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Minimization of exchanged data on the TSO-DSO cross border by the application of a new operation architecture

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SUMMARY

Traditional power system architecture together with the appertaining Grid Code has facilitated for a long time already a reliable, stable and efficient grid operation. However the rise of distributed generation have created big operation challenges in all grid parts: in distribution as well as in transmission. In those conditions the coordination between TSOs, DSO, and Significant Grid Users is of vital importance for maintaining the security and quality supply.
This paper shows how a new architecture impacts the requirements of the Network Code on Operational Security. The distributed *LINK*-based operational architecture is derived from a holistic model of power systems and the *LINK*-Paradigm. It includes all voltage levels and even costumer plants by allowing the full description of all smart power systems operation processes. Power systems are perceived by three main components: grid, producer and storage. Storage is split out from the traditional producer component and have created its own main component. This is done because of the recent advances in storage technologies and their vast diversity. From the main power system components and the *LINK*-paradigm are derived three architecture components: the "Grid-Link", the "Producer-Link", and the "Storage-Link". The proposed distributed *LINK*-based architecture establishes a suitable framework for the effective exchange of operational information between TSOs, DSOs and Significant Users. The number of exchanged data on the TSO-DSO border are reduced considerably. TSO and DSO shares only a small set of absolutely necessary electrical data with each other. Therefore the danger of cyber-attacks from outside is reduced drastically. Inter alia the proposed distributed *LINK*-based architecture postulates the change and simplification of Network Code on Operational Security.

KEYWORDS

Grid Code, Overall model, Smart grid, Smart grid architecture, Smart Grid Paradigm, Smart grid security, Technical functional architecture.

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INTRODUCTION

The traditional power system architecture in combination with the corresponding Grid Code has enabled for more than a century a reliable, stable and efficient grid operation. However the rise of distributed generation and the usage of the volatile energy resources like wind and photo voltaic have created big operation challenges on all parts of grids: in distribution as well as in transmission [1-4]. The coordinated operation of the transmission and distribution system has now become more and more difficult [5, 6]. Therefore, in retention-of the traditional architecture an extension of grid code on operational security is necessary [7].

This paper shows how a new architecture impacts the requirements of the grid code on operational security. The new *LINK*-based operational architecture is derived from a holistic model of power systems [8] and the *LINK*-Paradigm [9]. It includes all voltage levels and even costumer plants by allowing the full description of all smart power systems operation processes such as load-frequency balance, voltage assessment, static security, angular and voltage stability, demand response, etc. The necessary exchanged data on the TSO-DSO border are well defined based on the power systems operation processes. Therefore, the number of exchanged data on the TSO-DSO cross border are drastically reduced.

POWER SYSTEM OVERALL MODEL

The integration and the effective use of all available resources on the grid is possible only under a global view of power systems. A holistic, technical approach of power systems called “Energy Supply Chain Net” and the corresponding *LINK*-paradigm are shown in Figure 1. Power grid is arranged in autonomous parts as links in a chain net. Per definition a “Energy Supply Chain Net” is a set of automated power grids, intended for chain links, abbreviated links, which fit into one an-other to establish a flexible and reliable electrical connection. Each individual link or a link-bundle operates autonomously and have contractual arrangements with other relevant boundary links, link-bundles, and suppliers which inject directly to their own grid [8]. Power grid is divided into two parts: transmission which includes High Voltage Grid (HVG) and distribution, which includes Medium Voltage Grid (MVG) and Low Voltage Grid (LVG). Customer Plants have also their own Grid (CPG) where are connected different devices. *LINK*-paradigm is derived from the “Energy Supply Chain Net” model. It is defined as a composition of an electrical appliance (be a grid part, producer or storage), the corresponding controlling schema and the Link interface [9].

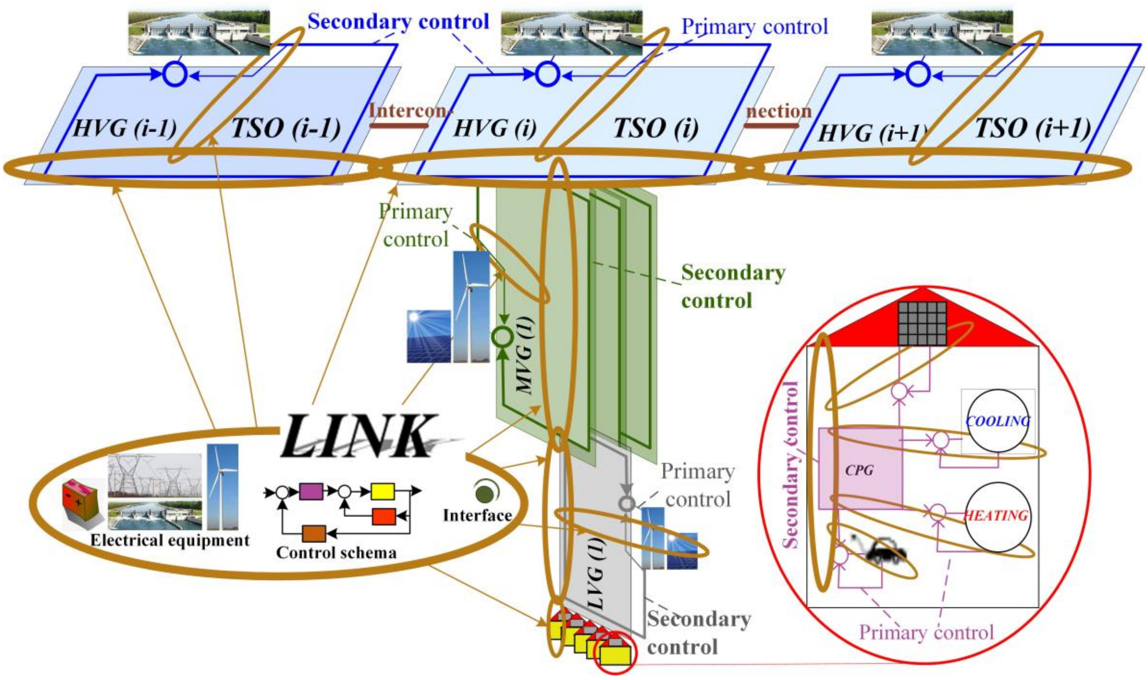

Fig. 1 Overview of the *LINK*-paradigm and the “Energy Supply Chain Net” – overall, technical power system model.

LINK – BASED ARCHITECTURE

Historically power systems are perceived as assembly of three main components: Power plants, Grid and Consumers, Figure 2a). Electricity storage, almost in form of pumped hydro storage, is historically presented as part of the power plants component. Nowadays storages are undergoing an intensive development process. Diverse technologies are developed and they are available in different sizes. Therefore storages can be integrated in any grid voltage level. Due to these developments and their technologies diversity storages are split out from the producer main component. In the new electricity era storage is perceived as an own, main component of power systems [10]. Figure 2b) shows the main components of power systems in the new electricity era. Main component Consumers is transformed to Prosumers.

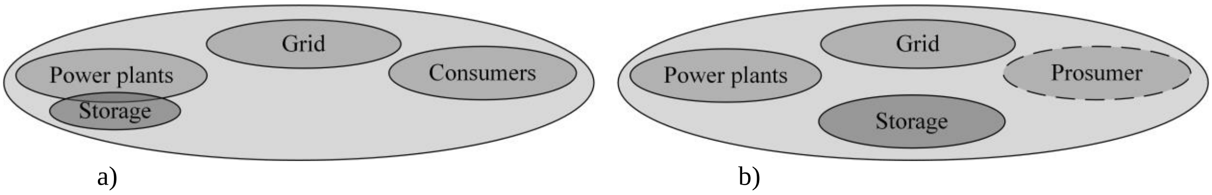

Fig. 2 Main components of power systems: a) historically and b) in the new electricity era.

Based on *LINK*-paradigm and the main components of power systems in the new electricity era are defined three main architecture components: 1. Producer-Link; 2. Grid-Link; and 3. Storage-Link.
The Producer-Link is defined as a composition of an electricity production facility be a generator, photovoltaic, etc., its Primary-Control and the Producer_Interface. The Storage-Link is defined as a composition of a storage facility be the generator of a pump power plant, batteries, etc., its Primary-Control and the Storage_Interface. The Grid-Link is defined as a composition of a grid part, called Link-Grid, the corresponding Secondary-Control and Grid_Interface. The Link-Grid size is variable and is defined from the area, where the Secondary-Control is set up. Thus, the Link Grid may include for e.g. one subsystem (the supplying transformer and the feeders sup-plied from it) or a part of the sub-transmission network, as long as the secondary control is set up on the respective area. As a result, depending on its size the Link may represent a costumer plant or even a large high voltage grid. As per definition, the Link-grid is upgraded with secondary control for both major entities of power systems frequency and voltage. Its algorithm needs to fulfil technical issues and calculate the set points by respecting the dynamic constraints which are necessary to enable a stable operation. Actually, the Link-grid own facilities, transformers and the reactive power devices are almost up graded with primary/local control. Thus the secondary control will send set points to own facilities and to all entities connected at Link-grid boundaries.
Data privacy and big data transfer are the two biggest challenges which the smart grids technologies are facing today. To overcome these two challenges, i.e. to guarantee the data privacy and to minimize the number of relevant data which need to be exchanged, the distributed *LINK*-based architecture [9] is chosen. Figure 3 shows the *LINK*-based technical functional architecture of power systems in the new electricity era. The key principle of this design is to prohibit access to all resources by default, allowing access only through well-defined boundary nodes, i.e. interfaces. Grid-Link is set up on the all three voltage level grids: i.e. on LVG, MVG and HVG. Additionally, it is set up also on the costumer plant grid. Thus, for the first time, Secondary-Control is used as a sustainable, resilient, base interaction instrument on a large scale throughout the different regions or portions of the grid. Grid-Links as autonomous parts are not lined up only on itself, but also in relations with the outside (neighbours Links) which are selected by design. In specific conditions each Grid-Link can disconnect and act self-sufficient and –sustaining. Storage- and Producer-Links are connected to the respective Grid-Links of all voltage levels. All Grid-Links communicate with each other via the Grid-Link interfaces. Grid-, Producer-Link interface and Grid-, Storage-Interface are also defined to guarantee a smooth interaction within the power system [9]. Accordingly, to ensure a stable and reliable operation of the Grid-Link, the power flow exchange at the boundary nodes and the neighbours' behaviour in contingency and emergency case should be known at every moment. Also, when a Grid-Link needs to

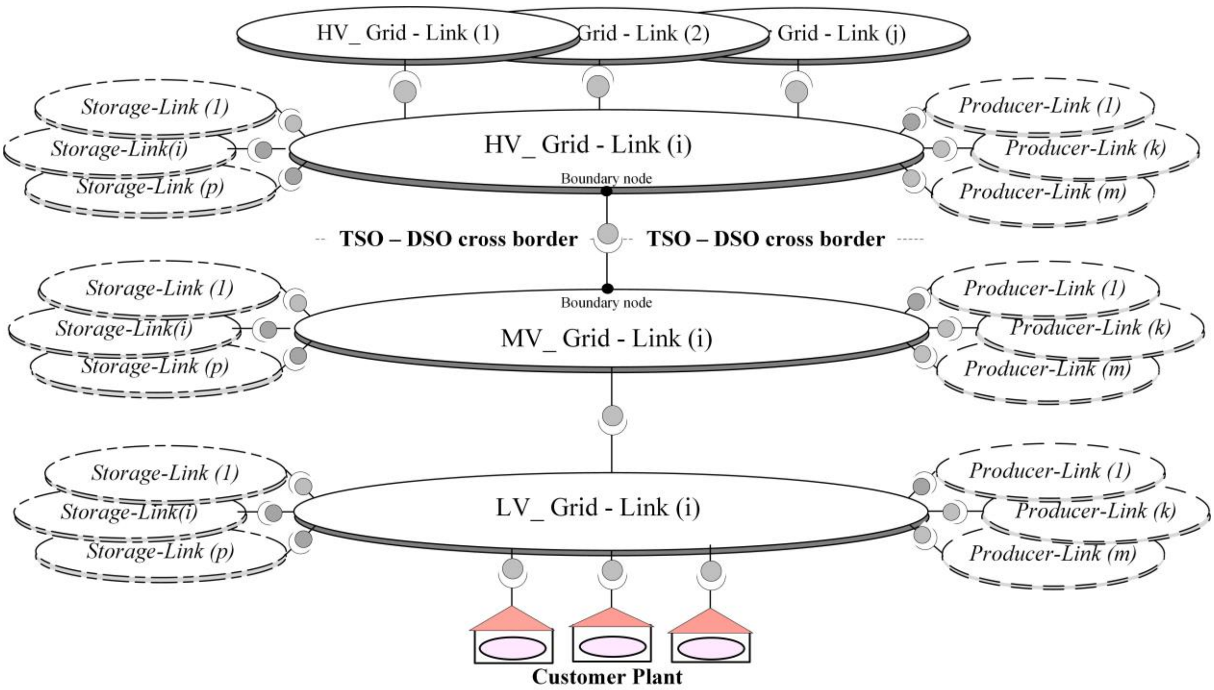

Fig. 3 *LINK* – based technical/functional architecture of power systems in the new electricity era.

optimize or adapt the operation under the prevailing circumstances, it shall exchange the predefined information by using the appropriate interface.

Finally, each Grid-Link shares only a small set of absolutely necessary electrical data with the neighbouring units, and the rest of the information is used only locally. The danger of cyber-attacks from outside is thereby reduced drastically.

TSO-DSO CROSS BORDER INTERFACE

Cooperation between TSOs and DSOs should be promoted as cornerstone of such an electric power supply system, which is necessary for integrating all available resources in an efficient and sustainable way [7]. Figure 3 shows the TSO-DSO cross borders in the case of *LINK*-based architecture. The interface between the HV_ and MV_Grid-Link denotes the instrument for the coordination between the TSOs and DSOs. Interface parameters are defined based on a meticulous investigation of all

Table 1 Interface parameters on the TSO-DSO cross border

Operation processes	**Data exchange between HV_Grid-Link and MV_Grid-Link**
Monitoring	$f_{\mathrm{meas}}, V_{\mathrm{meas}}, \delta_{\mathrm{meas}}, P_{\mathrm{meas}}, Q_{\mathrm{meas}}$
Load-generation balance	$P_{Schedule}^{dayahead} \pm \Delta P$, $P_{des}^{nexthour} \pm \Delta P$
Voltage assessment	$Q_{Schedule}^{dayahead} \pm \Delta Q$, $Q_{des}^{nexthour} \pm \Delta Q$
Short circuit calculation	$I_{\mathrm{equiv}}, Z_{\mathrm{equiv}}$
Static security (n-1)	$I_{\mathrm{equiv}}, Z_{\mathrm{equiv}}$
Dynamic security (angle, voltage)	Static and dynamic load characteristic k_{PV}, k_{QV}, k_{Pf}, k_{Qf} … Dynamic equivalent Generator parameters like x_d, x'_d, …, T'_{d0}, … Equivalent governors, turbine parameters like K_1, T_{G1}, … Equivalent voltage regulator, static exciter parameters like K_A, T_A, …
Reserve management	Schedule for secondary, tertiary reserves
Demand response	Schedule for demand response capability

processes, which are needed to be performed for the safe, reliable and efficient operation of power systems. In Table 1 are shown all power system operation processes and the corresponding interface parameters on the TSO-DSO cross border, which are needed to perform them. E.g. the exchange of the real time values V_{meas}, $\delta_{meas,}$ P_{meas}, Q_{meas} on boundary nodes are necessary for the monitoring process. Frequency f_{meas} is also necessary for this process almost in the case when MV_Grid-Link operates autonomously. Docking of the MV_Grid-Link into the HV_Grid-Link requires a synchronisation process, therefore a frequency monitoring of both Links. For the load-generation balance process are necessary $P_{Schedule}^{dayahead} \pm \Delta P$ and $P_{des}^{nexthour} \pm \Delta P$. For voltage assessment are necessary $Q_{Schedule}^{dayahead} \pm \Delta Q$ and $Q_{des}^{nexthour} \pm \Delta Q$. For the short circuit calculation and static security processes are necessary the online calculated parameters like I_{equiv} and Z_{equiv}. For the dynamic security (angle, voltage) calculation process are necessary the online calculated parameters like dynamic equivalent generator parameters, etc. [9]. For the reserve management and demand response processes are necessary different schedules for secondary, tertiary reserves and demand response capability.

IMPACT ON THE GRID CODE

One of the main goals of the distributed *LINK*-based architecture is the minimization of the exchanged data. Figure 5 shows the data flow from DSO to TSO in two cases: A) Actual power system operational architecture combined with the Grid Code [7], Figure 5a) and 5b), and B) Distributed *LINK*-based architecture. There are n Significant Grid Users, SGU, connected on the MVG-part that have only one connection point with the HVG. Based on [7] Article 25, each SGU shall provide three kind of schedules: (1) the scheduled unavailability; (2) the forecasted scheduled active output at the connection point in distribution grid and (3) any forecasted restriction in the reactive power control capability. In Article 29 are described two communication variants: firstly all schedules may be communicated by each SGU directly to its TSO and DSO, Figure 5a). Or secondly, they may be communicated via its DSO to the TSO, Figure 5b). Therefore, TSO will receive $3 \cdot n$ schedules in both variants of case A. Figure 5c) shows the data should be changed by using the decentralized *LINK*-based architecture, case B. In this case the SGU owners should exchange the data only with the operator of the Link where they are connected. Due to the enclosed nature of the links, the TSO shouldn't get any information about the network users, who are connected directly to the distribution grid. That means they should communicate only with the DSO. The TSO will receive the required scheduled data from the DSO. The exchanged data are the day a head scheduled active and reactive power and the corresponding active and reactive power support $P_{dayaheadSchedule} \pm \Delta P$, $Q_{dayaheadSchedule} \pm \Delta Q$,

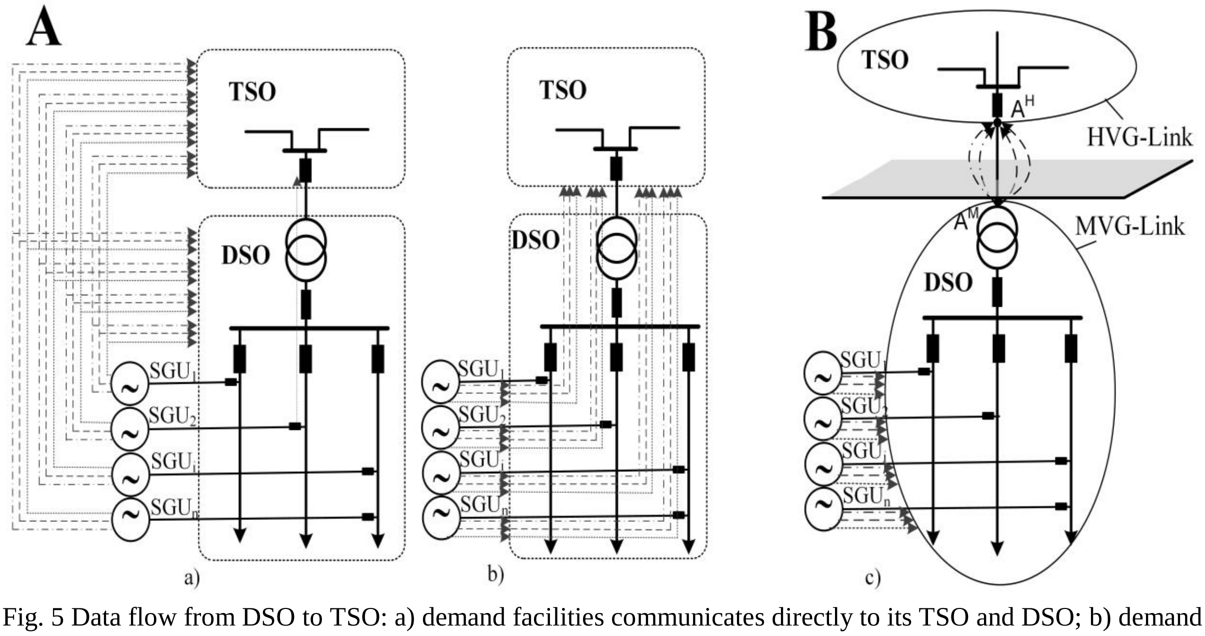

Fig. 5 Data flow from DSO to TSO: a) demand facilities communicates directly to its TSO and DSO; b) demand facilities communicates via its DSO to the TSO; c) data exchange in the case of *LINK*-based architecture.

that flow in the intersection point HV/MV; $A^H A^M$. The number of the data should be exchanged is always 4. As result, the scheduled data amount that should be exchanged in the case of the traditional architecture combined with the Grid Code increases continuously with SGU number by $3 \cdot n$, while in the case of distributed *LINK*-based architecture the number of exchanged schedules is independent from the SGU number. They remain constant at 4.

CONCLUSION

Coordination between TSOs, DSO, and Significant Grid Users is of vital importance for maintaining the security and quality supply with the rising share of electricity from renewable energy sources and developing Demand Response, both at the transmission and the distribution level. In Grid Code are defined almost fix parameter ranges, which are setting rigid barriers and allow no flowing optimized process of all its parts. With the increasing share of decentralised generation the number of rules is increasing

The proposed distributed *LINK*-based architecture establishes a suitable framework for the effective exchange of operational information between TSOs, DSOs and Significant Users. The number of exchanged data on the TSO-DSO border are reduced considerably. TSO and DSO will share only a small set of absolutely necessary electrical data with each other. The danger of cyber-attacks from outside is thereby reduced drastically.

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