ETIP SNET

EUROPEAN TECHNOLOGY AND INNOVATION PLATFORM

SMART NETWORKS FOR ENERGY TRANSITION

WHITE PAPER

Holistic architectures for future power systems (Short Version)

March 2019

INDEX

1. EXECUTIVE SUMMARY

Cost effective and secure transition to lower carbon electricity system require fundamental transformation of the power system control from traditional centralised to a decentralised paradigm. It necessitates the development of novel architectures that can reliably meet the needs of the emerging power system. The new emerging architectures should enhance the controllability associated with future power system operation in order to increase the infrastructure utilisation while cost-effectively managing security and resilience. In this context, this White Paper sets out the holistic architecture vision that should inform future demonstration projects that would enable large-scale rollout of the new control paradigms.

In this White Paper, some European projects that addresses some of the emerging challenges are discussed, in the context of the holistic architecture vision for future power systems.

Concepts from the ELECTRA IRP, IDE4L, SmartNet and ZUQDE projects are presented. These projects addresses similar challenges and at a system-wide level, from the transmission and distributions systems to the customer. Some of these approaches are based on upgrading the existing architecture (SmartNet and IDE4L). Whereas others propose fundamental change to the architecture (Web of Cells and *LINK*-Solution) to provide a network of decentralised systems with local autonomy over managing the optimal utilisation of available resources.

The **Web of Cells** concept was developed within the ELECTRA IRP project providing a decentralised control using non-overlapping geographical areas, known as cells, to maximise the utilisation of distributed sources. It effectively addresses problems locally, whereby each cell makes optimal use of the flexibility resources within its boundaries, thereby contributing to effective voltage and frequency control in the entire power system. WoC needs to enhance the research efforts with specific attention to cyber-security and data integrity.

Within the **IDE4L** project, a concept is developed based on existing power system infrastructure and systems for communications, control and automation. It proposes a combination of a hierarchical and distributed architecture. In order to facilitate the integration of renewable generation and new customers, the IDE4L enhances observability and controllability of the distribution networks enabling a cost-efficient operation of the whole power system. However, further investigation is needed to ensure data privacy and cybersecurity.

A concept based on TSO-DSO coordination was developed in the **SmartNet** project. It examines the implementation of a flexibility market to provide optimised instruments to improve the coordination between the grid operators at national and local level (respectively the TSOs and DSOs). Five different coordination schemes were developed and evaluated. They are being further developed in the projects Coordinet and Interfaces. SmartNet is not looking into a completely new system which will change the roles, functions of the existing actors.

The ***LINK*-Solution** designs the holistic architecture, enabling a large scale implementation of distributed energy resources. It considers the entire power system from high, medium to low voltage levels, including customer plants and the market, and facilitates all processes necessary to operate the emerging power system. Data privacy and cyber security are guaranteed by design. *LINK*-Solution is characterised by standardised structures. However, it is important to proof the concept on-site by implementing the full holistic architecture.

In conclusion, it is defined that a holistic architecture includes all electrical equipment, customer plants and the market, and through their automation and the use of information and communication technologies it enables the execution of all operational processes that are necessary for a reliable, safe and economical smart power system operation. It allows the investigation and operation as a large single entity. Optimising individual functionalities or taking the viewpoint of individual actors may lead to suboptimal solutions.

2. THE NEED FOR A HOLISTIC ARCHITECTURE FOR FUTURE POWER SYSTEMS

he main driver for the evolution of power systems has been the goal of protecting the environment, which is being expressed through the global push for decarbonisation that has resulted in a significant increase in the penetration of renewables. This process has led to the transformation of the power system from its traditional centralised form to a decentralised form characterising numerous generating units of various sizes connected across the grid at different voltage levels. This fundamental change in the electricity supply structure renders the traditional technical / functional architecture no longer sufficient, thereby paving the way for the establishment of novel architectures that can reliably meet the needs of the new power system era that have arisen.

In this new paradigm, the increased penetration of distributed and renewable energy sources, such as wind and solar, poses significant challenges in the fulfilment of daily power requirements. It increases the uncertainties related to power systems. Specifically, renewable sources of energy are characterised by both uncertain operation and uncertain deployment patterns. The uncertain operation is related to the fact that renewable sources of energy are by default intermittent and less predictable. The uncertain deployment patterns refer to the fact that system planners do not typically know with certainty in advance how much and at which specific locations in the system renewable capacity will connect given that its deployment at residential level typically does not require prior notice of the distribution network operators. Within this uncertainty setting power systems have tried to adapt so as to continue to deliver safe and reliable operation. This adaptation can be realised through the development and deployment of smart grid technologies. Examples of such technologies include the energy storage, demand side response and power-electronics-based assets such as soft-open points, distributed state estimator etc. All of these technologies can operate in combination with each only in context of a holistic architecture; the description of such architectures forms the core of this paper.

One of the main tasks associated with the new architectures is to enhance the controllability associated with power system operation. It is essential to note that the holistic architectures need to safeguard the power system from cyber threats that have the potential of causing huge damage both structural and operational. Therefore, the decentralisation of the power system should be wisely conducted to further enhance the supply resilience against natural and malicious intervention while improving reliability and minimising system costs. Additionally, it should cater for data privacy concerns by establishing transparency in the use of private data. In this context, the General Data Protection Regulation (GDPR), EU 2016/679 of the European Parliament and of the Council of 27 April 2016, sets the rules concerning data protection and privacy for all individuals within the European Union and the European Economic Area. Data exchange between the different players involved within the holistic architecture must comply with GDPR's provisions.

Although the electricity markets are undergoing a radical change, the current re-dispatch process for congestion management is still costly and is driving the transmission grid operation to its limits. The transformation of resource mix of fossil fuels to renewables and the rise of distributed generation calls for a radical review of the market rules under a holistic view of the power grid, customer plants and the market.

To overcome the issues discussed above, the holistic power system architectures are presented in this paper as a way to decarbonise the electricity power industry in a cost-effective manner through adopting advanced technologies that add value to utilities and consumers alike while at the same time respecting data privacy and guaranteeing safety against external threats.

3. WEB OF CELLS CONCEPT

The Web of Cells (WoC) is a new power grid control architecture that was proposed and developed within the ELECTRA IRP[1] (European Liaison on Electricity Committed Towards long-term Research Activity, Integrated Research Program) and allows for decentralised control. This scheme has been proven to be feasible through a series of simulations and lab experiments that have been conducted within the framework of ELECTRA IRP.

The main assumption that motivated the development of WoC constitutes that the future power system is highly decentralised and with high share of renewable resources at distribution system level.

In such a future power system, the frequency and voltage control may no longer be effectively managed centrally by Transmission System Operators (TSOs), which is the business-as-usual case, unless there are monitoring systems and ubiquitous sensors deployed across the grid that will be able to collect all necessary information at LV and MV levels and then transmit it to the TSO for further analysis. This analysis will allow for the detection of local problems that will then determine the need to activate reserves (flexible resources). In this context, achieving full network visibility may involve prohibitively high costs to cover for a system-wide deployed ICT control and monitoring system, especially given the big data generated by Distributed Energy Resources (DER) spread across the grid. Hence, ELECTRA IRP proposed the WoC on the idea that a decentralised control concept will most effectively address local problems locally.

In fact, ELECTRA IRP proposed the WoC concept given the emergence of the decentralised electricity supply paradigm and the following key trends:

- Generation will shift from classical dispatchable units to intermittent Renewables;
- Generation will shift from relatively few large units to many smaller ones, mainly connected at distribution level. Decentralisation will be supported also by the developments in information and communication technologies as well as by machine learning algorithms and big data techniques. It is expected that even the last mile of the power system is about to be covered by ICT;
- There will be more deviations compared to what was planned as well as incidents (e.g. generation outages);
- Greater power injection at LV and MV levels will increase the risk of local voltage problems and congestion. Thus resources that can address voltage and balancing problems will move to a large extent from transmission system level (HV) to distribution level (MV, LV);
- Availability of resources (e.g. production and storage) may vary significantly across different geographical locations. This availability will increase mainly at distribution system level;
- Electricity consumption will increase significantly given the drive towards electrification of transport and heating/ cooling. Much of the load will be controllable/responsive to market signals, making local consumption-forecasting even more challenging;
- Energy storage will be a cost-effective solution for offering ancillary services. Distributed ES will become a competitive solution compared to traditional resources for reserves;
- In such a future power system, coordination between operators of different voltage levels will be essential given that central TSOs will no longer have the system overview to effectively dispatch reserves

[1] ELECTRA IRP project funded under FP7 by the European Commission

According to the WoC concept the power system operation is split into a number of connected

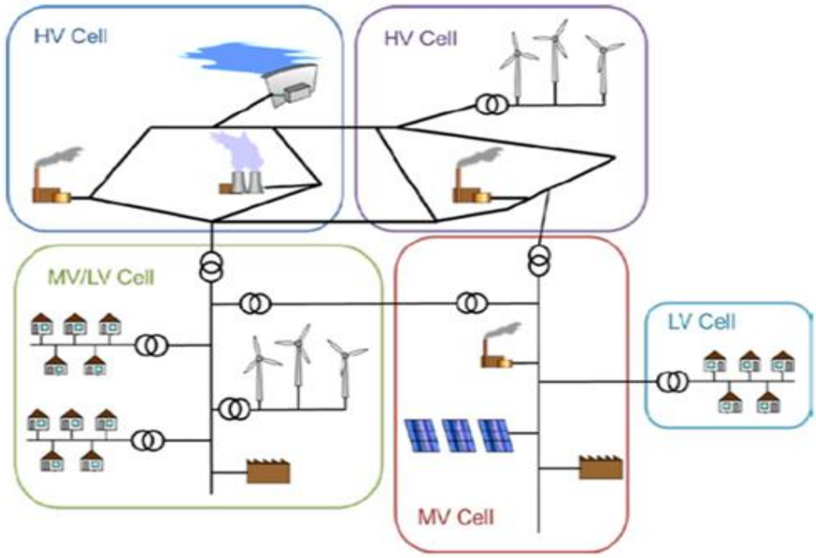


Figure 1: Schematic diagram of a power system split in cells of different voltage levels.

entities located in non-overlapping geographical areas of the power system and are known as 'control cells', with each one having the possibility of containing multiple voltage levels. Since the cells are non-overlapping subsets of the power system topology, the union of their topology is equal to the topology of the power system. Figure 1 illustrates this concept.

CONSIDERATIONS

The WoC[2] is a new power grid control architecture that was proposed and developed within the ELECTRA IRP and has been proven to be feasible through a series of simulations and lab experiments that have been conducted within the framework of ELECTRA IRP. The main assumption that motivated the development of WoC constitutes that the future power system will be highly decentralised and with high share of renewable resources at distribution system level.

In such a decentralised power system, the business-as-usual case of centralised control will lead to prohibitively high costs given that effective grid monitoring and control will require deployment of monitoring systems and ubiquitous sensors across the grid for collection and analysis of massive amounts of data (big data). On the other hand, WoC rests on the idea that a decentralised control concept will effectively address local problems locally, whereby each cell will be making optimal use of the flexibility resources within its boundaries, thereby contributing to effective voltage and frequency control in the entire power system.

In **conclusion ETIP-SNET considers WoC as a holistic architecture that is specifically developed for addressing the challenges related to a future highly decentralised power system with large share of renewable resources. Firstly, WoC has been proven technologically feasible through simulations and laboratory experiments. Secondly, it has the potential to effectively manage the flexible resources spread across the network, in a decentralised manner without the need for the deployment of system-wide monitoring and control ICT infrastructures that would potentially render the system costs prohibitively high. As a result, it is important to enhance the research efforts with specific attention to cyber-security and data integrity.**

[2] For more details see the long version: https://www.etip-snet.eu/wp-content/uploads/2019/03/ETIP-SNET_HolisticArchitecture_2019_03_03_Final-UPDATE2.pdf

4. IDE4L HIERARCHICAL AND DISTRIBUTED ARCHITECTURE

The increasing amount of distributed intermittent generation changes the operational and planning principles of the power system drastically. The centralised operation of the system will transform towards more distributed approaches where also small DERs need to actively participate to power system operation. The IDE4L[3] architecture enables utilisation of small-scale DERs for transmission and distribution system management purposes in a cost-efficient manner. The IDE4L hierarchical and distributed architecture was developed in IDE4L project.

Concept

The overview of the IDE4L automation concept is represented in Figure 2. The architecture builds on top of the existing power system infrastructure and reuses existing automation solutions such as DSO control centre IT systems (SCADA, Distribution Management System (DMS), etc.) by integrating them into the proposed architecture. Therefore, the proposed solution can be easily expanded from the existing systems.

The architecture has been designed based on monitoring, control, and business Use Cases and using the Smart Grid Architecture Model (SGAM) formulation. The European Commission mandate M/490 standardised the SGAM framework for definition of architectures for smart grids.

The automation architecture consists of automation systems owned by different power system actors as indicated in Figure 2. Distribution automation shown inside the DSO box includes control centre information systems, primary and secondary substation automation, and intelligent electronic devices (IEDs), including multiple types of devices like smart meters in the customer interface. It realises the real-time monitoring and controlling of all MV and LV networks and direct control of DERs. Commercial aggregator automation system enables participation of DERs to different market places. In addition to the already existing markets,

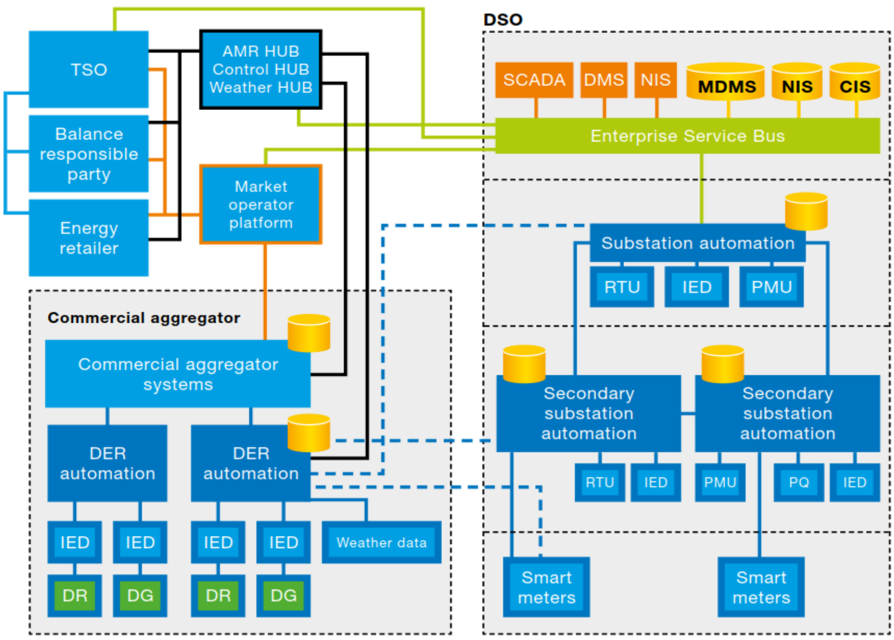


Figure 2: An overview of the IDE4L automation concept.

[3] IDE4L project funded under FP7 by the European Commission

DERs can participate also to local DSO markets. The development of distribution automation and addition of the commercial aggregator automation system enable efficient utilisation of DERs both for transmission and for distribution system operational purposes.

The architecture has been defined in all SGAM layers (business, function, information, communication and component) and more detailed representation of the whole architecture can be found in IDE4L project deliverables and publications. The most detailed analysis have been conducted for distribution systems and aggregator systems.

The IDE4L architecture enhances observability and controllability of the distribution networks and, therefore, enables more cost-efficient operation of the whole power system. The existing systems are utilised as the starting point for the architecture development and, therefore, step-wise implementation of the new smart grid functionalities is possible.

Traditional distribution automation solutions are not rapid and scalable enough to monitor and control large-scale DERs in real time on both MV and LV networks. In the hierarchical and distributed architecture, distribution system operation is distributed such that each MV and LV network is controlled by its own automation component substation automation unit (SAU). The SAU is the main new component in the architecture and is responsible for congestion management (both voltage and current congestions) and network optimisation in real-time.

The architecture is technology neutral as far as standards are used, so it can be implemented with heterogeneous types of measurement devices, controllers, and computation units. All data exchange and modelling are based on international standards to enable interoperability, modularity, the reuse of existing automation components, and the faster integration and configuration of new automation components.

CONSIDERATIONS

In the future smart energy system, small-scale DERs need to actively participate to power system operation. The IDE4L[4] hierarchical and distributed architecture enables utilisation of the DERs for transmission and distribution system purposes in a cost-efficient manner. The feasibility of the architecture was confirmed through simulations, lab testing and finally real network demonstrations.

IDE4L architecture builds on top of the existing power system infrastructure and can be taken into use gradually. New developments concentrate especially on distribution systems and aggregator systems but also other power system actors are taken into account. The main new automation component is the substation automation unit that will be responsible for monitoring and control of one MV or one LV network. The SAUs can be added to the network at first to locations where some problems already occur and the automation system can be extended when needed. This enables utilising the existing infrastructure efficiently and makes it easier to take the architecture into widespread real network use. The architecture utilises standard interfaces and is scalable. It was designed based on several smart grid use cases using the SGAM formulation and, therefore, has not been optimised for individual use cases but is suitable for all smart grid functionalities.

IDE4L gives a mixture of the hierarchical and distributed architecture concepts. Microgrids are used on the presented distributed architecture concept. The actual work is mostly concentrated on developing distribution automation and utilisation of small-scale DERs for both distribution and transmission system purposes. In **conclusion, ETIP SNET underlines that further developments in guaranteeing the data privacy and cybersecurity will distinctly increase the IDE4L relevance.**

[4] For more details see the long version: https://www.etip-snet.eu/wp-content/uploads/2019/03/ETIP-SNET_HolisticArchitecture_2019_03_03_Final-UPDATE2.pdf

5. SMARTNET ARCHITECTURE

SmartNet[5] project aims to provide optimised instruments and modalities to improve the coordination between the grid operators at national and local level (respectively the TSOs and DSOs) and the exchange of information for monitoring and for the acquisition of ancillary services (reserve and balancing, voltage balancing control, congestion management) from assets located in the distribution segment (flexible load and distributed generation).

As such the simulation platform develops 3 layers: physical layer, market, new players, ICT architecture layer. To evaluate the costs, 5 coordination schemes between TSOs and DSO are tested in 3 location: Italy (high penetration of hydro and real time information), Denmark (thermal inertia of the swimming pools), and Spain (flexibility from mobile telephone).

Technical and market holistic model

Five different coordination schemes: the Centralised Ancillary Services (AS) market model, the Local AS market model, the Shared Balancing Responsibility model, the Common TSO-DSO market model and the Integrated Flexibility market model. Figure 3 illustrates the five coordination schemes.

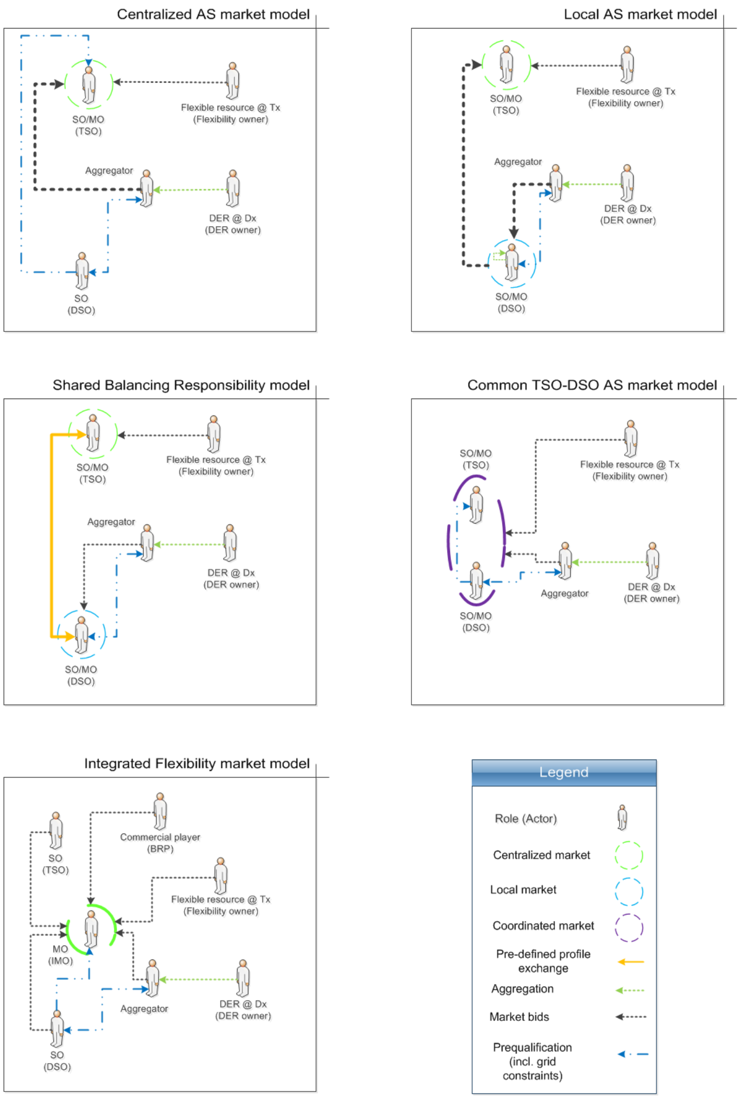


Figure 3: Illustration of five coordination schemes.

[5] SmartNet project funded under H2020 by the European Commission

The coordination schemes between TSOs and DSOs is mainly related to network planning, common data platforms or sharing of metering data. Although in most countries, DER units can provide flexibility-based services, there is still a wide heterogeneity in products and rules across countries.

A coordination scheme is defined as the relation between TSO and DSO, defining the roles and responsibilities of each system operator, when procuring and using system services provided by the distribution grid. The design of the market to procure system services will depend on the relation between system operators and the roles they will take up. A role is defined as an intended behaviour of a specific market party, with certain responsibilities, which is unique and cannot be shared

Depending on the coordination scheme, certain roles of system operators might be added, extended, modified or shifted.

Considerations

The SmartNet[6] project is a market place platform which defines 5 options for ancillary services market models and defines the roles of the DSOs and also TSOs in the different market places schemes. It takes into account the distribution grid constrains. It also defines ICT architecture which enables the 5 coordination schemes and the exchange of information. By looking into ancillary services market and the activation of the distributed resources such as swimming pools, PV installation etc. is taking into account the customer/prosumer.

In **conclusion, ETIP SNET** underlines that **SmartNet is not looking into a completely new system which will change fundamentally the roles, functions of the existing actors.**

[6] For more details see the long version: https://www.etip-snet.eu/wp-content/uploads/2019/03/ETIP-SNET_HolisticArchitecture_2019_03_03_Final-UPDATE2.pdf

6. *LINK*-BASED HOLISTIC ARCHITECTURE

The foundations of the *LINK*-based holistic architecture have emerged from the FENIX[7] and ZUQDE[8] projects. The concept of secondary control as a sustainable, resilient, base interaction instrument is realised in a reduced scope. It is successfully implemented in open-loop during the FENIX project, and in closed-loop during the ZUQDE-project. There are made the first steps of the architectural design. Whereas, the *LINK*-Paradigm is derived from the Smart Grid fractal pattern developed as part of an internal project of the TU Wien, Austria.

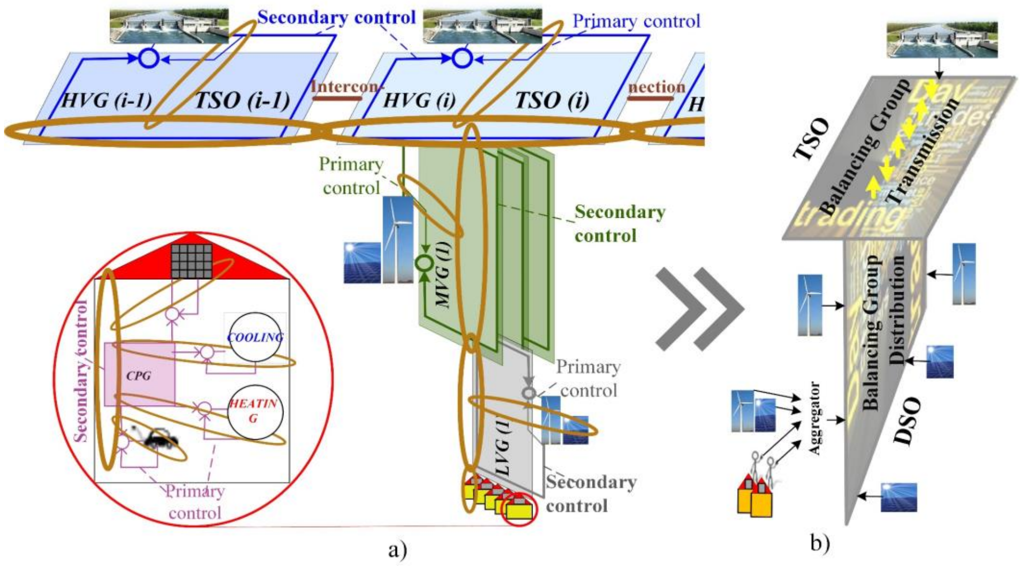
LINK - the smart grid paradigm

The *LINK*-based holistic architecture addresses the decarbonisation of power industry by preserving data privacy and cyber security. The already very complex operation processes of the power systems are becoming even more complex and unclear as a result of the DER penetration, and the latest renewable energy resources with very high volatility. Therefore, to understand and design the highly complex operation processes of the future power systems, the smart grid paradigm "*LINK*" shown in Figure 4 is defined as follows:

LINK-Paradigm is defined as a set of one or more electrical appliances - i.e. a grid part, a storage or a producer device -, the controlling schema and the interface.

Figure 4: *LINK*-paradigm

LINK-Paradigm is used as an instrument to design the *LINK*-based holistic architecture. It facilitates the modelling of the entire power system from high, medium to low voltage levels, including customer plants and the description of all power system operation processes such as load - generation balance, voltage assessment, dynamic security, price and emergency driven demand response, etc. *LINK*-Paradigm is the fundament of the holistic, technical and market-related model of smart power systems with large DER share, Figure 5.



HVG-High Voltage Grid; MVG-Medium Voltage Grid; LVG-Low Voltage Grid; CPG-Customer Plant Grid.

Figure 5: Overview of the holistic model: a) technical: the "Energy Supply Chain Net" and b) market-related.

[7] FENIX project funded under FP6 by the European Commission
[8] ZUQDE project funded by "Neue Energien 2020" of "Klima- und Energiefonds", Austria.

LINK-Paradigm reorganises the management of the grid, electricity production, energy storage facilities and consumers by dividing the whole system into clearly defined units, "Links", each with its own control system and well-defined interfaces to their neighbouring units and the market.

Holistic architecture

Figure 6 shows the *LINK*-based holistic architecture, where all relevant components of the power system are merged into one single structure. The electricity producers and storages are considered regardless of technology and size; the power grid is considered regard less of voltage level; all customer plants and the electricity market are taken into account.

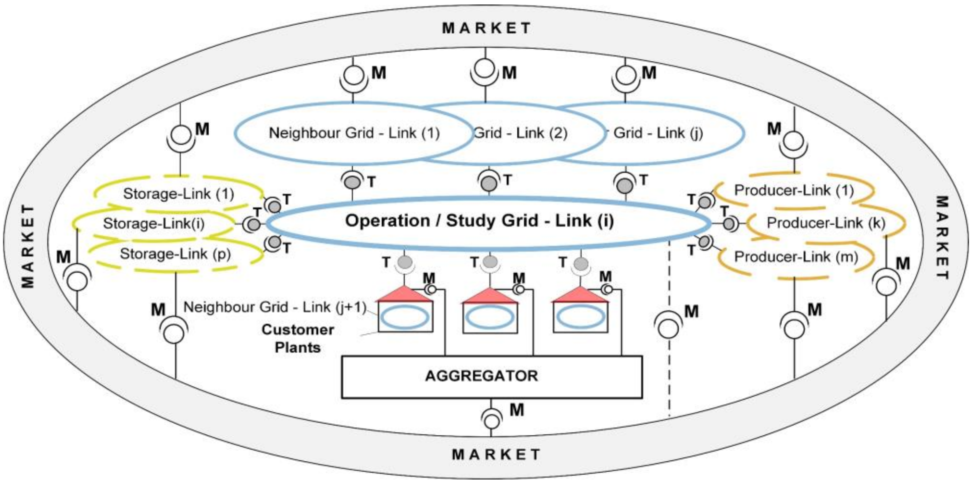


Figure 6: Overview of the *LINK*-based holistic architecture.

The basic of the *LINK*-Economics is the functioning of available advanced technologies of management systems and optimal investment. The accumulated knowledge and the available technologies for the operation of power systems is useful to *LINK*-Solution. However, it has some unique aspects that require innovations. New online and real time applications will be designed and developed to ensure reliable and resilient operation through the dynamic optimisation in each Link.

Considerations

During ZUQDE project a small part of the *LINK*-based holistic architecture[9] is successfully implemented and proofed on field. The main purpose of designing this architecture is the large scale DER integration, guaranteeing data privacy and cyber security. The *LINK*-Paradigm allows the design of a straightforward holistic architecture with standardised structures. The data needed to be exchanged to achieve a reliable, economic and environmental-friendly power supply are minimised and well defined. All processes that are needed to successfully operate the future power system are considered. The *LINK*-based holistic architecture accommodates the LECs, guaranteeing the fair market participation of all stakeholders without compromising the secure, economic and the environmental-friendly supply of electricity.

In conclusion, ETIP SNET finds that the *LINK*-based holistic architecture is comprehensive and promising. However, on-site some basics are realised on a reduced scope. Therefore, it is important to proof the concept on-site by implementing the full holistic architecture. This will highlight its strengths and help to formulate concrete steps for its large-scale implementation.

[9] For more details see the long version: https://www.etip-snet.eu/wp-content/uploads/2019/03/ETIP-SNET_HolisticArchitecture_2019_03_03_Final-UPDATE2.pdf

About ETIP-SNET

Find out more at: https://www.etip-snet.eu. European Technology & Innovation Platforms (ETIPs) have been created by the European Commission in the framework of the new Integrated Roadmap Strategic Energy Technology Plan (SET Plan) by bringing together all the interested and involved stakeholders and experts from the energy sector. The ETIP Smart Networks for Energy Transition (SNET) role is to provide advice on foreseeably important Research, Development & Innovation (RD&I) to support Europe's energy transition, more specifically, its mission is to:

- Set-out a vision for RD&I for Smart Networks for Energy Transition and engage stakeholders in this vision.
- Prepare and update the Strategic Research and Innovation Roadmap.
- Report on the implementation of RD&I activities at European, national/regional and industrial levels.
- Provide input to the SET Plan action 4 which addresses the technical challenges raised by the transformation of the energy system.
- Identify innovation barriers, notably related to regulation and financing.
- Develop enhanced knowledge-sharing mechanisms that help bring RD&I results to deployment.
- Prepare consolidated stakeholder views on Research and Innovation to European Energy Policy initiatives.

All illustrations and their descriptions published in this white paper originate from deliverables or papers published in the context of the respective projects.

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