IEC 61850 as long as it is possible, however this communication model is capable of defining its own logical communication nodes when necessary.

Part 8-1. Specific communication service mapping (SCSMs). MMS (ISO/IEC 9506 Part 1 and Part 2) and ISO/IEC 8802-3

This part of the standard specifies a method of exchanging information over **local networks** by mapping ACSI (Abstract Communications Service Interface) to MMS (Manufacturing Message Specification).

It specifies the mapping of objects and services carried out by ACSI to MMS, to define how ACSI concepts, objects and services can be translated into their MMS equivalent and therefore promote interoperability.

A standardized method is also defined to use the services of the ISO 9506 standard, additional protocols, and actual utility of its elements.

Part 9-2. Specific communication service mapping (SCSMs). Sampled values over ISO/IEC 8802-3

The mapping of the SCSM-specific communication service for the transmission of sampled values is defined here in accordance with the specification in IEC 61850-7-2.

Each SCSM consists of:

- A specialized communication protocols.
- Mapping the abstract specifications of the IEC 61850-7 series on the elements of the communication protocol.
- The functionality implementation specification, which is not covered by the communications protocol used.

Part 10. Conformance testing.

A set of specifications for the communications architecture in power systems is detailed, defining methods and cases for device and tool compliance testing.

Although battery usage is not directly mentioned, the test conditions of the devices are detailed, then it would be interesting to consider whether the storage and power distribution systems are included in that group, in addition to the rest of the equipment contained in the network system.

3.4.4 Control and Regulation Equipment

This section will analyze all the regulations concerning communication systems and networks for the connection and implementation of the E-LOBSTER system within a smart grid. To do this, current control measures in high voltage systems of automated electrical substations will be studied.

In this case it is mainly focused on current sensors for fault detection and grounding disconnectors in high voltage systems; therefore, IEC 6289N-100 and EN 66271-102 will be discussed. The study focuses on the following topics:

- Power generation and electricity facilities.
- Power networks of power companies.
- Substations and feeding equipment.

In the following sub-paragraphs, the information found for each of the standards are reported.

3.4.4.1 IEC 62689-100. Current and voltage sensors or detectors to be used for fault passage indications purposes

It provides information for current and voltage sensors, and detectors to be used as fault pass indicators. Mostly, it deals with sensors and their different configurations, emphasizing the observed magnitude and measurement parameters, as well as highlighting the communication tasks that such sensors can offer. Power storage and distribution systems are briefly mentioned to refer to the power systems of the sensors themselves.

From a distribution point of view, and considering the needs of the project**,** including the standards of use of current and voltage sensors, necessary for monitoring the health of the network and in the implementation of distribution systems. In this way, adjustment of requirements, classification measures and tests relevant to the use of these devices is required.

The standard offers part 2, which develops technical aspects of the system, mainly electrical phenomena produced during the failure of the network depending on the distribution system and the type of failure; thus defining the system requirements in these situations, so from a network and distribution point of view it becomes necessary to apply the standard.

3.4.4.2 66271-102. High voltage appliance. Part 102: AC grounding disconnectors and disconnectors

It deals with high voltage equipment that works with a digital interface based on IEC 61850, and is applicable to all high voltage equipment with voltage greater than 1KV.

This standard provides an application for the IEC 61850 standard defining a communication architecture for high voltage switching and control equipment.

For the implementation of a power distribution system of the electrical grid it is necessary to know the monitoring protocols of the IEC 61850.

3.4.5 Electromagnetic Compatibility

This section focuses on the study of EN 61000 on electromagnetic compatibility to establish the extent to which the electromagnetic environment can affect electrical and electronic equipment and establishes mechanisms and tests to ensure the reduction of these effects.

3.4.5.1 EN 61000. Electromagnetic compatibility EMC

Part 1-2. General. Methodology for the achieving of functional safety of electrical and electronic systems, including equipment with regard to electromagnetic phenomena

This deals with electromagnetic compatibility and methodology for obtaining the safety of electrical and electronic systems. The use of batteries is provided in the section of electromagnetic disturbance protection measures.

This regulation is considered to be of great importance since functional safety criteria are established with respect to electromagnetic phenomena, taking into account the implications of the network equipment itself, so that aspects related to the electromagnetic compatibility of the specific design phases and the application of systems and equipment in the context of obtaining minimum safety are mostly covered.

Part 2-4. Environment. Compatibility levels in industrial plants for low-frequency conducted disturbances

It refers to disturbances conducted in the frequency range from 0 kHz to 9 kHz, with an extension up to 148.5 kHz for signal transmission systems in the network.

These are:

- Voltage fluctuations.
- Flicker.
- Harmonics and interharmonics up to order 50.
- Voltage distortions at higher frequencies.
- Short gaps and voltage interruptions.
- Voltage imbalance.
- Transient surges.
- Fundamental frequency variations.
- Continuous components and signal transmission systems in the network.

The numerical values of compatibility levels are given for **low voltage, medium voltage, and industrial power distribution networks** with a maximum rated voltage of 420 V single-phase or 690 V three-phase, and a nominal frequency of 50 Hz or 60 Hz.

Batteries are mentioned in Annex B of the standard, which states that sources that need direct current and do not have batteries use electronics devices, and these kind of devices generates undesired voltages and currents in the network. Batteries are also mentioned as transient surge-resistance when performing capacitor battery connection maneuvers.

Part 2-8. Environment. Voltage dips and short interruptions on public electric power supply systems with statistical measurement results

It deals with voltage dips and brief interruptions in supply power grids, concerning phenomena such as:

- Electromagnetic disturbance of voltage gaps.
- Sharp voltage reductions at a certain point in the network.
- Origin and effects of interruptions.
- Corrective measures.
- Measurement methods.
- Results.

The study of this technical report should be used to understand the phenomena of voltage variation that can occur in the network, as well as containment measures.

In relation to energy storage and distribution systems, stored energy systems are mentioned, commenting on the measures to be taken against gaps from the observation point near the storage device, as well as the immunity of certain equipment to the gaps according to their storage capacity.

Part 2-9. Description of the HEMP environment. Radiation disturbances. Basic EMC standard.

It defines the environment of the electromagnetic impulse of nuclear origin at high altitude, which can be caused by a nuclear explosion (radiated disturbances).

The purpose of this standard is to establish a common reference for the HEMP environment (high-altitude nuclear electromagnetic impulse).

Part 3-2. Limits. Limits for harmonic current emissions (equipment with input current < = 16 A per phase).

It deals with the limitation of harmonic currents injected into **the public supply network.** It is applicable to electrical and electronic inlet current equipment less than or equal to 16 A per phase and designed to be connected to public low voltage supply **networks.**

It also refers to optional conditions for measuring harmonic emissions from information technology equipment with external power supplies or with battery chargers.

Part 3-3. Limits. Limitation of voltage changes, voltage fluctuations, and flicker in public low-voltage supply networks for equipment with rated current ≤16 A per phase and not subject to a conditional connection.

It deals with the limitation of voltage fluctuations and flickers that affect **the low voltage public distribution network.** It applies to electrical and electronic equipment with input current less than or equal to 16 A per phase and intended to be **connected to public low voltage distribution networks** between 220 V and 250 V between phase and neutral at 50 Hz and which are not subject to a conditional connection.

Part 3-6. Limits. Assessment of emission limits for distorting loads in MV and HV power systems - Basic EMC publication (IEC/TR 61000-3-6:1996)

It offers the principles to follow in the connections of high-powered disruptive loads in order to ensure quality of service for the entire network. It is advisable to consult these standards to define the emission limits for individual equipment or for the load as a whole, ensuring voltage quality criteria.

Part 3-11. Limits. Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems - Equipment with rated current = 75 A and subject to conditional connection

It deals with the emission (harmonics) of voltage variations, voltage fluctuations and flicker produced by the equipment and transported by the **public low voltage supply network.**

It applies to electrical and electronic equipment with a power-assigned current between 16 A and 75 A per phase, intended to be connected to **public low voltage distribution networks** with a phase-neutral rated voltage between 220 V and 250 V 50 Hz, and subject to a conditional connection.

Part 3-12. Limits for harmonic currents produced by equipment connected to public low voltage systems with input current > 16 A and <TM 75 A per phase.

It deals with the elimination of harmonic currents injected into the **public supply network.** The limits defined in this standard apply to electrical and electronic equipment with an input assigned current greater than 16 A and less than or equal to 75 A per phase, intended to be connected to public **low voltage** distribution networks in alternating current with single-phase rated voltage of up to 240 V or three-phase rated voltage up to 690 V.

Part 4-10. Testing and measurement techniques. Damped oscillatory magnetic field immunity test

It describes the requirements for immunity of equipment under operating conditions against damped oscillatory magnetic disturbances in medium and high voltage substations and defines their testing and measurement techniques.

It does not consider disturbances due to capacitive or inductive couplings between cables and other parts of the installation.

Part 4-12. Testing and measurement techniques. Ring wave immunity test

It deals with immunity requirements and test methods for electrical and electronic equipment under operating conditions, for transient non-repetitive damped oscillations manifested in low voltage power grids, as well as for control and signal lines connected to public or private networks.

Part 4-13. Testing and measurement techniques. Harmonics and interharmonics including mains signalling at AC power port, low frequency immunity tests

It defines immunity testing methods, as well as the range of basic test levels recommended for electrical and electronic equipment, with rated input current up to 16 A per phase, harmonics and interharmonics in **low voltage supply networks** at disruptive frequencies up to and including 2kHz and 2.4 kHz.

The purpose of this standard is to establish a common reference for the assessment of the functional immunity of electrical and electronic equipment subjected to harmonics and the frequencies of transmission signals through the network**.**

Part 5-5. Installation and mitigation guidelines. Section 5: Specification of protective devices for HEMP conducted disturbance. Basic EMC publication.

It defines how the proposed protection devices should be specified against disturbances driven for HEMP protection. Covers protection devices currently used for protection against transients induced by HEMP on signal lines and low voltage power lines. In addition, battery issues are mentioned in the generalities of the generator, which states that the output must be decoupled from ground.

Part 5-7. Installation and attenuation guides. Degrees of protection provided by enclosures against electromagnetic disturbances (EM code).

It specifies the requirements, test method and classification procedure applicable to the degrees of protection against electromagnetic disturbances provided by the empty enclosures, for frequencies between 10 kHz and 40 GHz. It is intended to indicate a reproducible mean for the evaluation of the results of electromagnetic shielding of empty mechanical enclosures including cells and frames.

Part 6-5. Generic standards. Immunity for equipment used in power station and substation environment.

This standard focuses on the EMC immunity requirements to be applied to electrical and electronic equipment to be used in the substation, including equipment intended for the generation, transport, and distribution of electricity.

This regulation compliance is mandatory, establishing the immunity measures relevant to distribution equipment, and carrying out the tests referred to above.

On the other hand, it refers to batteries within the considerations of "DC distribution network", specifying that the connection to a remote local battery does not count as a local distribution network provided that the connection consists only of power for a single piece of equipment. Batteries are also referred to in this standard, within the causes of electromagnetic phenomena.

Part 6-7. Generic standards. Immunity requirements for equipment intended to perform functions in a safety-related system (functional safety) in industrial locations.

It is intended to be used by suppliers when making statements for the immunity of equipment intended for use in systems related to safety against electromagnetic disturbances.

The purpose is to define immunity test requirements for equipment in relation to continuous and transient disturbances, conducted and radiated, including electrostatic discharges. It only deals with distribution networks when it refers to the feeding system, to characterize the test.

3.4.6 Power Quality

Within this point, the characteristics of the voltage supplied by the AC network are studied by defining the main parameters that ensure the quality of the energy according to **EN 50160** and the criteria of its application by **TR 50422**.

3.4.6.1 EN 50160. Voltage characteristics of electricity supplied by public electricity networks

This standard defines, describes, and specifies the main characteristics of the voltage supplied by a general AC current network in low, medium, and high voltage under normal operating conditions at the point of delivery to the network user. It focuses on the maximum and minimum voltage values that can be found in a general European distribution network; not so in the usual value that a user can find.

It does not apply under abnormal operating conditions such as:

- Feeding conditions after breakdown or during maintenance and construction work.
- Non-conformity of the installation or equipment of a network user with applicable standards or with technical connection requirements.
- Exceptional situations (exceptional weather conditions, strikes, force majeure...).

This standard is sought to define, describe, and specify the characteristics of the supplied supply voltage: amplitude, waveform, and line stress symmetry.

It also provides information on voltage levels and frequency of signals used in high and medium voltage distribution networks.

About batteries, it is mentioned in the integration with the system to compensate for frequency fluctuations.

3.4.6.2 TR 50422. Guide to the application of the European standard EN 50160

It is a guide to the correct application of the European standard **EN 50160**, already described in section 3.4.6.1.

3.4.7 Cybersecurity

This section aims to define the criteria in the protection of the computational structure that interacts with the E-LOBSTER system.

The following points will be considered for this purpose:

- Overview, network protocol requirements, physical layer and data link layer requirements, and communication interface compliance tests between the physical layer and the data link layer. The physical layer and data link layer are defined as the first two layers in the seven-layer OSI model (Open System Interconnection). The first one is responsible for transforming the bit stream for sending, while the second one transfers the data reliably.
- Security requirements for automation and industrial control systems, including security program requirements for ACSI asset owners, service providers, system requirements, security levels, product development and security for ACSI components.
- Data and communications security for the management of power systems, considering the different profiles such as TCP/IP and MMS, in addition to the procedures and algorithms that ensure the correct functioning of the protocols.
- Data exchange in data power measurement equipment.
- Features and functions of IEDs in the cybersecurity environment under aspects such as access, configuration, firmware review and data recovery.
- Standards for IEDs in automation, protection, and energy management systems.
- Infrastructure for online certificates in public key.
- Enrollment of certificates through CMS messages by secure transport.
- Security in cryptographic modules.
- Safety controls in the energy industry in systems dedicated to monitoring and managing power generation, storage, and transmission.
- Criteria and actions regarding IT security assessment.

3.4.7.1 ISO 15118

It deals with the communication interface between a vehicle and the electrical grid.

Part 1. Road vehicles - Vehicle to grid communication interface - General information and use-case definition

This standard describes general application and typical use cases. In particular, it provides general context for upload/download identification, association, control and optimization, cybersecurity, and privacy.

It specifies general terms, definitions, and requirements, and use cases for HLC (high-level communication) wirelessly between the EVCC (communication controller of an electrical vehicle) and the SECC (supply equipment communication controller).

It applies to HLC involved in wireless transfer and power conductive technologies. It also applies to the transfer of power of the power supply equipment of the electric vehicle to the battery of the electric vehicle or in the opposite direction to supply power to other charges or to the electricity grid.

Part 2. Road vehicles - Vehicle-to-grid communication Interface - Network and application protocol requirements

About the requirements between the vehicle and the mains. The purpose of this document is to detail the communication between the electric vehicle (100% electric or plug-in hybrid) and the source of supply for it. This part of the standard specifies the shared communication protocols and interface methods used by communication networks designed to support the transfer of energy between electric vehicle and its source of supply.

Part 3. Road vehicles - Vehicle to grid Communication interface - Physical and data link layer requirements

This standard discusses the requirements of the physical layer and the data link layer. This part of the standard specifies the requirements of the link between the physical layer and the data layer for high-level communication, directly between battery-powered electric vehicles or pluggable hybrid vehicles, based on wired communication technology and fixed electrical recharge installations (supply equipment).

It covers the general exchange of information between all related actors in the exchange of electrical energy. It involves the architecture of the communication system, the coordination between connections, the coupling process "electric vehicle – Source of supply", signal coupling and electromagnetic requirements.

Part 4. Road vehicles - Vehicle to grid communication interface - Network and application protocol conformance test

Describes the application and network protocol compliance tests. Forming tests are specified in the form of an ATS (*abstract test suite*) for a SUT (system under *test*) implementing an EVCC (communication controller of an electric vehicle) or an SECC (communication controller of supply equipment). These tests specify the capabilities and behavior of the system in accordance with the requirements in **ISO 15118-2**.

Implementing an ATS involves a separate and complete set of specifications required from a process to achieve a specific purpose of the test.

Part 5. Road vehicles - Vehicle to grid communication interface - Physical layer and data link layer conformance test

It describes the physical layer and data link layer compliance test. Forming tests are specified in the form of an ATS (abstract test suite) for a SUT (system under test) implementing an EVCC (communication controller of an electric vehicle) or an SECC (supply equipment communication controller) with support for high-level communication (HLC) based on PLC and basic signaling in accordance with **ISO 15118-3**.

Part 8. Road vehicles - Vehicle to grid communication interface - Physical layer and data link layer requirements for wireless communication

This standard defines the physical and data link layer requirements for wireless communication. This part of the standard specifics the requirements of the link between the physical layer and the data layer for high-level wireless communication (contrary to **ISO 15118-3**), directly between electric vehicles and power supply. It covers the general exchange of information between all related actors in the electrical exchange of electrical energy. It establishes the requirements of wireless communication regarding the EVCC (communication controller of an electric vehicle) and the SECC (communication controller of supply equipment).

3.4.7.2 IEC 62443. Security for industrial automation and control systems. Industrial communication networks - Network and system security

Security requirements for automation and industrial control systems are discussed. It is applied in its widest possible form, covering all types of plants, facilities, and systems in all industries.

Part 2-1. Establishing an industrial automation and control system security program: Security program requirements for IACS asset owners

The standard describes what is required to define and implement an effective IACS (Industrial Automation and Control Systems) cybersecurity management system.

Part 2-4. Security program requirements for IACS service providers

The specific standard requirements for IACS (Industrial Automation and Control Systems) suppliers.

Part 3-3. System security requirements and security levels

The standard describes fundamental system security requirements and security assurance levels.

Part 4-1. Secure product development lifecycle requirements

This part of the standard specifies the process requirements for the safe development of products used in automation and industrial control systems. It defines a development lifecycle in order to perform production in the safest way, as well as product maintenance. These requirements are therefore applied to developers and product conservatives, but not to the user or integrator.

The main objective of these requirements is to provide a framework for a safe system approach, so that it describes a product life cycle that defines the design, construction, maintenance and removal of those equipment used in industrial automation and control systems. It contemplates various practices like:

- Security management.
- Specifying security requirements.
- Security by design.

- Secure deployment.
- Security verification and validation tests.
- Management of security-related issues.
- Security update management.
- Security guidelines.

Part 4-2. Technical security requirements for IACS components

The technical requirements of the detailed components of a control system associated with the seven fundamental requirements are indicated:

- IACS.
- Usage control.
- System Integration.
- Confidentiality of data.
- Restricted data flow.
- Timely response to events.
- Resource availability.

These requirements are the basis for defining the security capacity levels of control systems. All components defined in this document must be developed and supported following the safe product development processes described in the first part of this section (IEC 62443-4-1).

3.4.7.3 EN 62351:2017. Power systems management and associated information exchange - Data and communications security

It deals with the management energy systems and the associated information exchange, along with data and communication security.

Part 3. Communication network and system security - Profiles including TCP/IP

This part deals with the system and communication network security, including TCP/IP profiles. It focuses on confidentiality, protection, and authentication measures for SCADA and remote protocols that use TCP/IP as the transport layer. The main objective is to provide security between the entities at either end of the TCP/IP connection.

In this way, the standard clarifies how to protect TCP/IP-based protocols through restrictions on the specification of messages, procedures, and algorithms.

Part 4. Profiles including MMS and derivatives

About the different security profiles including MMS profiles. It extends the scope of **IEC TS 62351-4:2007** by specifying the compatibility mode that provides interoperability with the implementation based on **IEC TS 62351-4:2007**. Specifies security requirements at both transport layer and application layer; it also provides extended authentication and support for the protocol phase as well as for the data transfer phase. This document represents a set of mandatory and optional security specifications for the protection of protocol application.

Part 5. Security for IEC 60870-5 and derivatives

This standard specifies the procedures and algorithms that ensure the operation of remote-control systems based on IEC 60870-5.

Part 6. Security for IEC 61850

This part of the standard specifies messages, procedures, and algorithms to guarantee the operation of all protocols based on or derived from the **IEC 61850** standard. It applies at least to the **IEC 61850-8-1**, **IEC 61850-9-2**, and **IEC 61850-6** protocols.

This part is critically important to Smart Grid.

Part 7. Network and system management (NSM) data object models

Network and system management data object models that are specific to power system operations, are defined in this part. This network and system management data will be used to:

- To check the health of networks and the system.
- To detect potential security intrusions.
- To manage the performance and reliability of your information infrastructure.

The purpose of this standard is to establish a set of objects that will allow remote monitoring of the conditions of intelligent electronic devices (IEDs), remote terminal units (RTU), distributed power resources (DERs) and other system that is important for the operation of operating systems.

Part 8. Role-based access control for power system management

It covers the access of users and automatic agents to control systems. These standards deal with everything necessary for interoperability between different systems.

Part 9. Cyber security key management for power system equipment

It specifies cryptographic key management: generate, revoke, and manage public key certificates and keys to protect digital data and its communication. Includes handling both asymmetric and symmetric keys.

This document assumes that the type of key and cryptography used has already been established, so it provides management techniques for the infrastructure of that selected key. The main objective is to define the requirements and technologies to achieve the interoperability of key management, ensuring the coupling between the different types of existing vendors by setting limits of key manager options.

Part 10. Security architecture guidelines

It provides a description of the criteria to follow for security design based on energy system controls. Alongside this, a guide is provided to support system integrators to securely implement power generation, transmission, and distribution systems by applying available standards.

Part 11. Security for XML files

It focuses on security of XML files, and specifies the scheme, procedures, and algorithms to protect XML documents that are used within the IEC domain as in other domains such as IEEE, and so on.

3.4.7.4 IEC 62056. Electrical power measurement equipment

Electrical power measurement equipment and data exchange for meter reading, rate, and load control.

Part 21. Direct local data exchange

This part of the standard describes hardware and protocol specifications for local data exchange. Its field of study are systems in which a portable reading terminal or a unit with equivalent functions is connected to a pricing device or a group of devices, which can be the permanent or disconnecting connection through an optical or electrical coupling. The aim is to ensure electrical insulation and data security in the field of electrical measures.

An annex (D) of IEC 62056 is also included in which a definition of up to four levels of system access security may be used by pricing devices.

Part 42. Physical layer services and procedures for connection-oriented asynchronous data exchange

Describes physical layer services and protocols within the three-layer COSEM-oriented profile (Companion Specification for Energy Metering) for asynchronous data communications. No signals or mechanical aspects of the physical layer are specified, nor are specific aspects of local implementation.

An annex describing the operating principles of a smart modem under the physical layer interface is also included, and another that provides an overview of defining the functionality of a COSEM object measurement equipment.

Part 43. Link layer in HDLC

It defines the link layer for the connection-oriented HDLC-based asynchronous communication profile.

3.4.7.5 IEEE 1686. Standard for intelligent electronic devices

It defines a standard for intelligent electronic devices, applicable to cybersecurity. Here, IEDs' functions and features for the use of cybersecurity programs are defined, addressing security related to access, configuration operations, firmware review and IED data recovery, as well as aspects related to interface confidentiality and integrity.

3.4.7.6 IEEE C37.240. Standard for smart electronic devices – cybersecurity

Standard cybersecurity requirements are defined for automation, protection, and control systems for power systems. It provides technical requirements for electrical system cybersecurity, which can be applied to achieve high levels of security in automation, protection, and control systems regardless of network voltage level or asset criticality.

3.4.7.7 IETF-RFC 6960. Public key infrastructure for online certificates

About the OCSP public key infrastructure to the internet. A protocol is specified to determine the status of the digital certificate without requiring the certificate itself.

3.4.7.8 IETF-RFC 7030. Registration criteria for safe transport

About secure transportation. Describes certificate enrollment for clients that use certificate management through CMS messages over secure transport. This profile is called EST, enrollment over secure transport.

3.4.7.9 ISO/IEC 19790. Security criteria for cryptographic modules

It discusses, within information technologies, security techniques and security requirements for cryptographic modules. This standard sets security requirements for a cryptographic module used within a security system that protects sensitive information from telecommunications equipment and systems. Using these requirements, four levels of security for cryptographic modules to provide a broad spectrum of data sensitivity and a variety of application environments are defined.

3.4.7.10 ISO/IEC TR 27019. Security controls for the energy industry

ISMS (Information Security Management Systems) for electrical systems. It offers principles for the management of safety in the management of process control systems in the energy services industry. Therefore, those systems designed to control and monitor the generation, transmission, storage and distribution of electrical energy, gas and heat are covered in combination with the control of support processes.

3.4.7.11 ISO/IEC 15408. Evaluation criteria for IT security

Discuss the assessment criteria for IT security. It offers a standard to ensure that products meet the necessary requirements that ensure that devices or systems have an optimal level of trust for your application. This provides a useful guide to criteria as the basis for assessing properties and security features of IT systems.

3.4.7.12 ISO/IEC 18045. Actions for the assessment of safety criteria

About the methodology for security assessment. This standard defines the minimum actions to be carried out in the assessment of safety criteria in accordance with **ISO/IEC 15408**.

4 Energy Storage and installations

There is an increasing number of standards related to battery systems that could be related to their specific applications (grid-scale, PV, automotive), specific battery technology (Li-ion, lead-acid NiMH, etc.), specific objective (design, testing, commissioning, safety) and related to their integration with a specific type of power system (EMC, energy quality, etc.).

A broader overview of these standards can be found in:

- Link to international Standards and Testing Applicable to Batteries.
- Link to survey on standards for batteries and system integration with them.

This section deals with grid-scale battery storage standards, in order to take into account the type of batteries implemented in the E-LOBSTER system dealing with traction applications and low voltage grids, and therefore, focusing on li-ion battery related standards. Moreover, consideration on new battery standards filling existing gaps is being performed.

4.1 Innovative battery solution proposed by E-LOBSTER

A highly efficient, modular, and reliable battery storage system for the E-LOBSTER demonstrator is being developed. The system offers very fast time response and high electrical performance with a minimal charging/discharging losses and low standby losses (auxiliary power consumption). The system was also designed to offer good performance in highly varying and harsh environment temperatures. Moreover, this system offers extraordinary safety characteristics and requires minimal O&M works.

The system operation was designed to increase its lifetime and to provide a wide range of self-diagnostics and state estimation algorithms.

The following section provides the list of standards that E-LOBSTER stationary battery storage system complies to.

4.2 Relevant existing standards for storage systems and relevance with respect to E-LOBSTER

There are several standards which covers grid-scale battery storage. These standards could be classified as:

1. Battery system safety related standards.
2. Battery transportation related standards.
3. Grid integration standards (EMC immunity and emission standards, electrical energy quality).

The first group is related to battery system safe design and operation. The E-LOBSTER system complies with the standard reported in the following table.

Table 3: Battery system safe design and operation

Standard reference	Description
EN 62619:2017	Secondary cells and batteries containing alkaline or other non-acid electrolytes. Safety requirements for secondary lithium cells and batteries, for use in industrial applications. This standard specifies requirements and tests for the safe operation of secondary lithium cells and batteries used in industrial applications including stationary applications.
EN 61010-1:2010 A1:2019	Safety requirements for electrical equipment for measurement, control, and laboratory use. General requirements. This standard sets out general safety requirements to reduce the hazards faced by electrical test, measurement and process-control equipment and accessory operators.

Furthermore, in addition to the above mentioned standards, the certification mark that proves the conformity with safety, health and environmental protection standards for products sold in European Economic Area (EEA) has to be considered.

Second group is related to battery safe transportation. Here E-LOBSTER BESS complies with:

Table 4: Battery safe transportation

Standard reference	Description
UN Transportation Testing (UN/DOT 38.3)	For Lithium Cells and Batteries, Lithium batteries are classified as dangerous goods and might pose a safety risk if not tested or packaged in accordance with the transport regulations. UN 38.3 presents a combination of significant environmental, mechanical, and electrical stresses designed to assess lithium batteries' ability to withstand the anticipated rigors incurred during transport.

The last group of standards is related to grid compliance (DC or AC grid). In the E-LOBSTER project, BESS will not be directly connected to the grid, but it would be decoupled from DC grid (railway) and AC grid (low voltage grid) by power electronics devices (sSOP). So, the sSOP system provided by Turbo Power Systems is a subject of AC and DC grid compliance.

Lithium Balance develops also stand-alone solutions with its own integrated power converter. In this case, system is compliant to the standards illustrated in the following table.

Table 5: Batteries grid compliance (DC or AC grid).

Standard reference	Description
EN 50549-1:2019	Requirements for generating plants to be connected in parallel with distribution networks. Part 1: Connection to a LV distribution network - Generating plants up to and including Type B. This standard provides technical requirements for the connection of generating plants up to and including Type A / Type B which can be operated in parallel with a public LV distribution network.
EN 61000-6-2	Industrial level - Electromagnetic compatibility (EMC), Generic standards – Immunity for industrial environments.
EN 61000-6-4	Class A - Electromagnetic compatibility (EMC) - Part 6-4: Generic standards - Emission standard for industrial environments.
Local country grid code	Country specific grid code is a technical specification which defines the parameters a facility connected to a public electric grid has to meet to ensure safe, secure and economic proper functioning of the electric system.

In addition to these, several standards or recommendations related to the sizing of battery system in the specific application can be found. One of those that is related to DC traction applications is "IEEE Guide for Wayside Energy Storage Systems for DC Traction Applications". The guide provides a description of the data, techniques, and procedures applicable to specification, selection, deployment and testing of wayside energy storage system in DC traction power systems.

4.3 Gap with respect to existing standards

There is no battery safety standard which is devoted only to battery systems connected to the railway application or hybrid DC railway and AC grid application (like in case of E-LOBSTER solution). However, all these aspects are covered in more general **EN 62619:2017** standard and **EN 61010-1:2010 A1:2019** which deals with safety of battery systems in the stationary applications.

In this context, there is no need for an additional battery safety related standard for the E-LOBSTER type of application. Actually, due to the operation of the battery system in this type of application, there is no need to impose any specific regimes which might compromise the safety of the battery system.

On the other hand, a standard focused on evaluating requirements and testing compliance of battery systems in the applications where a battery is a shared asset between two power systems, might be missing.

This standard could provide specific testing profiles (mission profiles) in order to evaluate electrical performance of battery and power electronics, and evaluate whether a specific battery system is appropriate for a given application requirements in terms of functional requirements, response time, short-term electrical and long-term electrical (lifetime), and thermal performance.

The experience gained within the scope of the E-LOBSTER project could also result in the recommended practice for design and control of battery sharing assets solutions.

5 sSOP technology and R+G Management System

The growth of Low Carbon Technologies (LCTs) will have a significant effect on electricity distribution networks. The E-LOBSTER demonstrator aims to prove that active reconfiguration of the Rail and low voltage Grid network with power electronics can be used to manage these effects.

The E-LOBSTER demonstrator will deliver three physical smart solutions, referred to as Power Electronic converters, which can provide a range of benefits, including the deferral of costly network reinforcement. These solutions, of which there are three types, are combined to deliver the Low Voltage (LV) smart Soft Open Point (sSOP). The power semiconductor converters are:

- The Rail Converter, unidirectional operation.
- The Grid Converter, bidirectional operation.
- The Energy Storage System Converter, bidirectional operation.

The sSOP can control power flows and voltages on the Battery Energy Storage System (BESS) and the 400V Distribution System Operator (DSO) networks without increasing fault levels.

For the power electronics converters' design, silicon carbide (SiC) semiconductor switches have been utilised. Those have recently become available for use within power electronics converters and have many key advantages. The sSOP was designed using silicon carbide devices for the following key reasons:

- Higher efficiency: Reduced loss and hence higher efficiency relative to silicon devices due to lower conduction and switching losses.
- Lower audible noise: The silicon carbide devices enable switching frequencies of ≥ 20kHz, meaning that no audible switching noise is produced.
- Reduced size of equipment: The size of the equipment can be reduced relative to if using silicon devices as magnetics reduced in size due to higher switching frequency and fewer losses to dissipate from the converter.

The sSOP was designed to be compliant to the following relevant design and validation standards.

Figure 3: Relevant Converter Design standards

Applicable Design Standard Reference	Title	Release /version
EN 60146-1-1	Semiconductor converters – General requirements and line commutated converters.	2010
EN 60730-1:2016+A1	Automatic electrical controls. General requirements.	2019
EN ISO 9001	Management and Quality Assurance Standards.	2015
EN ISO 14001	Environmental management systems – specification with guidance for use.	2015
***IEC 60529*:1989 AMD2:2013 COR1**	Degrees of protection provided by enclosures (IP Code).	2019
IEC 60076-10-1	Power transformers - Part 10-1: Determination of sound levels - Application guide.	2016
IEC TS 61000-3-5	Electromagnetic compatibility (EMC) - Part 3-5: Limits - Limitation of voltage fluctuations and flicker in low-voltage	2009

	power supply systems for equipment with rated current greater than 75 A.	
EN IEC 61000-6-1	Electromagnetic compatibility (EMC) - Part 6-1: Generic standards -Immunity for Residential, Commercial and Light-Industrial Environments.	2019
EN IEC 61000-6-2	Electromagnetic compatibility (EMC) - Part 6-2: Generic standards -Immunity for Residential, Commercial Generic standards. Immunity standard for industrial environments.	2019
EN IEC 61000-6-3	Electromagnetic compatibility (EMC). - Part 6-3: Generic standards. Emission standard for residential, commercial and light-industrial environments.	2007
EN IEC 61000-6-4	Electromagnetic compatibility (EMC) - Part 6-4: Generic standards - Emission standard for industrial environments.	2019
IEC 62477-1	Safety requirements for power electronic converter systems and equipment - Part 1: General.	1.1 Edition, July 2016
TS 50238-2	Railway applications - Compatibility between rolling stock and train detection systems - Part 2: Compatibility with track circuits.	2015
	UK Specific Safety Related Standards	
HSE HSG224	The Construction (Design & Management) Regulations 2015.	
HSE (EaWR)	The Electricity at Work Regulations 1989.	
HSE	The Health & Safety at Work Act 1974.	
HSE	The Control of Substances Hazardous to Health Regulations 2002.	
HSE PUWER 1998	Provision and use of work equipment regulations.	
MIL-HDBK-217F	Military handbook: reliability prediction of electronic equipment.	Dec. 1991

Table 6: Relevant Railways standards

Applicable Railways Standard Reference	Title	Release/ version
EN 50121-2	Railway applications. Electromagnetic compatibility. Emission of the whole railway system to the outside world.	2017
EN 50121-3-1:2017+A1	Railway applications. Electromagnetic compatibility. Rolling stock. Train and complete vehicle.	2019
EN 50121-3-2:2016+A1	Railway applications. Electromagnetic compatibility. Rolling stock. Apparatus.	2019
EN 50121-4:2016+A1	Railway applications. Electromagnetic compatibility. Emission and immunity of the signalling and telecommunications apparatus.	2019
EN 50124-1	Railway applications: Insulation coordination – Basic requirements – Clearance and creepage distances for all electrical and electronic equipment	2017
EN 50124-2	Railway applications. Insulation coordination- Part 2: Over-voltages and related protection	2017

EN 50163:2004+A2	Railway applications — Supply voltages of traction systems	2020
EN 50328	Railway applications – Fixed installation – Electronic power converters for substations.	2003
IEC 60850 (EN 50163:2004+A2)	Railway applications – Supply voltages of traction systems.	2014 (2020)
IEC 62128-1 **(EN 50122-1)**	Railway applications - Fixed installations - Electrical safety, earthing and the return circuit - Part 1: Protective provisions against electric shock	2013 (2011)
IEC 62128-2 (EN 50122 -2)	Railway applications - Fixed installations - Electrical safety, earthing and the return circuit - Part 2: Provisions against the effects of stray currents caused by DC traction systems	2013 (2011)
IEC 62236-1	Railway applications - Electromagnetic compatibility - Part 1: General	2018
IEC 62236-5	Railway applications - Electromagnetic compatibility - Part 5: Emission and immunity of fixed power supply installations and apparatus	2018
IEC 62313 **(EN 50388)**	Railway applications - Power supply and rolling stock - Technical criteria for the coordination between power supply (substation) and rolling stock	2009 (2012)
IEC 62589	Railway applications - Fixed installations - Harmonization of the rated values for converter groups and tests on converter groups	2010
IEC 62590 (EN50328)	Railway applications - Fixed installations - Electronic power converters for substations	2019 (2003)
IEC 62924 (EN 62924)	Railway applications – Fixed installations – Stationary energy storage system for DC traction systems	2017
TSI ENERGY	Technical Specification Interoperability (TSI) relating to energy subsystem of the rail system in the union – Commission Regulation (EU) No 1301/2014	2014

Table 7: Relevant Low-Voltage Grid standards

Applicable LV Grid Standard Reference	Title	Release/ version
UNE EN 50438	Requirements for Micro-Generating Plants to be Connected in Parallel with Public Low-Voltage Distribution Networks	2014 /IS1:2015
UNE EN 50160	Voltage Characteristics of Electricity Supplied by Public Electricity Networks	2011
UNE 206007-1	Requirements for connecting to the power system. Part 1: Grid-connected inverters.	2013
UNE 206007-2	Requirements for connecting to the power system. Part 2: Requirements concerning system security for installations containing inverters.	2014
MT 3.53.01	Condiciones Técnicas de la Instalatión de Producción Electrica Conectada a la Red de Iberdrola Distribución Eléctrica, S.A.U.	2016
ITC-BT-40	Instalaciones Generadoras de Baja Tensión	
GUIA-BT-40	Guía Técnica de aplicación al Reglamento Electrotécnico de Baja Tensión	

At present we are not aware of any gaps related to the existing standards. For the demonstrator is based in Spain, specific Spanish standard have been investigated. During the replication activities, in the final phase of the project, a specific analysis of some specific national standards could be needed.

5.1 R+G Management System

As mentioned in section 1, the R+G Management system is the component of the overall E-LOBSTER systems that should enable the effective and efficient management of the energy flows.

Actually the E-LOBSTER R+G Management System provides a unique platform for the energy flow management between rail, grid and storage (also considering EVs) aiming at a multi-objective optimization of the three energy networks, increasing the self-consumption of RES locally connected to the distribution networks and regenerative braking.

5.1.1 Development of the overall R+G Management System

In this section, an overview of the relevant standards with respect to the R+G Management System software is reported.

5.1.1.1 ISO/IEC/IEEE 15288: Systems and software engineering — System life cycle processes

This International Standard establishes a common framework of process descriptions for describing the life cycle of systems created by humans. It defines a set of processes and associated terminology from an engineering viewpoint. In particular, it provides processes that support the definition, control and improvement of the system life cycle processes used within an organization or a project. More in details, this standard concerns those systems that are man-made and may be configured with one or more of the following system elements: hardware, software, data, humans, processes (e.g., processes for providing service to users), procedures (e.g., operator instructions), facilities, materials and naturally occurring entities.

When a system element is software, the software life cycle processes in ISO/IEC/IEEE 12207:2015 may be used to implement that system element. The two standards are harmonized for concurrent use on a single project or in a single organization.

5.1.2 Development of the R+G Management software

In the following paragraphs, an overview of the relevant standards with respect to the R+G Management System software is reported.

5.1.2.1 ISO/IEC/IEEE 12207:2015: Systems and software engineering — Software life cycle processes

This international standard provides processes that can be employed for defining, controlling, and improving software life cycle processes within an organization or a project.
The processes, activities, and tasks of this document can also be applied during the acquisition of a system that contains software, either alone or in conjunction with the ISO/IEC/IEEE 15288:2015, *Systems and software engineering-System life cycle processes*. Both standards should be taken into account as it is rare to encounter a complex system without software, and all software systems require physical system components (hardware) to operate, either as part of the software system-of-interest or as an enabling system or infrastructure. Thus, the choice of whether to apply ISO/IEC/IEEE 12207:2015 or ISO/IEC/IEEE 15288:2015, on *Systems and software engineering* depends on the system of interest. Processes in both documents have the same process purpose and process outcomes, and the difference is on the activities and tasks to perform (software engineering or systems engineering respectively[10]).

5.1.2.2 Guidelines for the development of safe software: Digital Italy Agency (Agenzia per l'Italia Digitale - AGID)

These best practices prepared by the Digital Italy Agency for the development of safety software. There are specific indications about the potential vulnerability of the software and countermeasures to be adopted. Best practices for different software languages are provided like Java, PL/SQL, Javascript, PyThon, C#, ASP, ASP.NET, PHP, VBNET, AJAX, GO and including C/C++ which is intended to be used for E-LOBSTER.

5.1.2.3 ISO/IEC 15408-1: Information technology -Security techniques - Evaluation criteria for IT security

This standard establishes the general concepts and principles of IT security evaluation and specifies the general model of evaluation given by various parts of ISO/IEC 15408 which in its entirety is meant to be used as the basis for evaluation of security properties of IT products.
Moreover, it defines the various operations by which the functional and assurance components given in ISO/IEC 15408-2 and ISO/IEC 15408-3 may be tailored through the use of permitted operations. The key concepts of protection profiles (PP), packages of security requirements and the topic of conformance are detailed and the consequences of evaluation and evaluation results are illustrated[11].

5.1.2.4 NIST SP 800-115: Technical Guide to Information Security Testing and Assessment

These guidelines provide references for organizations on planning and conducting technical information security testing and assessments, analyzing findings, and developing mitigation strategies. It provides practical recommendations for designing, implementing, and maintaining technical

[10] https://www.iso.org/standard/63712.html
[11] https://www.iso.org/standard/50341.html

information relating to security testing and assessment processes and procedures, which can be used for several purpose (such as finding vulnerabilities in a system or network and verifying compliance with a policy or other requirements).

5.1.2.5 Web Security Testing Guide (OWASP)

The Web Security Testing Guide is a comprehensive open source guide to testing the security of web applications and web services

No specific standard Gaps have been identified as far as the R+G Management system is concerned.

6 E-LOBSTER Installation & Distribution – guide for marketability

As a first approach to the study of marketability, an analysis that contemplates the current situation of the E-LOBSTER system, its environment and what its integration entails should be carried out.

To do so, the situation in which the system finds itself has been observed from a technical point of view, highlighting the following sections:

- The benefits of its implementation in the management of energy losses and conflicts over its use.
- Functions of the smart grid.
- The coordination between systems already existing as batteries or alternative energy sources.
- The bases proposed by projects

In addition, an approach to the product life cycle based on standardization and legislation around the system is proposed, exposing how the regulations already studied could be applied and the challenge generated in certain aspects by the likely lack of specific standardization for this innovative product after the first demonstrations will be performed. The study concludes with an analysis of the method of calculating electricity consumption, considering the possibility of monitoring it in real time, estimating the sum of the total energy and losses and with the need to introduce other variables, such as the total energy obtained in regenerative braking and what is returned to the catenary.

The purpose of this study is therefore to define under which technical or regulatory criteria the E-LOBSTER system can be integrated, highlighting which aspects are of greater importance for its release.

6.1 Issues and Current Situation

This section mainly discusses the benefits of implementing the E-LOBSTER system, its integration, and expected issues that could arise in this system.

Thereby, a study is made from a technical point of view considering the improvements that the implementation of E-LOBSTER can entail in the management of losses. Then we proceed to study its connectivity through the smart grid, defining its usefulness, which will be the benefit that could be obtained from this system and a first approximation to its coordination with other systems. After this, the use of other R&D projects (i.e. MERLIN[12]) as a basis is proposed in the mapping of power flows and the integration of systems such as batteries or photovoltaic panels in it.

The main objective of this study is to group the necessary information to better understand the integration of the system in current installations, taking advantage of the advances already developed, thus being able to detect the conflicts derived from this integration discussed at the end of this section.

[12] EU FP7 Project "MERLIN (2015)". GA – 314125

6.1.1 Power losses

Power losses are divided between:

- Fixed, constant and inherent losses to the normal operation of the system (losses in iron, mechanics, friction etc.).
- Variable losses, which depend on the flow of power circulating during the energy transmission. Even within variable losses there is a part that is considered inevitable, due to technical limitations on the distance between the generation point and the point of consumption. However, the losses associated with intermittent power consumption (and the intermittent generation that this would require) may be minimized or even eliminated with good overall system design.

The E-LOBSTER system focuses on reducing or eliminating the latter type of variable losses and it is configured for that function. This system is encompassed within the so-called smart grid, designed for the distribution of power and whose insertion within the network decreases the values of variable losses.

6.1.2 Smart Grid Connections and other relevant railways projects dealing with energy management

Firstly, smart grid is basically an electric network that uses digital solutions to monitor the characteristics of supply and power consumption in order to efficiently integrate and manage the actions of the different producers and consumers connected to it. In this way, an efficient network of higher quality is obtained with less energy losses.

Within the E-LOBSTER system, the main aim of the product to propose a R+G Management System able to manage the energy flow rail, grid and storage (also considering EVs) aiming at a multi-objective optimization of the three energy networks, increasing the self-consumption of RES locally connected to the distribution network and regenerative braking..

Energy management is a key element within rail systems, and everything suggests that it will remain so in the near future. International collaborations developed during the last decade have already identified technologies that will be able to contribute to energy optimization, as well as have developed tools that evaluate this contribution. The smart energy concept aims to go further and provide integrated optimization that includes multiple elements, forecasting power supply and demand scenarios, and cost considerations to support operational decisions involving an intelligent energy and resource management system.

Nevertheless, the smart grid proposes to integrate efficiently all the equipment connected to the network to reduce losses, by monitoring consumption and controlling the distribution of energy with systems such as smart metering. So, it would be sensible to consider other factors such as:

- How storage will be managed.
- The supply of energy from renewable sources (solar panels).
- How the E-LOBSTER device will manage the power between the different computers that make up the network.

Therefore, due to the similarity of this application with the objectives of other projects, which focused on sustainable energy management for railway systems, a review of the applications and resources of these projects could be undertaken, and the learning could lead to a better approach to the E-LOBSTER. The use of the MERLIN[13] mapping system of the railway electrical network is mainly proposed. This project proposes the investigation of the use of energy management systems to optimize its use. To do this, it describes and characterizes the different elements of the network, in order to carry out its monitoring. Given this, E-LOBSTER can take this information from the monitored network to carry out efficient energy management.

In addition, as mentioned above, another aspect that is worthy of consideration within the smart grid is the energy supply from different energy sources, as well as the management of surplus stored power.

Within the use of alternative energy sources the use of different technologies, like photovoltaic panels, have been successfully proved. Panels can be used by connecting them to the electrical grid and when it operates on an overproduction basis, the energy from the photovoltaic panel is sent to the grid, thus consuming this type of power. In case the panel cannot meet the energy demand (far from the previous overproduction regime), the power is taken from the electrical network.

On the basis of this knowledge, it might be considered how to integrate similar sources into a system that unifies regenerative braking, the electricity grid itself, and the extra supply of alternative energy depending on demand and production.

However, in addition to this, considering cases of overproduction of energy, excess could be stored, in order to reduce line losses and level overall energy consumption.

Therefore, there are similar projects that help to provide a basis for studying the combination of multiple generating, consumer, and storage elements that under the power mapping can be managed for consumption leveling and loss reduction, thus, the approximation of this base to E-LOBSTER should be considered.

Typical problems detected with discontinuous power sources implemented in a smart grid system are:

- The difficulty of predicting the actual power supply that will be needed.
- The quality of the power.
- Sometimes, in the long run, it is a big cost.

As it is the energy from regenerative braking, energy is not constantly provided, but an irregular power supply, which involves somewhat complex forecasting models.

The fact that smart grid systems work in alternating current deserves a special mention**.** In case the electricity provided is DC power, it is essential to use electric converters (inverters or rectifiers) to transform that electricity. However, these converters add a large harmonic signal to the network, which can influence the proper functioning of the elements connected to it.

The generation of these harmonics is mainly due to the introduction of non-linear loads. That is to say, loads that non-linearly consume energy. This results in a distortion wave of greater or lesser magnitude, which is known as the Total Harmonic Distortion (THD).

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[13] EU FP7 Project "MERLIN (2015)". GA – 314125

The biggest problem found, as mentioned, is when harmonic currents occur, due to their effect over the correct operation of the equipment. In this way, the performance of these is reduced or they can even be seriously damaged, in the case of sensitive loads and protective equipment. For this reason, it would be necessary to carry out a study of the harmonics introduced into the network, in order to establish the need for containment measures, the use of detection systems, and high-voltage filters.

6.2 Life Cycle analysis: Legislation & Standards

Throughout section 3.4 of this document, a study of the applicable standards to E-LOBSTER has been carried out. So, an approach to how these regulations can be applied throughout the product life cycle is offered down below. To do this, a first approach has been made describing the situation of the system in general and highlighting standards that are of interest. Then, the main study focuses on the application of standards for each particular section previously defined.

6.2.1 Applying regulations to the product

When implementing this system, the need of performing the study and monitoring the regulations mentioned in the document is remarkable.

The E-LOBSTER is a device that performs the power management between the different equipment that makes up the network. These elements are included within an automated network with the aim of performing the intelligent distribution of power. To do this, it is necessary to take into account all the energy sources that will intervene in the train:

- Batteries and connections between elements.
- Renewable energy, which might be introduced through the use of photovoltaic panels.
- The energy from the regenerative braking.

In the previous chapters, all the standards that refer to these topics have been introduced and discussed, trying to infer whether there would be any application to E-LOBSTER project or gaps considering this or not. To sum up this knowledge with the aim of developing the marketability of the product this collection of standards talks about the following aspects:

- Communication between equipment (**IEC 61850** or **EN 62271-3**).
- The use of sensors required for such communication (**EN 62689**), necessary for real-time power monitoring or power distribution.
- Other aspects directly related to equipment power values, load values and network distribution.

Therefore, in order to implement this system on the market, it is considered necessary to study the standards reported in the following table.

Table 8: Standards considering the E-LOBSTER implementation on the market

IEC 60919	From the point of view of the network and distribution, due to the need to know the parameters of the equipment, security measures and network delivery points.
IEC 61803	
CLC-TS 50549-1	
EN 50549-2	
EN 50160	
EN 50549-2	In addition, it is recommended to define aspects of system protection.
IEC 61850	To define the communications architecture for network automation between devices, in addition to the necessary devices and sensors.
EN 62271-3	
EN 62689	
EN 61000	To know aspects of electromagnetic compatibility, possible phenomena and containment measures and protection against them.

It is important to underline that the E-LOBSTER project involves the development of a new type of electrical infrastructure, and that the studied standards focus on communication, electrical networks and distribution of existing facilities, and are governed by fixed conditions and parameters. Thus, it will be important to understand whether the conclusions drawn from these standards are applicable under the operating conditions of the E-LOBSTER system or whether, on the contrary, it is necessary to seek more specific regulations.

In this context, it is worth mentioning that the regulations studied hardly refer to battery parameters or charging and discharge energy.

In this way, it is necessary to study the project from a normalization point of view, defining all the parameters of the system, and the search for an approach to cover the gaps that may exist in the topics of storage and distribution of energy, connection with smart grids and power meters (smart metering).

Thus, the following aspects are considered of interest:

- Approximation to the installations referred to in IEC 61850-420 for the application of the criteria of the standard.
- HVDC parameters.
- The use of sensors considered.
- Powers, voltages, and currents required in the mains.
- Connection to the mains.
- Battery storage capacity.
- Overcharging management.
- Telecommunication terminals.
- Network access points.
- Cybersecurity.

The study of the vast majority of the aspects (i.e. those that are related to R+G management system like system life cycle processes, development of the R+G Management software, software life cycle processes, development of safe software, information technology, security techniques, evaluation criteria for IT security, or web security testing, which were explained on - section 5 -) shown above is covered with the standards shown in the previous table and with the development of the standards study carried out in section 3.4. However, since the cybersecurity section encompasses many aspects of protocols, communication and system security, a breakdown of the different standards has been developed below according to their application.

6.2.2 Cybersecurity

The same difficulty is found here as in the other approaches: being a novel product with little track record, it is difficult to find a regulation that exactly fits the characteristics of E-LOBSTER.

However, taking as a reference similar application and uses, it is possible to identify regulations that can be applied in certain uses that may be given to the product.

6.2.2.1 Communication between road electric vehicle and the power grid

ISO-15118 mainly applies to the communication interface between a vehicle and the electrical grid**.** It should be noted that the standard is mainly focused on electric vehicle working with batteries, whose conditions are different from those used on the E-LOBSTER backup facility. If it is desired to use it for the study, the following headings are recommended:

Table 9: ISO-15118 considerations

Part 1	For the transfer of power from the mains to the battery or in the opposite direction.
Part 2	To determine communication protocols between the vehicle and the electrical grid.
Part 3	For the exchange of information (link) between the physical layer and the data layer.
Part 4	For application and network protocol compliance tests.
Part 5	For physical layer conformity and data link testing.
Part 6	For physical layer and data link requirements for wireless communication.

6.2.2.2 Safety for automation and industrial control systems

IEC 62443 defines security requirements **for industrial automation and control systems.** Consultation of this standard is advised if the automation of the E-LOBSTER clamp is sought in procedures that may resemble those in the industrial field. Within it, the parts that are considered to be most applicable are reported in the following table.

Table 10: Requirements for industrial automation and control systems

Part 4-1	Which specifies process requirements for the safe development of products used in automation and industrial control systems.
Part 4-2	Which specifies technical security requirements for IACS identification and authenticity control components.

6.2.2.3 Power and information exchange systems

EN 62351:2017 discusses the management of power systems and the exchange of associated **information,** together with data **and communications security.** The following headings are highlighted:

Table 11: Exchange of associated information, data and communications security

Part 3	Which focuses on the confidentiality, protection, and authentication measures of TCP/IP profiles through restrictions on the specification of messages, procedures, and algorithms.
Part 4	About the different security profiles and MMS profiles, as well as the specifications that must be met to follow the protocols.
Part 5	Which specifies the procedures and algorithms to ensure the operation of remote-control systems.
Part 6	Which specifies messages, procedures and algorithms to secure protocols based on or derived from the IEC 61850 standard. This contains information of particular relevance for Smart Grids.
Part 7	Which defines specific system and network management data object models for power system operations.
Part 8	Covering user access and automatic agents to control systems, as well as all matters relating to interoperability between systems.
Part 9	Which specifies cryptographic key management assuming that the type of key and cryptography used has already been established.
Part 10	Which describes the criteria to be followed for energy system controls.
Part 11	Which focuses on the processing of XML files and their security protocols.

6.2.2.4 Electric power measurement and data exchange equipment

IEC 62056 about electrical power measurement equipment and data exchange for meter **reading, rate, and load control.** This standard is considered useful for the E-LOBSTER's built-in load control system. The headings that are considered useful are:

Table 12: Electrical power measurement equipment and data exchange for meter reading, rate, and load control

Part 21	Which describes the hardware and data exchange protocol specifications to be met by the load control systems to which they apply.
Part 42	Which describes physical layer services and protocols within a three-layer profile oriented towards asynchronous data communications.
Part 43	Which defines the link layer for the connection-oriented HDLC-based asynchronous communication profile.

6.2.2.5 Security, certificates, and cryptography

A compendium of standards that mark references in digital security issues, digital certificates and data encryption is offered.

Table 13: References in digital security issues, digital certificates and data encryption

IEEE 1686	Defines a standard of smart electronic device features and functions for the use of cybersecurity programs.
IEEE C37.240	Defines the cybersecurity requirements for power system automation, protection, and control systems. The technical requirements it offers stands out here, being able to obtain high levels of safety regardless of the voltage level of the network.
IETF-RFC 6960	The standard talks about the public key infrastructure to the Internet, as well as a protocol for determining the status of the digital certificate.
IETF-RFC 7030	The standard focuses on the secure transport of certificates through CMS messages.
ISO/IEC 19790	Establishes security requirements for a cryptographic module used within a security system that protects sensitive information from telecommunications equipment and systems.
ISO/IEC TR 27019	Provides principles for safety management in the management of process control systems in the energy services industry.

ISO/IEC 15408	Offers a standard to ensure products meet the necessary safety requirements as long as they have an optimal level of confidence for your application.
ISO/IEC 18045	Talks about the methodology for the assessment of security in IT.

6.3 Commissioning constraints for rail or metro uses

The calculation of electricity consumption in Spain is carried out by an average of measurements obtained in short periods of time. However, this application would allow real-time tracking, taking a total count of consumption closer to the actual value from the point of view of the railway, estimating the total consumption as the sum of the energy consumed and the estimated outputs at the entrance of the substation, so that the losses between generating plant and substations, and between substation and train output would not be considered.

Therefore, in order to know the total consumption of the train, an energy balance must be set out in a system in which a defined circular route is considered, with the characteristics of the theoretical cycle of the case of study itself and with a start and arrival at 0 Km/h. Under these conditions it is considered that the total energy entering the train is the sum of the energy necessary to overcome the resistances to the advance in curve and straight, the losses in the traction chain, the consumption of auxiliary equipment, and the energy dissipated in the brake.

However, there are doubts on what consumption should be considered on the braking. When considering the effects of regenerative braking and the application of the smart grid for energy management and distribution, this energy generated in braking can be provided and distributed to:

- Ancillary power equipment, being a large portion of energy if it approaches a suburban model.
- Distribution to catenary to feed other trains.
- Return to the public network, in which case the substation must be bidirectional.
- Battery storage for further reuse mounted on rolling stock or on the railway infrastructure itself.

This storage has advantages over the speed of response to electrical demand and low losses, although it also has reduced output power.

Therefore, the electrical energy generated during the braking, regardless it is used or storage, should be considered in the total energy count.

In addition to consumption, the indicator of precalculated theoretical consumption and the efficiency of the application in regenerative braking situation can be obtained by means of absolute and specific indicators, which do not offer an energy estimate such as the previous methods, but a way of estimating how efficient the railway and the system is. Thus, for a system with regenerative braking, an absolute index can be defined as the kWh of energy delivered to the pantograph minus those generated in the regenerative braking after feeding the auxiliaries. If you want to apply the specific index, it can be obtained by dividing the value of the absolute index previously defined and the capacity of the train itself.

7 Proposal of a standard

This section aims to point out the process of how a proposal for a standard could be formed. To do so, it is necessary to understand the following concepts: the standards process review and the development of an EN standard.

7.1 Standards process review

It is important to fully comprehend how a standard is created and reviewed. Therefore, this section introduces some concepts regarding the field of standards within the European context.

7.1.1 Political and historical context

In the Railway and Energy sectors, the EU is setting out a "target system" of technical and regulation through the Interoperability Directive, (2016/797/EC) Directive and their "Essential Requirements", with the aim of moving the legal framework from country-by-country legislation and technical standards. The political aim is a single European market where products and services can be freely traded and will be technically compatible.

7.1.2 European and International Standards

European standards (ENs) are Europe-wide standards that help to develop the single European market for goods and services in all sectors[14]. The intention of ENs is to facilitate trade between countries, create new markets, and cut compliance costs.

Compliance with ENs could be one or more of:

- Voluntary – where industry chooses to use the EN when it is useful to do so
- Harmonised – where the EN is harmonised with a European Directive or a Technical Specification for Interoperability (TSI), compliance with the EN gives a presumption of conformity with the Directive or the TSI
- Mandatory – where the EN is referenced in the text of a document which must be complied with in specified circumstances, such as a TSI or a Railway Group Standard (RGS), compliance with the EN becomes mandatory.

ENs are produced by these European standards organisations:

- The European Committee for Standardisation (CEN)
- The European Committee for Electrotechnical Standardisation (CENELEC)
- The European Telecommunications Standards Institute (ETSI)

International standards are prepared by these standards organisations

- International Electrotechnical Committee (IEC)
- International Standards Organisation (ISO)

[14] https://www.cenelec.eu/standardsdevelopment/ourproducts/europeanstandards.html

In each country, ENs are published by the national Standards Body.

7.1.3 Harmonised European standards

The European Commission publishes in the EU Official Journal, lists of ENs that are harmonised against particular Directives or TSIs. The effect of this is that compliance with the standard gives a "presumption of conformity"

Harmonised ENs relating to railway applications have one or more 'Z Annexes' (the Annexes at the back of European Norms explaining how the standard relates to the legal, essential requirements of the appropriate Directives). These identify the legislation and essential requirements that are supported by the EN. If a harmonised EN supports more than one European Directive or TSI, there will be an 'Annex Z...' (ZA, ZB, ZC, etc.) for each Directive or TSI.

7.1.4 How does the industry influence the content of a European standard?

European standards in the field of railway engineering are drafted in two European Standards Technical Committees: **CEN/TC 256** (CENELEC) and **CLC/TC9X** (CEN). Other Technical Committees address other technical areas. Most countries establish "Mirror Committees" that follow the development of a particular Standard.

These committees provide a mechanism for input into the development of new or revised standards. They also give national views when the EN is circulated for consultation and voted on for approval.

The catalogues produced by the European standards organisations are available from their websites:

- European Committee for Standardization (CEN)
- European Committee for Electrotechnical Standardization (CENELEC)
- European Telecommunications Standards Institute (ETSI)

ENs are converted to National Standards which are sold by their respective national standards bodies.

7.1.5 Possible deviation from a European standard

Due to the nature of an EN, there is no need to formally deviate from it. If you cannot comply with an EN that is 'mandatory' because it is referenced in a mandatory document, you need to follow the procedure for deviating from the particular document that references the EN.

7.1.6 Company and Project Standards

Standards may be agreed at company or project level, for example to manage risk in areas not covered by industry standards or through specific laws, or as a way of providing local detail to legal and standards compliance.

7.1.7 When organisations would need to develop company-level standards

Company-level standards supplement publicly available standards by:

- Setting out specific ways of implementing publicly available standards or meeting mandatory requirements.
- Imposing additional constraints to meet business objectives (for example, when designing a track layout, setting a minimum radius greater than that set out in publicly available standards)
- Defining the company's (or project's) methods for managing and mitigating risk
- Dealing with issues not covered by publicly available standards

There are likely to be many scenarios where an organisation will find it necessary or useful to develop their own company-level standards, that do not duplicate shared, publicly available standards which already exist and are fit for the company to use.

7.2 Development of an EuroNorm

An outline of the process for development of an EN is given below, with timescales. The start of the process is a New Work Item (NWI) proposal made by a national committee. For a new standard the NWI is essentially a simple business case to justify the proposal and is normally accompanied by a content list or outline standard. Gaining this agreement to progress a project may take up to a year, and the drafting process for a European Standard will normally take a minimum of three years. Overall, a time scale of five years for a new standard is quite typical. The process for drafting a European Standard is shown in the graphic below.

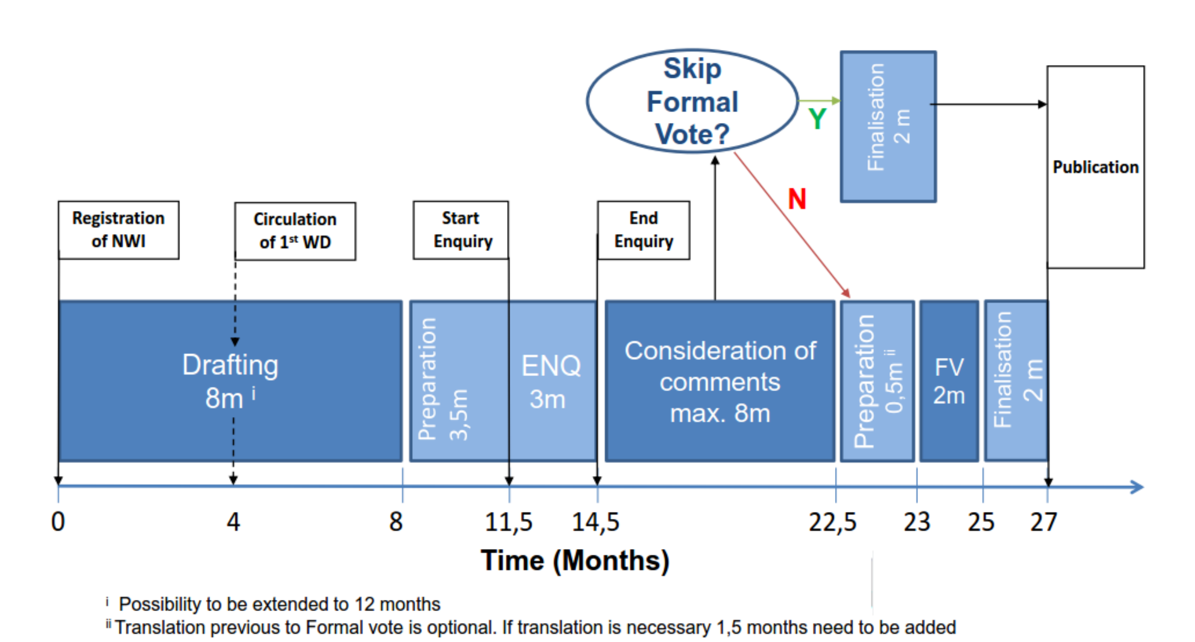

Figure 4: Process for drafting a European Standard[15]

7.2.1 Drafting

Technical content of standards is drafted by a Working Group which is responsible for writing the initial draft document, managing the comments from the "Enquiry" phase to produce a final draft to

[15] CEN

progress to a “Formal Vote”. The formal rules for a Working Group are given in the CEN/CENELEC Internal Regulations that set out all the requirements for the development of European Standards.

Working group members are nominated by National Standards Bodies (NSBs) in response to a Call for Convenor by the **CEN/TC 256** Secretariat. A suitably qualified Convenor (Working Group Leader) is appointed from the members nominated. The working group prepares a first draft for Enquiry.

7.2.2 Harmonised European Standards

The European Commission publishes in the EU Official Journal lists of ENs that are harmonised against particular Directives or TSIs. Where a standard is proposed for harmonisation against a Directive, an additional process is used. A Harmonised Approach (HAS) Consultant, contracted by the EU, plays an essential role in the EN development process where it is likely that the standard will be harmonised, e.g. to support a specific EU Directive by a presumption of conformity. Engagement with the appointed HAS consultant is strongly recommended at the drafting process.

7.2.3 Formal Enquiry

The draft document is sent to the secretariat editing, checking for conformance to rules and producing an Enquiry draft standard (prEN) for sending to National Standardisation Bodies for comment.

At this stage, the document is translated into the three official languages (English/French/German). This enquiry document is sent to all Member States National Standardisation Bodies (NSB) for comments and vote. NSBs provide their comments using a standard tabular format and in English.

Comments can be technical or editorial.

7.2.4 Comments Resolution

The consolidated table of comments is sent to the WG convenor who will organise a series of meetings to resolve the comments received into a final draft and annotate the table of comments to show how each has been addressed. The resultant “final draft” is circulated to NSBs in a Formal Vote.

7.2.5 Formal Vote

The NSBs respond to the “final draft” document with their editorial comments and their decision to vote in support or against the standard. If technical comments are submitted at this stage these are retained by the secretariat for consideration at the next revision of the standard. The Working Group may be consulted on comments to ensure that text changes are only editorial. Only by exception can technical comments be included at this stage.

7.2.6 Publication

If the standard receives a positive vote, CEN/CENELEC management will make any necessary formatting changes to finalise the document for publication. The document is into the three official languages (English/French/German) and published as an EN.

7.2.7 NSB Publication

The European Standard is approved by CEN or CENELEC on and national members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for publishing a national member version of the European Standard in the status of a national standard without any alteration.

Each standard states the latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement together with the latest date by which the national standards conflicting with the standard document have to be withdrawn (normally two years later).

7.2.8 Standard Forewords

The European Standard will contain a Foreword giving an explanation of the status of the standard, including changes from previous versions. National Standardisation Bodies may include a National Foreword providing local information.

7.3 Distribution system types relevance to standardisation

The electricity directive 2019 distinguishes different classes of distribution system operator. Most distribution systems are public networks that are open and available to all users of the electricity network in a common market.

The directive permits some networks to be “closed” and limited to certain areas or sites where this is the optimal solution. Most railway networks (Power supply to railway sites) are likely to fit within this class (i.e, a closed system) – but may not have determined this in any formal way. Some Member States have decided that the railway distribution system should not be so limited.

Distribution system

The electricity directive, states that the distribution system operator shall be responsible for ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity, for operating, maintaining and developing under economic conditions a secure, reliable and efficient electricity distribution system in its area with due regard for the environment and energy efficiency.

In any event, it must not discriminate between system users or classes of system users, particularly in favour of its related undertakings. The distribution system operator shall provide system users with the information they need for efficient access to, including use of, the system. In the UK, the operation is defined in the Distribution Code, in Spain, this legislation is steered by the so called “Reales decretos” (RD) that are official documents published in the BOE (Spanish official bulletin, literally translated), whilst in Italy the electricity market was set-up through the Legislative Decree No. 79 of 16 March 1999 (Decree 79/99, “Bersani Decree”), as part of the implementation of the EU Directive 96/92/EC repealed by Directive 2003/54/EC regarding common rules for the internal market in electricity into national legislation. See D3.2 for a more complete overview of different market regulations in Spain, Italy and UK.

Closed Distribution system

The electricity directive describes a closed distribution system which is used to ensure the optimal efficiency of an integrated energy supply requiring specific operational standards, or a closed distribution system is maintained primarily for the use of the owner of the system. It should be possible to exempt the distribution system operator from obligations which would constitute an unnecessary administrative burden because of the particular nature of the relationship between the distribution system operator and the users of the system. Industrial, commercial or shared services sites such as train station buildings, airports, hospitals, and large camping sites with integrated facilities, or chemical industry sites can include closed distribution systems because of the specialised nature of their operations.

Most railway networks are likely to fit within this class – but may not have determined this in any formal way. Some Member States have decided that the railway distribution system should not be so limited.

Distribution system combining railway and public networks

In some countries, the overhead line system and the railway distribution systems are owned by a separate company. In this model, the railway does not own any of the electrification infrastructure. In this model, the railway distribution network may be integrated within a distribution network, which may include generation and connections to non-railway load. The distribution network is acting fully as a public distribution network, with the railway as customer at the train to overhead line interface.

7.3.1 Third party access

One fundamental principle within the directive is that of third-party access. In the spirit of a "common market", it should be possible for a customer on a network to be able to purchase energy from any supplier in the market. Taking the historical nature of railway power supplies, this concept is not fully implemented in all railway networks, and achievement of this concept may require the installation of further hardware, such as metering, and the creation of a suitable billing system.

7.3.2 E-LOBSTER case

If a generic standard is to be developed for E-LOBSTER, then it must be suitable for inclusion in "open" and "closed" distribution networks. Crossing any commercial boundary or a boundary "open" and "closed" distribution networks, brings with it the potential for challenging commercial and legal issues that are not related to the technical requirements for the device, but may require additional billing quality metering, or limitations in the control strategy.

8 Conclusions

The big picture of the E-LOBSTER project from the perspective of standards has been analysed through this document, performing a study that covers the fundamental characteristics of the technology to be developed. The proposed system may be partially split into several parts taking into account the standards and requirements that are linked to them, among which it is important to highlight those that refer to railway applications, power distribution grid, energy storage systems, and advanced power electronics systems technology (sSOP).

The idea of the present analysis is to gather and study the current existing standards of the elements that are part of the E-LOBSTER system, together with the environment where it is going to be implemented, trying to spot if there are potential gaps in these standards.

Consequently, in order to accomplish a thorough analysis, an interdisciplinary study has been performed thanks to the participation of experts from all the aspects and fields that the E-LOBSTER project involves, whose framework is considered to be fairly wide due to the merging of railway, ESS, power electronics and electrical grid areas, resulting in an advanced smart grid concept.

The main conclusion that may be extracted after performing this analysis is that the framework where the E-LOBSTER technology is regarded to be implemented already counts on a consistent, strong and wide range of standardisation rules, which virtually cover the functioning of the whole system, once all the elements considered to be installed will be defined and detailed. As the E-LOBSTER project involves the implementation of a smart grid where a railway infrastructure is connected to the distribution grid, partially supplied by RES and, at the same time, connected to an ESS facility which is controlled by innovative power electronic systems (introduction of the sSOP), the whole assembly is considered to be an innovative technology that needs to be adjusted to the current existing standards and regulations, in order to ease its implementation and replication in an actual facility.

When the ELOBSTER system finally reaches its precommercial phase then, proposing a new work process for standardization that will cover all the possible new aspects introduced by this system will be considered. This will be clear when the pilot of the E-LOBSTER to be developed in Madrid are finished and all the specifics of the system are clear. The standardization process is so long that it will surpass the duration of this project, but the E-LOBSTER will propose a series of guidelines and working papers that will help the consortium understand and kick-off the process of building a standard according to the CENELEC rules and framework. If needed and considered, a New Work Item Proposal could be submitted to CENELEC through committee SC9XC to propose this standard be developed and adopted. Submission of a New Work Item (NWI), which if approved, starts the process for the creation of a working group to fully develop the standard.

At present we are not aware of any gaps related to the existing standards. For the demonstrator based in Spain, specific Spanish standard have been investigated. During the replication activities, in the final phase of the project, a specific analysis of some specific national standards could be needed.