Smart grid functionality for the high-voltage transmission grid: On the market readiness of Digital Substation technology

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ABSTRACT

The energy challenges the world is facing will fundamentally change the electricity supply infrastructure. The basic architecture of the primary grids has been developed to meet the needs of large and predominantly carbon-based or nuclear generation technologies. The transition towards a more sustainable electricity supply requires a flexible and smarter power infrastructure, prepared to cope with the massive growth of renewable generation and the correlated bi-directorial load and information flows. As most smart grid initiatives today only cover low and medium voltage levels, the present contribution highlights the technological advancements taking place in high voltage transmission. The digital substation concept represents a smart grid enabling technology necessary for a power infrastructure based on bulk renewable infeed.

***Index Terms* — Smart grid, automated grid control, data analytics, centralized asset management**

INTRODUCTION

Grid-integrated renewable generation mainly by wind and solar affects the operational characteristics of the existing power infrastructure because of the stochastic nature of the sources. With an increasing share of fluctuating renewable infeed, the dynamics and complexities in operating the electric power supply systems continuously rise. To cope with the enhanced requirements and to enable a near real-time and high-resolution information flow, next-generation energy networks based on innovative digital infrastructure are necessary.

TOWARDS A SMARTER POWER INFRASTRUCTURE

Currently, energy systems undergo a dramatic change: from monopoly power supply to deregulated markets and from downstream power delivery to smart distribution. Two-way flow of electricity and information between power network and prosumers becomes a reality.

The first official definition of "Smart Grid" was provided by the Energy Independence and Security Act of 2007, approved by the US Congress in the same year [1]. The European Regulators Group for Electricity and Gas stated that a fully-functioning smart grid will exploit communication networks to "cost-efficiently integrate the actions of all users connected to it – generators, consumers and those that do both – in order to ensure an economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety." A corresponding conceptual model is shown in Fig. 1.

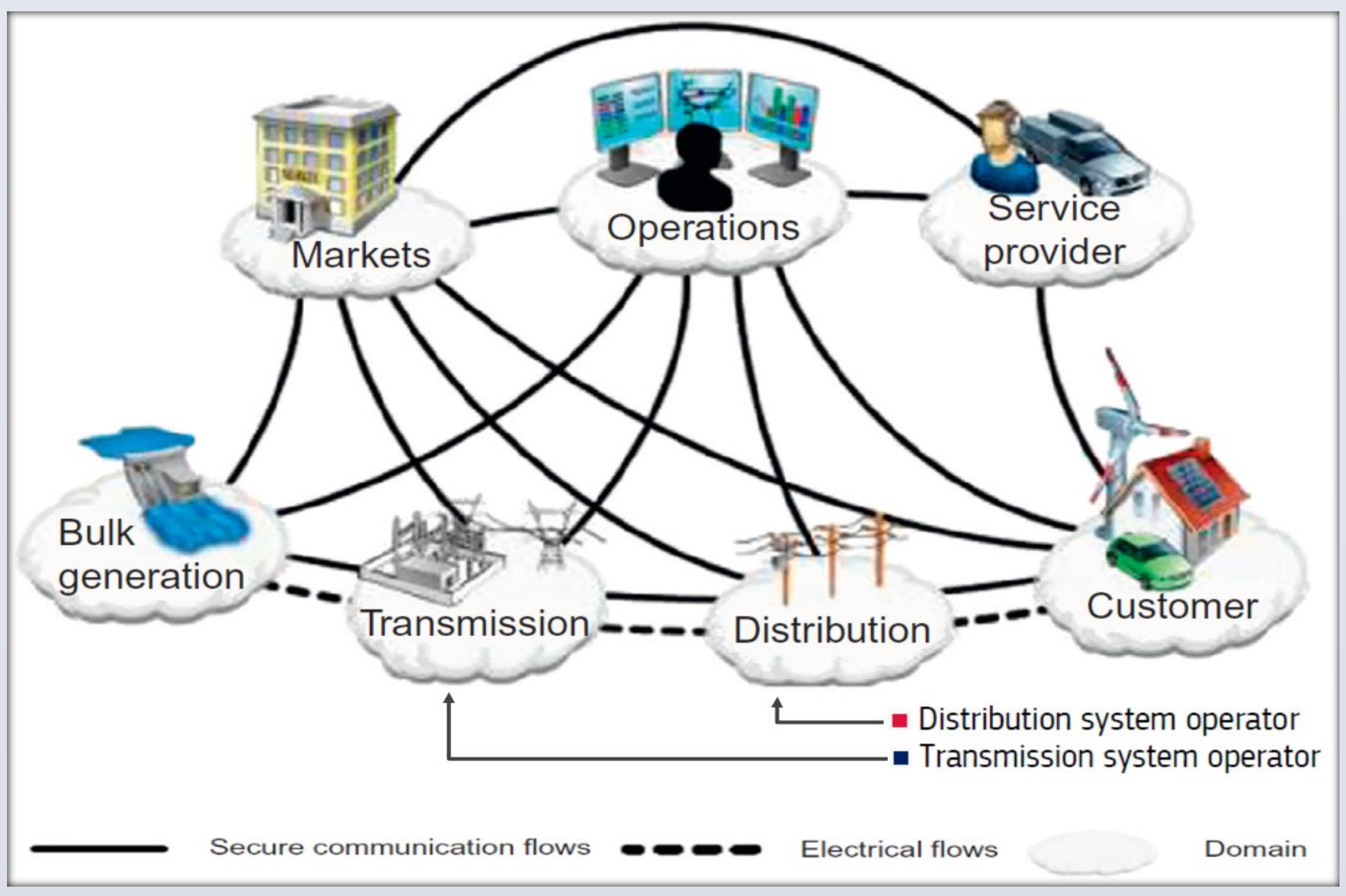

Fig. 1: The concept of smart grid [2, adapted]

Smart grid comprises the comprehensive modernization of the electrical power infrastructure consisting in the integration of various technologies, such as decentralized renewable generation, next-generation communication systems and grid-scale storage to deliver sustainable, economic and secure electricity. As outlined in detail in [3], smart grids allow the increasing penetration of renewable resources and the participation of consumers in the network operation, help to decrease the transmission and distribution losses and subsequently to lower the energy cost for customers.

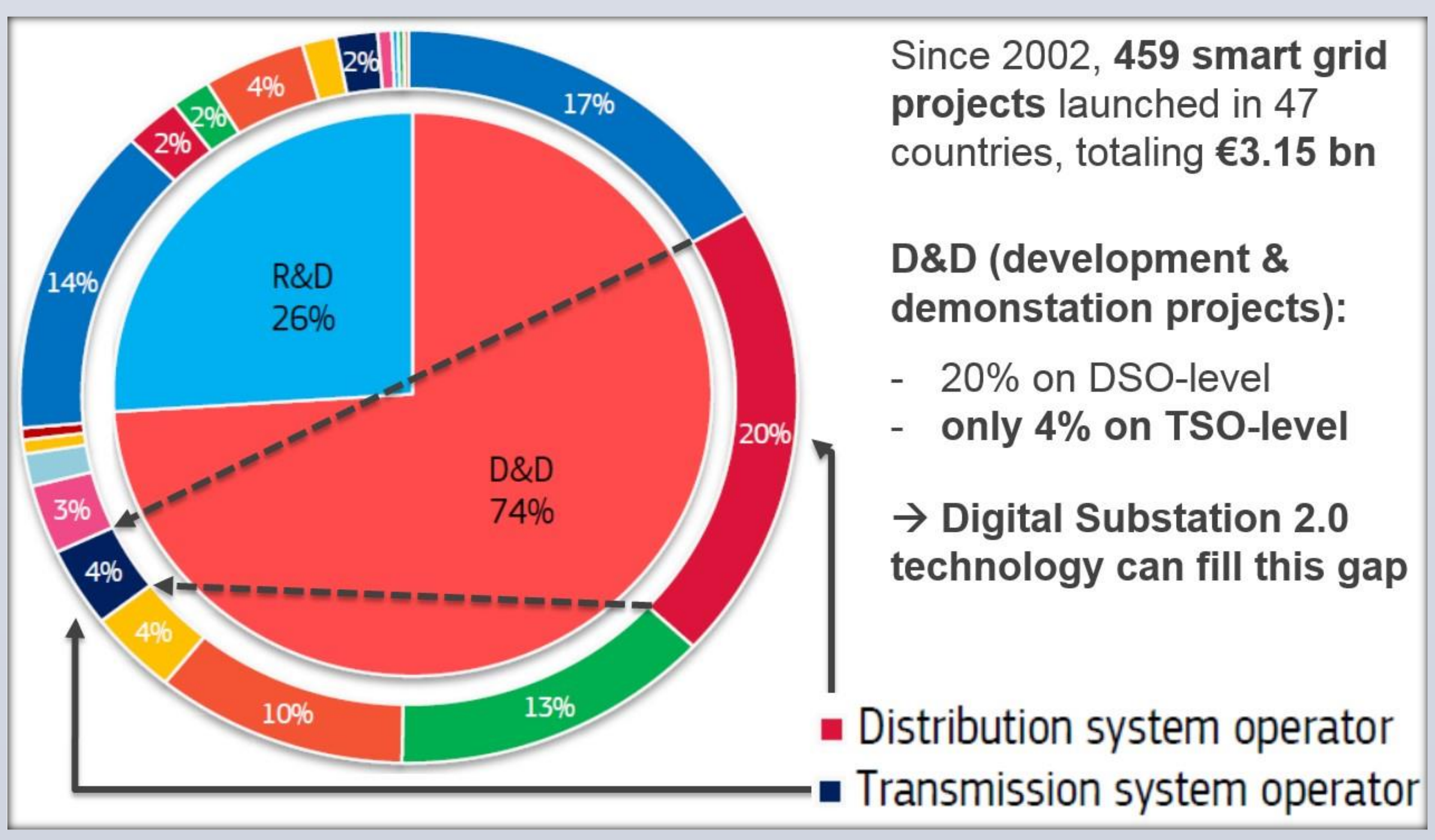

Fig. 2: Distribution of smart grid RD&D projects as per voltage levels [4]

As per the above referenced European Commission study, the majority of performed smart grids RD&D projects cover the distribution system voltage level and (still) not the transmission level of above 110 kV (Fig. 2).

LIMITATIONS BY CONVENTIONAL SUBSTATIONS

Existing medium and high voltage substations provide little flexibility for adopting new functionalities, increasingly required by external information systems [5-7]. It is difficult to implement retrospective additions of monitoring, protection and control. A further negative aspect is the limited interoperability due to vendor-specific designs. The mostly inadequate quality of measurements prohibits automated grid control functions and wide area monitoring. Regarding health and safety aspects, the cabling between the current transformers and the secondary equipment creates an inherent safety hazard in case of an open circuit situation.

INNOVATION BY DIGITAL SUBSTATION TECHNOLOGY

Digital data communication via station bus between the substation central control and the bay control / protection is standard since years. A key novelty by Digital Substation technology is that now also the primary equipment as well as the protection, control and monitoring devices are digitally connected via process bus. Binary communication based on fibre optic cables replaces traditional copper wiring using analog signals. Further key aspects of Digital Substations are:

- Intelligent electronic devices (IEDs) for protection and control of transformers, circuit breakers, etc.;
- Novel measurement principles by non-conventional instrument transformers (NCITs);
- Functionality to support wide-area control infrastructure (quality & latency requirements); and
- Multi-vendor interoperability.

Smart substations are characterized by providing a higher operational flexibility and allow operation closer to design limits. Automated grid control and monitoring of T&D networks enable the further integration of renewables. Cost-benefit analyses show significant OpEx reduction potential by risk- or condition-based maintenance and fewer constraints by planned outages. The stress-dependent determination of residual life enables the transition from "break-and-fix" to "predict-and-prevent" operation and maintenance concepts. The potential for CapEx reduction is highly project-specific.

TECHNOLOGY READINESS LEVEL & MARKET SITUATION

Substations of up to 400 kV using process bus and non-conventional instrument transformers are in operation. The digitization on the process level has started and global operational experience now has to be gained. Out of the number of manufacturing firms offering corresponding equipment and services, in the course of questionnaire-based semi-structured interviews with 3 multinational corporations, the market readiness of the solutions was independently assessed. The intention was to identify, what equipment is available on the market, what was successfully implemented and is in operation and what is presently still under research and development.

SEQUENTIAL FAMILIARIZATION BY PILOT PROJECT

DSOs/TSOs increasingly request data-intensive analytics from power producers aiming on realizing smart grid functionalities. In the course of the technology convergence process and the manufacturing trend towards process bus with IEDs and NCITs, cost will decrease.

Considering a first-time utility rollout, it is recommended to implement a pilot bay or reference substation to get familiar with the technology and to exploit cost saving potentials. Extensive factory and site testing is recommended. The procedure of factory and site testing will change in so far as the practice of secondary injection is no longer applicable. Parallel to the process bus, copper wiring is recommended for critical signals. This level of conventional backup is recommended for the transition phase.

CYBER SECURITY

The increasingly high standardization of hard- and software makes modern information and communications technology as well as automation and control systems vulnerable to cyber-attacks [8]. Consequently, critical power infrastructure needs to be secured against such risks. Because the operating period of substation control systems is longer than the innovation cycle of IT and OT products and applications, cyber security has to be designed to protect and secure equipment outside the life-cycle of the basic software products and operating systems.

CONCLUSION

Digital Substation technology represents a step-change innovation and is close to the market breakthrough. It represents a smart grid enabling technology necessary for a power infrastructure based on bulk renewable energy infeed. Digital substations are critical for the efficient integration of renewable generation by centralized monitoring of T&D networks and automated grid management. Already today, high-performance tools can provide decision-making support for critical network operation and outage management.

The technology ensures improved asset performance by cloud-based data analytics. The prioritization of service efforts based on the equipment condition and its strategic relevance helps to optimize operational expenditure. By the transitional overloading of high voltage equipment (i.e. transmission lines, transformers), supply peaks that may occur during periods of strong wind or high solar radiation can be benefitted from. Costly peak shaving can be reduced and the overall efficiency of renewable-based power systems is increased.

For a first-time utility rollout, it is recommend to implement a pilot bay or reference substation to get familiar with the technology. Before investing, we see the need to perform an independent market research on the actual technology readiness level and the supplier reference situation.

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