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A survey on the critical issues in smart grid technologies

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ABSTRACT

The hierarchical and the centrally-controlled grid topology of existing electrical power systems has remained unchanged over the 20th century. On the other hand, there is a rapid increase in the cost of fossil fuels coupled with the inability of utility companies to expand their generation capacity in line with the rising electricity demand, without modernizing the grid. For these reasons, it is needed to modernize the existing power grids and consequently smart power grids have emerged. Unlike the benefits and features ensured by smart grids, this paper provides a detailed survey of the critical challenges in smart grids in terms of information and communication technologies, sensing, measurement, control and automation technologies, power electronics and energy storage technologies. It is expected that this paper will lead to the better understanding of potential constraints in smart grid technologies.

Contents

1. Introduction

A traditional power grid focuses on the generation, transmission, distribution and control of the electricity [1]. In addition, the existing electrical grids have an electromechanical structure, one-way communication, centralized generation, fewer sensors, manual recovery, manual checks/test, some degree of control and fewer customer choices [2]. However, a smart power grid is an intelligent electrical network used for improving efficiency, sustainability, flexibility, reliability and security of the electrical system by enabling the grid to be observable, controllable, automated and fully integrated [3–5]. In contrast with the existing electrical grids, the intelligent electric grids have digital structure, two-way communication, distributed generation, numerous sensors, self-monitoring, self-healing capabilities, remote checks/tests, pervasive control and many customers [2]. Moreover, a smart electricity grid opens the door to new applications with far-reaching impacts: providing the capacity to safely integrate more renewable energy sources, electric vehicles and distributed generators into the network; delivering power more efficiently and reliably through demand response and comprehensive control and monitoring capabilities; using automatic grid reconfiguration to prevent or

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Nomenclature

Wi-Fi	Wireless-fidelity
WiMAX	Worldwide interoperability for microwave access
QoS	Quality of service
GPRS	General packet radio service
EDGE	Enhanced data rates for gsm evolution
HSPA	High-speed packet access
EVDO	Evolution-data optimized
LTE	Long-term evolution
IPsec	Internet protocol security
MPLS	Multi-protocol label switching
IGP	Interior gateway protocol
DoS	Denial of service
DNP	Distributed network protocol
HMI	Human–machine interface
GPS	Global positioning system
IG	Induction generator
SG	Synchronous generator
MVDC	Medium voltage direct current
APF	Active power filter
DVR	Dynamic voltage restorer
UPQC	Unified power quality conditioner
DFM	Doubly-fed induction machine
TCR/FC	Thyristor-controlled reactor with fixed capacitor
R&D	Research and development
NaS	Sodium–sulfur
NiCd	Nickel–cadmium
NiMH	Nickel–metal–hydride
NaNiCl	Sodium–nickel–chloride
Zn-Air	Metal–air
ZnBr	Zinc–bromine
ZnCl	Zinc–chloride
SMES	Superconducting magnetic energy storage
EDLC	Electrochemical double layer capacitor
PHES	Pumped hydroelectric storage
CAES	Compressed air energy storage
IED	Intelligent electronics device
AC	Alternating current
HVDC	High voltage direct current
PMU	Phase measurement unit
PLC	Power line communication
SPS	Static phase shifter
VPN	Virtual private network
FC	Fixed capacitor
ICT	Information and communication technologies
LCL	Bobbin–capacitor–bobbin
PV	Photovoltaic
PWM	Pulse width modulation
VAR	Volt ampere reactive

restore outages; enabling consumers to have greater control over their electricity consumption and to actively participate in the electricity market [2,6–11]. The evolutionary process of smart grids is illustrated in Fig. 1.

European electricity consumption is projected to increase at an average annual rate of 1.4% up to 2030 and it is needed to replace ageing electricity grids with intelligent ones for meeting the growing electricity demand [13,14]. In case of investigating the smart grid reports prepared by the Joint Research Centre (JRC) of European Commission [11,15], 459 smart grid projects are developed in 47 countries as of 2014. The discriminating criterion for including a smart grid project in the JRC's database is the involvement of at least one partner from the European Union; this brought to the total number of 47 countries featured in that study. 211 of them are R&D (Research and Development) projects with a total budget of around €830 million. The rest of them include demonstration and deployment projects with a total budget of around €2320 million. More than 50% of all projects are situated in seven countries: Denmark, Germany, Italy, Austria, United Kingdom, France and Spain. France, UK, Germany, Spain and Italy are the leading investors in smart grid projects. Denmark is the country most actively involved in R&D projects, supporting a large number of small-scale projects. Denmark is also the country that spends the most on smart grid projects per capita and per kWh consumed.

According to the mentioned reports, project budgets have been rising steadily. The investment share for the projects with budgets bigger than €20 million grew from less than 30% in 2006 to about 60% in 2012. In 2006, projects with budgets below €20 million accounted for more than half % of the total investment. In 2012, this share shrank to less than 40%, in favor of large and very large scale projects, which now represent the bulk of investments in smart grid projects. This implies that the smart grid technology has reached a mature stage and investors do not see it anymore as something risky. The mentioned reports include around 170 projects (51% R&D) carried out by multinational consortia. An analysis of the countries involved in these projects provides an interesting representation of the relations between smart grid players in different European Union countries. Organizations from France, Spain and Germany are the most active in multinational projects. Italy and the UK also have a high number of collaboration links, particularly with Spain, France and Germany. A second group of

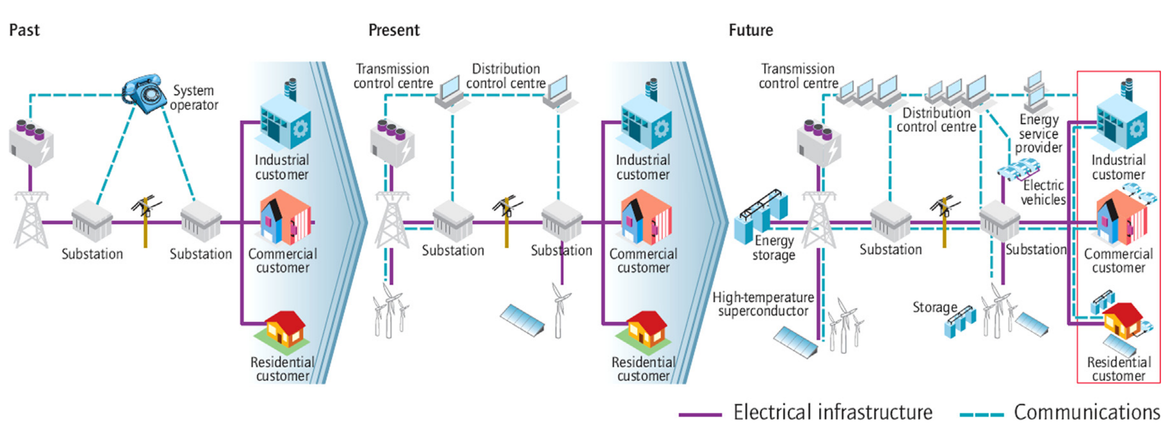

Fig. 1. The evolutionary process of smart grids [12].