Development of Smart Grid Standards in View of Energy System Functionalities

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***Abstract*—A range of technologies must be developed and deployed for achieving a decarbonised energy system. A smart grid aims to integrate these different technologies into a single, over-arching system that is at the same time both complex and interoperable, which cannot be achieved without standardisation. Moreover, standardisation is a method of transferring research into successful processes and products. Without this, existing conventional energy systems will not change much longer, as it is more difficult to achieve significant market penetration of new technologies and deployment of new functions and applications. It seems that standardisation issues are not sufficiently addressed in scientific publications and are treated as a very specific topic by community of researchers despite the fact that standards may serve as a knowledge base for further research and improvement of emerging technologies and approaches. This paper presents a bird's-eye smart grid standardisation review based on a unique functionality - technology approach developed within Horizon 2020 project PANTERA.**

Keywords—decarbonisation, functionalities, interoperability, smart grid, standardisation.

I. Introduction

The European Union (EU) has set the ambition to reduce greenhouse gas emissions to the point of becoming climate neutral by 2050 and prevent the negative and irreversible effects of climate change. Reaching this goal will require transition of the energy system to a renewable-based operation and radical technological, behavioural and organisational changes in the economy and society. Smart grid is expected to play a major role in this process, corresponding to an enhancement of the power grid to accommodate the immediate challenges of today (such as the integration of growing share of decentralised renewable energy resources, the appearance of new loads caused by electrification of transport and use of heat pumps for space heating). However, several Pan-European studies conducted by, among others, the Joint Research Centre (JRC) in 2017 discovered an uneven level of implementation of smart grid technologies, with several member states not giving sufficient attention to Energy Research and Innovation (R&I) activities in this area [1].

The paper has been developed within the framework of Horizon 2020 coordination and support action (CSA) Pan-European Technology Energy Research Approach (PANTERA), which works on development and deployment of EIRIE – European Interconnection for Research Innovation & Entrepreneurship platform supporting the Energy R&I community in Europe. EIRIE aims to provide tools and functionalities for the needed access to knowledge, information, and thus provide support to broad community of stakeholders active in smart grid, storage and local energy system areas.

This paper presents results of the work dedicated to the smart grid standardisation. Standardization plays a significant role for the scalability and replicability of innovation as seen in [2]. The main advantage of standards is that they connect innovators, as they systemise and disseminate knowledge, such as the current state of the art and best practice. Standardisation improves the communication and information sharing between researchers, innovators and developers, thus avoiding "reinventing the wheel", which is wasteful in terms of time and resources. Instead, researchers can build on the knowledge of others and make improvements. There is of course the issue of the reluctance of researchers to share their findings, preferring to strive for intellectual property rights. However, this way of thinking is inefficient and does not align with the collaborative, interoperable concept of a smart grid and decarbonised energy system.

II. The Role of Smart Grid Standartisation

Standardisation sets technical or quality specifications that are complied with by current or future technologies. In terms of the smart grid, standardisation would identify minimum performance standards for the digital equipment involved and provide rules for how these components interact and share information, thus eliminating differences that inhibit the flow of information and data. Interoperability between the components of the network and the ability to not only communicate information, but to make sense of it and react accordingly, is vitally important for enabling efficient and safe operation of energy system.

As smart grids rely heavily on the use of smart metering on the demand-side, there are issues arising surrounding data protection and security, including compliance with the terms of the European General Data Protection Regulation. Standards will be vital in this area to ensure that consumers are protected and to increase acceptance of smart metering technologies [3], [4].

Furthermore, while smart grids require a range of new technologies, they must also be compatible with the existing components wherever possible, such as grid infrastructure,

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consumer devices and generators. Therefore, standardisation can ensure that these new technologies are compatible and can be used simultaneously and seamlessly [5]. Standardised smart grid technology is a prerequisite for a secure investment climate, especially considering the long lead times of the distribution business [6].

It cannot be ignored that standardisation activities in smart grid domain are clearly linked with the European Green Deal [7] and a long-term objective to reach climate-neutrality by 2050, and, hence with a range of legislative acts and strategies developed under these headlines. For example, the legislative framework "Clean energy for all Europeans package" (CEP) builds on the principles of "energy efficiency first" and a consumer in the centre of energy transition [8], thereby marking important directions in smartening the grid. Meanwhile, smart sector integration strategy [9] highlights the important role of standardisation also in coordinating sector-coupling. Furthermore, advanced, interoperable ICT solutions are in the core of a smart grid. Thus, smart grid standardisation is linked with European digital agenda [10] and cybersecurity policy.

As a result, smart grid standardisation activities are becoming more and more multipurpose and interdisciplinary, covering divergent technical areas and regulatory and market aspects. These focus on the common objective – the implementation of the desired services and functions which the smart grid as a complex system is to provide [11]. The above considerations create a motivation for smart grid standardisation review from the perspective of future energy system functions and applications.

A preferred approach is based on Functionality concept established by European Technology and Innovation Platform on Smart Networks for the Energy Transition (ETIP SNET) [12]. The ETIP SNET R&I roadmap [13] identifies twelve Functionalities as a set of actions to archive energy system transition (Table II) in accordance with the Building Blocks defined in the ETIP SNET Vision 2050. This way, current analysis is built on the future energy system needs.

III. EIRIE Platform: Technologies in Support of ETIP SNET Functionalities

The EIRIE platform aims to support the innovation activities in different ways through dedicated thematic areas offering knowledge, information, data and related tools. It targets to consolidate the community of stakeholders active in smart grid domain, not limited to researchers only, as a one stop shop by providing state-of the-art information in coherent structured way.

For these purposes it should be adopted an effective way of organising the data and knowledge that is universal, inclusive and sustainable. Therefore, the EIRIE platform in agreement with initiatives such as ETIP SNET [12] and BRIDGE [14], has adopted a new classification of technologies and systems that is covering all layers of the smart grid concept from end to end. The classification has been validated through an extensive process with contribution of ETIP SNET experts.

Under this prism, all data coming from cooperating platforms, information on R&I projects, information on relevant policy developments, regulations and standardisation, and community accumulated knowledge and expertise in forms of different reports can be found within EIRIE under this united technology and system approach that is presented in a concise form in Table I.

TABLE I. Technologies ans Systems

Group of Technologies	**Technology/Systems**	**№**
Itegrated grid	Flexible ac transmission systems (FACTS)	1
	Models, Tools, Systems for the operation analysis, control and the development of the integrated grid including cost elements	2
	HVDC	3
	Forecasting (RES)	4
	Asset management	5
	Outage management, fault finding and associated equipment (including protection)	6
	Equipment and apparatus of the integrated grid	7
	Equipment, sensing, monitoring, measuring for analysis and solutions and control	8
	Advance distributed control	9
	Feeder auto-restoration / self-healing	10
	Smart metering infrastructure	11
Customers and market	Distributed flexibility, load, forecasting, management & control and demand response including end devices, communication infrastructure and systems	12
	Smart appliances	13
	Building control, automation and energy management systems	14
	Electric vehicles	15
	Energy communities	16
	Lighting	17
	Electricity market	18
Storage	Electric Storage	19
	Thermal Storage	20
	Power to X	21
	Pumped storage	22
	Other Storage	23
Generation	Flexible generation	24
	Solar including PV & Concentrated Solar Power	25
	Wind	26
	Hydropower	27
	Hydrogen & sustainable gases	28
	Other generation	29
Digitalization, Communication and Data	Communication networks including devices and systems for signals and data connectivity and solutions	30
	Digital Twins	31
	Artificial intelligence	32
	Data and cyber security including repositories	33

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TABLE II. ETIP SNET FUNCTIONALITIES AND CORESPONDING TECHNOLOGIESIES

Energy System Building Blocks	Functionality Full Title	Abbreviation	Relevant Systems and technologies
The efficient organisation of energy systems	Cooperation between system operators	F1	5, 6, 7, 8, 9, 10, 11
	Cross-sector integration	F2	15, 18, 20, 21, 22, 23, 24, 25, 28
	Integrating the subsidiarity principle - The customer at the centre, at the heart of the Integrated Energy System	F3	12, 14, 18
Markets as key enablers of the energy transition	Pan-European wholesale markets	F4	4, 18, 19 ,24, 25, 26
	Integrating local markets (enabling citizen involvement)	F5	4, 12, 13, 15, 16, 18, 19, 24
Digitalisation enables new services for Integrated Energy Systems	Integrating digitalisation services (including data privacy, cyber security)	F6	8, 11, 13, 30, 31, 32, 33
Infrastructure for Integrated Energy Systems as key enablers of energy transition	Upgraded electricity networks, integrated components and systems	F7	1, 3, 5, 6, 7, 8, 9, 10, 11, 12
	Energy System Business (including models, regulations)	F8	11, 12, 13, 14, 15, 16, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29
	Simulation tools for electricity and energy systems (Software)	F9	2, 4, 31, 32
Efficient energy use	Integrating flexibility in generation, demand, conversion and storage technologies	F10	12, 14, 16, 17, 18, 19, 20, 21, 22, 23, 24, 27, 28, 29
	Efficient heating and cooling for buildings and industries in view of system integration of flexibilities	F11	12, 14, 16, 18, 20, 22
	Efficient carbon-neutral liquid fuels & electricity for transport in view of system integration of flexibilities	F12	16, 18, 19, 28, 29

Furthermore, Functionalities can be seen as confined systems served by different technologies (Table II). Technology classification aims at providing a quantified and solid index of maturity of the Functionalities through the maturity of underling technologies and systems, and serves as a building block of the ETIP SNET established process for identifying R&I needs. The described classification was used for the smart grid standardisation review presented below.

IV. SMART GRID STANDARTISATION REVIEW

A. *Smart Grid Standartisation Landscape*

The international standardisation landscape has a complicated structure, comprising a number of different organisations. Some insights into the activities of major organisations in smart grid standardisation development and coordination are given below.

The International Electrotechnical Commission (IEC) established a System Committee (SyC) Smart Energy that aims to provide systems level standardisation, coordination and guidance in the areas of smart grids and smart energy, including interaction in the areas of heat and gas. A Smart Grid Standardisation Roadmap by IEC [15] drafts a technology-oriented strategy which represents the standardisation requirements for smart grids. The roadmap [15] presents an inventory of existing and future standards, and puts them into perspective regarding the different applications (standards in relation with electrotechnics, standards related to communicating systems and standards which cover cross-cutting areas such as communication, data modelling, cyber-security, etc. A number of standards are valid for almost all applications and are considered as core standards (IEC 61850, IEC 61508, IEC 61970. IEC 61968, IEC 62325, IEC 62056, IEC 62351) [15]. Additionally, IEC has developed a Smart Grid Standards map [16] – an online tool that allows the smart grid stakeholders to identify the standards that are needed for any part of the grid positioned in relation to technical components and systems onto the Smart Grids Architecture Model (SGAM) plane.

At the same time, to guide efforts in smart grid standardisation, European standardisation bodies - the European Committee for Standardisation (CEN), the European Committee for Electrotechnical Standardisation (CENELEC) and the European Telecommunications Standards Institute (ETSI) - established CEN-CENELEC-ETSI Smart Grid Coordination Group (SG-CG). A number of different reports was produced by the SG-CG, and, in particular, [17] proposing a widely acknowledged technical reference architecture for smart grids - SGAM. The SGAM framework introduced interoperability aspects and how these are considered via a domain, zone and layer-based approach. Moreover, the SG-CG developed the list of standards [18], enabling or supporting the deployment of smart grids in Europe. The last revision [19] was updated in 2017 by the Coordination Group on Smart Energy Grids (CG-SEG), which took over the responsibilities of SG-CG. Furthermore, in the context of adoption of the Clean Energy Package (CEP) an initial assessment of relevant standardisation requirements was performed and summarised in [20].

The National Institute of Standards and Technology (NIST) of United States is continuously working on coordination and acceleration of smart grid interoperability and security standards and has recently published Version 4.0 of the NIST Framework and Roadmap for Smart Grid Interoperability [21]. Interoperability is described as a principal enabler of new system control schemes necessary to manage the active participation of distributed resources and empowering consumers to provide solutions across numerous scales. This revision uses evolving technology and power system architectures (i.e., updated NIST Smart Grid Conceptual model, Communication Pathway Scenarios and an Ontology of the Smart Grid based on cyber-physical system approach) as context for identifying grid interoperability

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requirements in four key areas: grid operations. cybersecurity, grid economics, and standards testing and certification.

Institute of Electrical and Electronics Engineers Standards Association (IEEE SA) develops global standards in a broad range of technologies, including smart grids. IEEE SA is uniquely positioned to guide smart grid standardization, while it is not a body formally authorized by any government, but rather a community. It has more than 100 standards and standards in development relevant to smart grid [22]. However, there is no doubt that IEEE standards are of great value for promotion of smart grid technologies, these are not included in the current review.

Even this brief overview of standardisation bodies shows the overall complexity of the structure, unclear relationship and prevailing of corresponding standards.

B. *DSO Smart Grid Standartization Priorities*

Distribution domain appears to be the most affected in the process of energy system transformation and smartening the grid because of proliferation of distributed generation and increasing role of consumers/prosumers who become active energy market participants. Therefore, special attention shall be paid to the needs of distribution system operators (DSOs). The role of the new EU DSO entity in the standardisation of Smart Grids remains somewhat unclear, however the EU Regulation 2019/943 defines among its responsibilities "to contribute to the establishment of interoperability requirements" [23].

To support the smart grid standardisation process, European DSOs, represented by the EURELECTRIC and European Distribution System Operators (E.DSO) have identified the major priorities for smart grid standardisation for the distribution business. The report [6] provides description of gaps and relevant recommendations in the three key areas: smart network management, smart integration of distributed generation and e-mobility and smart market and active customers. The standardisation priorities are divided into clusters, illustrating the level of urgency from DSOs perspective. Relevant standards which need to be revised or enhanced are identified for each of the priority.

As time has passed since the report has been published, it is possible to trace the progress made in the identified directions. Table III illustrates current situation for DSO primary and secondary priority clusters of smart grid standardisation. Some of the priorities are already fully covered and the standards identified in the report have been developed and published, while other are progressing with standards being prepared in their final stage. This clearly illustrates the efforts and time needed for establishing new standards, thus preparing for wide adoption of technologies which will enable new applications and functions of the power system.

Other important concerns addressed in [6] are the system interoperability testing and conformance testing. Conformance tests and/or conformance assessment refer to testing a device or a system against a defined set of criteria, and evaluating the test results against the metrics defined within the criteria [24]. These criteria and metrics could be defined in the relevant standard itself or in the so-called conformance test profiles developed on top of the standard. Thus, conformance testing is only possible if technical requirements set in standards are covered with test methods, evaluation criteria and metrics. Meanwhile, interoperability testing is a procedure in which two or more implementations (systems and products) are tested in combination with each other [25]. A review of testing and certification programs for smart grid interoperability standards was performed within NIST Smart Grid Program. The results published in [26] showed that out of the 240 standards reviewed, 169 standards were found to be functionally related to interoperability and of those only a small percentage were found to have testing and certification programs of any form - either existing or planned.

TABLE III. DSO STANDARTISATION PRIORITIES

DSO Priority	**Corresponding Standards**
DSO primary priority cluster	
Feeder and advance distribution automation	EC TR 61850-90-6:2018
Connecting of distributed energy resorses (DER) to the grid	EN 50549-1:2019 EN 50549-2:2019 IEC TS 62786 (parts 1, 2, 3, 41, 42) (currently under development)
Seamless communication between control centre and substation	IEC TR 61850-90-2:2016 IEC TR 61850-90-11:2020 IEC 61850-8-2:2018
Harmonized glossary, semantic and modelling between back-office applications and field applications	IEC 61968 (parts 1, 3-14, 100) IEC TR 61968-900:2015 IEC 61968 (parts 3, 8, 9, 100) (currently under development) IEC 61970 (parts 301, 302,452, 453, 456, 457, 552) IEC TS 61970 (parts 555, 556, 600-1, 600-2) IEC 61970-CGMES:2020 IEC 61970 (parts 301, 302, 303, 401, 452, 456, 459, 501, 600-1, 600-2) (currently under development) IEC TR 62325-103:2017 IEC 62325 (parts 301, 351, 450, 451-(1-7), 451-10, 503) IEC TS 62325-504:2015 IEC 62325 (451-8) (currently under development)
DSO secondary priority cluster	
Harmonisation between IEC 62056 series data model and IEC 61850	IEC 61968-9 (new edition) (currently under development) IEC 62056-6-2:2017 IEC 62056-6-2 (new edition) (currently under development)
Smart grid communication standards relying on the internet based standard web services	IEC TR 61850-80-3:2015 IEC 61850-8-2:2018
Extended field data modelling standard to support demand response, DER, virtual power plants and home /building /industry automation	IEC 61850-7-420 (new edition) (currently under development) IEC 61400-25-(1-6) IEC TS 61400-25-71:2019 IEC 61400-25-2 (new edition) (currently under development) IEC TS 61400-25-41
From smart metering to smart grid,and e-mobility	IEC 60364-7-722:2018 ISO 15118 (parts 1,2,3,4,5,8) ISO 15118 (parts 9, 20) (currently under development)
Harmonize activities on data transport technologies	EN 50065 series no new developments
Develop cyber security around IEC 62351	IEC 62351 series a number of new additional parts and revisions, few parts in work

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C. *The State of the Art in Smart Grid Standartisation*

As a way to create an up-to-date picture of developments in smart grid standardisation, a review of standardisation documents including standards, technical specifications (TS) and technical reports (TR) was performed. Therefore, an exhaustive search of publications, was carried out through IEC, CENELEC, CEN and ISO standard databases by specifying a technical committee. Relevant committees were identified mainly based on their task descriptions and CEN-CENELEC-ETSI SG-CEG report [19]. This resulted in obtaining a list of more than five hundred documents, including publications in force and publications which are currently being developed and already have the identification number (i.e. standard reference).

While not pretending to be completely exhaustive, the review proved that all core standards have been modified and/or enhanced during the past ten years. Additionally, completely new publications with new standard references, have been developed or are being developed at the moment. Fig. 1 illustrates the number of publications per year adopted during past ten years (2011-2020) and number of documents in progress (planned adoption date obtained from CENELEC and IEC databases). It covers new publications and new parts of standards adopted earlier, excluding amendments and corrections of existing publications. It can be noticed, that the number of adopted publications per year is gradually increasing.

Additionally, completely new publications with new standard references, developed during the last five years (2016-2020) and new publications in progress were selected and analysed through Functionality prism. This list included all major developments in the field of smart grid standardisation and demonstrated that activities have been taking place across multiple technical committees and thematic directions including DER connection (IEC TS 62786, IEC TS 63102, IEC TS 63276), electric vehicles (IEC 63110, IEC 63119), storage (IEC 62933), microgrids (IEC TS 62898), virtual power plants (IEC 63189), sensors (IEC 62689, IEC TR 63262:2019), communications (ISO 17800:2017, CLC/TS 50586:2019) and other. A number of documents in work included in the list was almost twice as large as the number of newly adopted publications during past five years. Hence, it seems that nowadays standardisation efforts for new applications tend to accelerate.

In order to understand trends in the light of ETIP SNET proposed Functionalities, all of the selected new publications over a five-year period were linked to one or more relevant Functionality based on technology systems classification. Fig. 2 illustrates the standardisation efforts development in each of the Functionality. While digitalisation (F6 (in grey)), infrastructure (F7, F8, F9 (in red)) and market (F5, F4 (in blue)) issues are partially addressed, it appears that issues linked to the efficient organisation of energy systems (F1, F2, F3 (in green)) and efficient energy use (F10, F11, F12 (in yellow)) are not sufficiently covered. This could be because technologies related to smart sector coupling and integrating flexibility in demand, storage, vehicle to grid and power to gas are not mature enough to require standardization. Availability and application of standards for interoperability and data exchange between sectors is one of prerequisites [27] for creating a truly integrated energy system. Therefore, more efforts and investments, as well as closer cooperation between various stakeholders is needed in order to foster developments in this area. However, positive trend is that some publications related to these Functionalities appear on a future standardisation horizon. Similarly, DSO identified standardisation priorities analysed above contribute to advancing mainly of F8, F7, F6 and partially F10, F5 and F4.

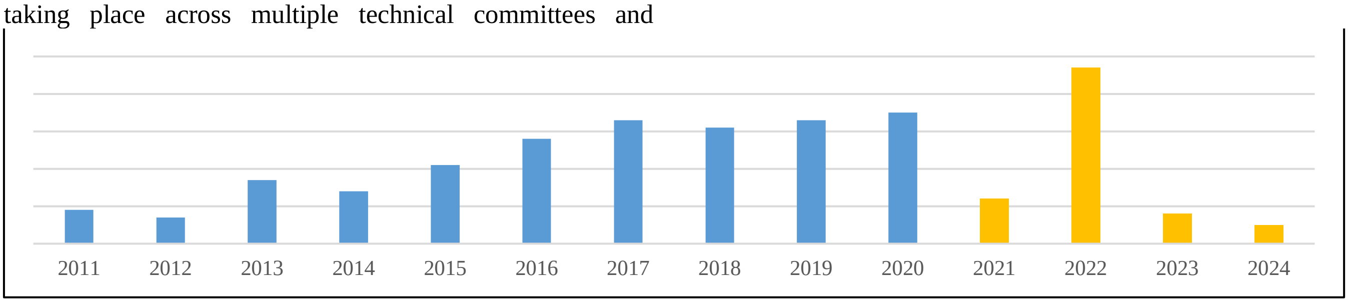

Fig. 1. Number of publications per year

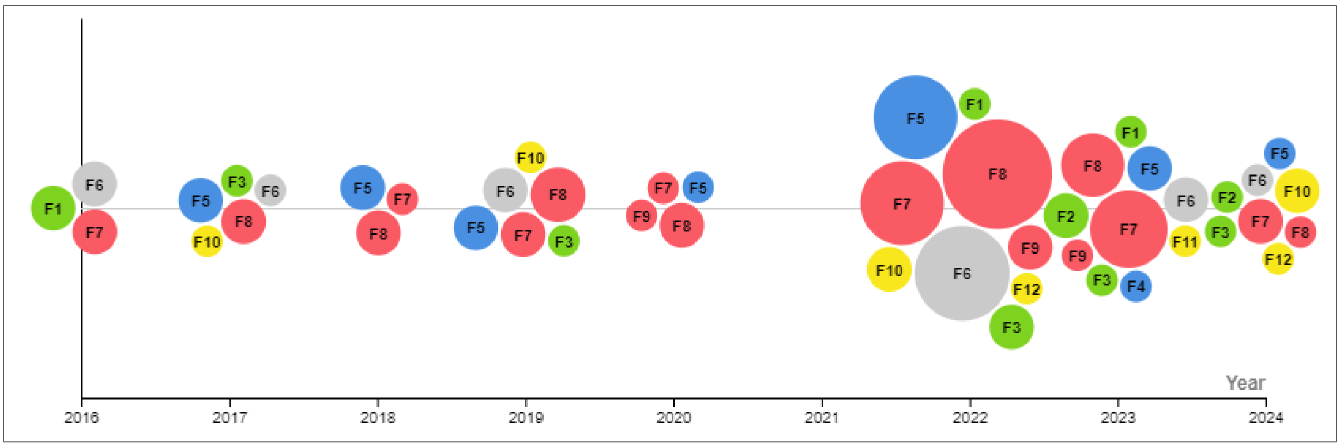

Fig. 2. Distribution of adressed Functionalities in new standard publications

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V. DISCUSSION AND CONSLUSIONS

The review illustrates that significant efforts have been made in smart grid standardisation domain, and topics on standardisation agenda are gradually increasing. Developments are taking place across multiple thematic areas, including DER connection, electric vehicles, storage, sensors and metering equipment, etc. Moreover, standardisation priorities identified by important stakeholders, like DSOs, are being constantly addressed.

However, more advancements are still needed in order to enable true integration of energy system. Standardisation is a critical issue for enabling coordination of different energy vectors (e.g., electricity and hydrogen), scales (e.g., cities and communities) and infrastructures (e.g., electricity grids and transport). Stakes are high to assure that technologies and systems interoperate as advertised and can provide expected contribution to the overall energy efficiency, and thus to decarbonisation targets.

Given a range of technologies covered and stakeholders involved, communication and cooperation are vital in development and deployment of smart grid. The EIRIE platform aims to support collaborative approach in fostering smart grid R&I activities. Moreover, in the rapidly changing legislative environment and considering fast advancement of new technologies, accumulated knowledge and expertise shall be systemised in an effective and sustainable way. This can be done by adopting approach based on envisaged future energy system needs, i.e., functionalities. As can be seen from standardisation review, this helps to create a common picture and contributes to assessing the whole system maturity and identifying necessary advancements on the way to 2050 vision.

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