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Foreword

The development of Smart Grid is a global trend. The activities in different parts of the world reflect the regional resources and needs. We have seen large scale integration of wind generators and solar energy devices into the power grids. Very large off-shore wind farms are on the horizon. Increasingly automated and intelligent distribution systems are in operation in various countries. On the transmission side, a significant number of Phasor Measurement Units (PMUs) are now collecting a massive amount of information for monitoring of power system dynamics. Demand side response and other programs for customers' choice are being developed and enhanced by the power industry. To enable the demand side response and customers' services, millions of smart meters are acquiring the customers' electric energy consumption data. These new smart features of the power grid rely on the information and communications technology (ICT) that brings critical connectivity for all elements of the Smart Grid. The increasing degree of integration in a Smart Grid from renewable generations to the power grid, from transmission to distribution, and from smart meters to the distribution system brings a new vision and opportunities for the future power grids. Although we are well under way toward this unprecedented creation, it is also important to recognize the challenges that Smart Grid development is facing from the diverse viewpoints of technology, economics, sociology, and public policy.

The scope of Smart Grid is wide and the complexity is great. There is a growing literature about various aspects of research, development, deployment, and operating experience. However, there is a great need for a comprehensive source of knowledge that spans the spectrum of Smart Grid subjects. This book, "Smart Grids—Fundamentals and Technologies," represents a timely and significant step in our long journey to an ultimate Smart Grid. The vast amount of knowledge as well as industry and leadership experience represented in this book serves as the foundation for an excellent source for practicing engineers, researchers, managers, and policy makers to learn about the exciting field of Smart Grid.

This book is organized in a logical flow of subjects. The vision of the future power grid is articulated in Chap. 1. In Chap. 2, various renewable energy and storage devices are discussed. New technologies for transmission networks and substations are covered in Chap. 3. Chapter 4 is concerned with engineering design of distribution systems including network configurations, grounding, protection, and power quality. The issues of transmission system operation, protection, and control in a wide area are addressed in Chap. 5. The subject of Chap. 6, smart distribution systems, is about the distribution system's capabilities to handle voltage and power flow control, energy management, feeder protection and recovery in an environment with dispersed and renewable devices. Smart metering provides new possibilities for energy markets and consumer's participation. The market design to incentivize stakeholders of electricity supply and demand to follow the Smart Grid strategy is discussed in Chap. 7. The enabling ICT for Smart Grids cannot be an effective support infrastructure unless the critical issues of standards, information and cyber security, and protocols are addressed. Chapter 8 describes the new developments related to ICT. Last but not least, the global development of Smart Grid is summarized in Chap. 9, which reflects the characters and priorities of various regions in the world.

As a professional colleague, I would like to thank Dr. Buchholz and Professor Styczynski for their tremendous effort to bring together this interesting and informative volume. It is a significant contribution to Smart Grid R&D, engineering, and education.

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Acknowledgments

The transformation of the existing electric power systems into Smart Grids is currently embedded in worldwide development and investment programs. This book describes the challenges of the electricity supply in the future and specifies the drivers, the fundamentals, the concepts and technologies of Smart Grids. Special attention is paid to practical experiences. The additional needs and challenges to be solved as well as visions and innovations for the future are also presented in order to offer the readers the main ideas of the Smart Grid concepts for generation, transmission, distribution and consumption.

The book summarizes the experiences of the authors over the last two decades concerning the research and development from both sides (industry and academia) at the Siemens AG and at the Otto- von Guericke University Magdeburg, the leading of national expert groups, the management of practice related Smart Grids projects and the participation in international study committees or working groups (e.g. CIGRE, CIRED European advisory council for the technology platform Smart Grids, IEC, IEEE, VDE).

The initial idea for this book was born in 2012 as a result of the Russian Mega Grant No.132 and the initiation of the project "Baikal—Smart Grid Technologies". The main objective of this project "Baikal" was to introduce an education program regarding the Smart Grid technologies into the Russian research community. The authors are grateful to the Russian Ministry of Education for the opportunity to participate in this program and to Prof. Dr. N. I. Voropai, Director of the Siberian Energy Institute in Irkutsk (member of the Russian Academy of Science), for the discussions regarding the table of contents.

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Germany, Spring 2014

Dr. Bernd Michael Buchholz
Prof. Dr. Zbigniew Antoni Styczynski

Contents

Abbreviations

2DCF	Two-Day Congestion Forecast
AAL	Ambient Assisted Living
AC	Alternating Current
ACER	Agency for the Cooperation of Energy Regulators
ACSI	Abstract Communication Service Interface
AES	Average Energy Saving
AM	Asset Management
AMI	Advanced Metering Infrastructure
ANSI	American National Standards Institute
API	Application Programming Interface
APLS	Average Peak Load Shifting
ASAI	Average System Availability Index
ASN.1	Abstract Service Notation One
BACnet	Building Automation and Control Networks
BB	Busbar
BCU	Basic Currency Unit
BDEW	Federal association for energy and water supply (Bundesverband der Energie- und Wasserwirtschaft)
BGM	Balancing Group Manager
BMU	Federal Ministry for Environment, Nature Conservation and Nuclear Reactor Security (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit)
BMWi	Federal Ministry of Economics and Technology (Bundesministerium für Wirtschaft und Technologie)
BPL	Broadband Power Line
BSI	Federal Office for Information Security (Bundesamt für Sicherheit der Information)
CAES	Compressed Air Energy storage
CAIDI	Customer Average Interruption Duration Index
CAIFI	Customer Average Interruption Frequency Index
CAPEX	Capital Expenses
CB	Circuit Breaker
CC	Control Center

CCG	Central China Grid
CCGT	Combined Cycle Gas Turbine
CDC	Common Data Class
CDV	Committee Draft for Voting
CE	Continental Europe
CEN	European Committee for Standardization
CENELEC	European Committee for Electro-technical Standardization
CHP	Cogeneration of Heat and Power
CID	Configured IED Description
CIGRE	Conseil International des Grands Reseaux Electriques
CIM	Common Information Model
CIS	Component Interface Specification
COMTRADE	COMmon format for TRAnsient Data Exchange
COS	Catalogue Of Standards
COSEM	Companion Specification for Energy Metering
CPU	Central Processing Unit
CRC	Cyclic Redundancy Check
CS	Customer Support
CSC	Current Source Converter
CSPGC	China Southern Power Grid Company Limited
DACF	Day-ahead Congestion Forecast
DC	Direct Current
DCC	Distribution Control Center
DER	Distributed Energy Resource
DFIG	Doubly Fed Induction Generator
DIN	German Institute for Standardization (Deutsches Institut für Normung)
DKE	Deutsche Kommission Elektrotechnik, Elektronik, Informationstechnik (German Commission for standardization in the fields of electro-technology, electronics and ICT)
DLMS	Device Language Message Specification Distribution
DMS	Distribution Management System
DOE	Department of Energy (USA)
DSA	Dynamic Security Assessment
DSI	Demand Side Integration
DSL	Digital Subscriber Line
DSM	Demand Side Management
DSR	Demand Side Response
ECG	East China Grid
EDSO	European Distribution System Operators' Association
EEG (REA)	Erneuerbare Energien Gesetz—(Renewable Energy Act)
EEGI	European Electricity Grid Initiative
EESS	Electric Energy Storage Systems
EHV	Extra High Voltage
EIB	European Installation Bonus

EMS	Energy Management System
ENS	Energy Not Supplied on time
ENTSO-E	European Network of Transmission System Operators for Electricity
EPM	Enterprise Process Management
EPRI	Electric Power Research Institute (USA)
ERGEG	European Regulators Group for Electricity and Gas
ESO	European Standardization Organization
ETSI	European Telecommunications Standards Institute
FAT	Factory Acceptance Test
FERC	Federal Energy Regulatory Commission (USA)
FGC	Federal Grid Company (of Russia)
FP	Framework Programme
FRCC	Florida Reliability Coordinating Council
GDOF	General Decision and Optimization Functions
GES	Generic Event and Subscription
GIL	Gas Insulated Line
GIS	Gas Insulated Switchgear (Chap. 3–5)
GIS	Geographical Information System (Chap. 8)
GOMSFE	Generic Object Model for Substation and Feeder Equipment
GOOSE	Generic Object-Oriented Substation Event
GPS	Global Positioning System
GSE	Generic Substation Event
GSM	Global System for Mobile Communications
GSSE	Generic Substation State Event
HAN	Home Area Network
HMAC	Hash Message Authentication Code
HMI	Human Machine Interface
HSDA	High Speed Data Access
HTTP	Hypertext Transfer Protocol
HV	High Voltage
IC	Industrial Computer
ICD	IED Capability Description
ICT	Information and Communication Technologies
IDCF	Intra-Day Congestion Forecast
IEC	International Electrotechnical Commission
IED	Intelligent Electronic Device
IEEE	Institute of Electrical and Electronics Engineers (professional association headquartered in New York City that is dedicated to advancing technological innovation and excellence)
IES-AAS	Intelligent Electro-energy System based on Active-Adaptive Networks (the Russian term for networks is Set)
IID	Instantiated IED Description
IGBT	Insulated Gate Bi-polar Transistor
IP	Internet Protocol

IPS	Integrated Power System
ISDN	Integrated Services Digital Network
ISO	International Organization for Standardization
ISTU	Irkutsk State Technical University
LAN	Local Area Network
LBS	Load Break Switch
LCC	Line Commutated Converter
LD	Logical Device
LED	Light Emitter Diode
LN	Logical Node
LON	Local Operating Network
LTE	Long-Term Evolution
LV	Low Voltage
M-Bus	Meter Bus
MC	Maintenance and Construction
MCC	Mobility Control Center
MENA	Middle East and Northern Africa
MMS	Manufacturing Message Specification
MP	Micro-Processor
MPPT	Maximum Power Point Tracking
MR	Meter Reading
MRO	Midwest Reliability Organization (USA)
MUC	Multi Utility Controller
MV	Medium Voltage
NA	Network Applications
NCG	North China Grid
NE	Network Extension
NECG	North-East China Grid
NEPCC	North-East Power Coordination Council (USA)
NERC	North American Electric Reliability Corporation (USA)
NIST	National Institute for Standards and Technology (USA)
NSM	Network and System Management
NTP	Network Time Protocol
NWCG	North–West China Grid
OBIS	Object Identification System
OE	Office of Electricity Delivery and Energy Reliability (USA)
OHL	Overhead Line
OLE	Object Linking and Embedding
OP	Operational Planning
OPC UA	OLE for Process Control, Unified Architecture
OPEX	Operational Expenses
ORC	Orcanic Rankine Cycle
OSI	Open Systems Interconnection
PAP	Priority Action Plan
PCC	Point of Common Coupling

PDU	Protocol Data Unit
PES	Primary Energy Source
PKI	Public-Key-Infrastructure
PLC	Power Line Communication
PMU	Phasor Measurement Unit
PSA	Protection Security Assessment
PSHPP	Pumped-Storage Hydroelectric Power Plant
PWM	Pulse Width Modulation
RBAC	Role-Based Access Control
RDF	Resource Description Framework
RES	Renewable Energy Source
RFC	Request for Comment
RFC	Reliability First Corporation (USA)
RG	Region
RTD	Research and Technological Development
RTU	Remote Terminal Unit
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SAS	Substation Automation System
SAT	Site Acceptance Test
SCADA	Supervisory Control and Data Acquisition
SCD	Substation Configuration Description
SCL	Substation Configuration Language
SCSM	Specific Communication Service Mapping
SERC	South-East Reliability Corporation (USA)
SET plan	Strategic Energy Technology plan
SFTP	Secure File Transfer Protocol
SGAM	Smart Grid Architecture Model
SG-CG	Smart Grid Coordination Group
SGCC	State Grid Corporation of China
SGIP	Smart Grid Interoperability Panel
SGIS	Smart Grid Information Security
SIL	Surge Impedance Load
SMB	Standardization Management Board
SML	Smart Message Language
SMS	Short Message Service
SNMP	Simple Network Management Protocol
SNTP	Simple Network Time Protocol
SOA	Service Oriented Architecture
SOC	State Of Charge
SOH	State Of Health
SPP	Southwest Power Pool (USA)
SS	Substation
SSA	Steady State Assessment
SSC	Smart Supply Cell

SSD	System Specification Description
TC	Technical Committee
TCI	Tele-Communication Interface
TCP	Transmission Control Protocol
UCA iug	Utility Communication Architecture international user group
UCMR	Use Case Management Repository
UCTE	Union for the Co-ordination of Transmission of Electricity
UHV	Ultra High Voltage
UK	United Kingdom
UML	Unified Modeling Language
UPS	Unified Power System (of Russia)
VDE	Verband der Elektrotechnik, Elektronik und Informationstechnik (the German technical-scientific association of Electrical, Electronics and ICT engineers)
VDEW	Verband der deutschen Elektrizitätswerke (Society of the German Power Plants)
VPP	Virtual Power Plant
VSC	Voltage Source Converter
W2E	Web2Energy
WAM	Wide Area Monitoring
WAN	Wide Area Network
WAP	Wide Area Protection
WECC	Western Electricity Coordination Council
WG	Working Group
XML	Extensible Markup Language

Chapter 1
Vision and Strategy for the Electricity Networks of the Future

1.1 The Drivers of Smart Grids

Efficient transmission and distribution of electricity is a fundamental requirement for sustainable development and prosperity throughout the world. However, the world will have to face great challenges in this area in the 21st century.

The main challenges that need to be solved in the European Union are [1]:

- the decreasing availability of fossil and nuclear primary energy sources (PES) and,
- accordingly, their rapidly increasing prices,
- the 70 % dependency of Central Europe on imported PES,
- the increasing impact of greenhouse emissions on the environment.

The expectations regarding the number of years of production of nuclear and fossil PES left in the ground with the most optimistic projected reserves are depicted in Fig. 1.1. This data is based on the current knowledge about the geological production sites and the current worldwide demand. It can be seen that the statements from two different sources regarding the reserves that are exploitable at the known locations are similar. The main difference in the figures consists in the differentiation between the known reserves and the expected increase of resources which could be exploited by non-traditional technologies (e.g. hydraulic fracturing of rock for gas exploitation).

However, both references underline that the extent of nuclear and fossil PES is limited. It is expected that the demand for PES will increase significantly until 2050 (especially according to the rapid economic growth of the countries in Asia and Southern America), which in turn will cause a shorter availability of the traditional energy sources. It is clear that both, fossil fuels and uranium are non-renewable energy resources, and their supply is diminishing rapidly.

Furthermore, the production and use of fossil fuels raise environmental concerns regarding the carbon emissions as shown in Fig. 1.2. A global movement

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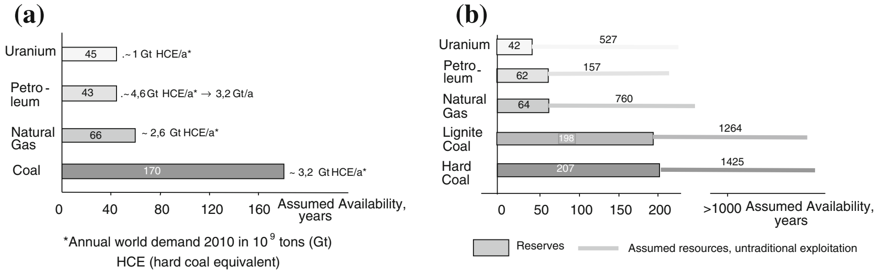
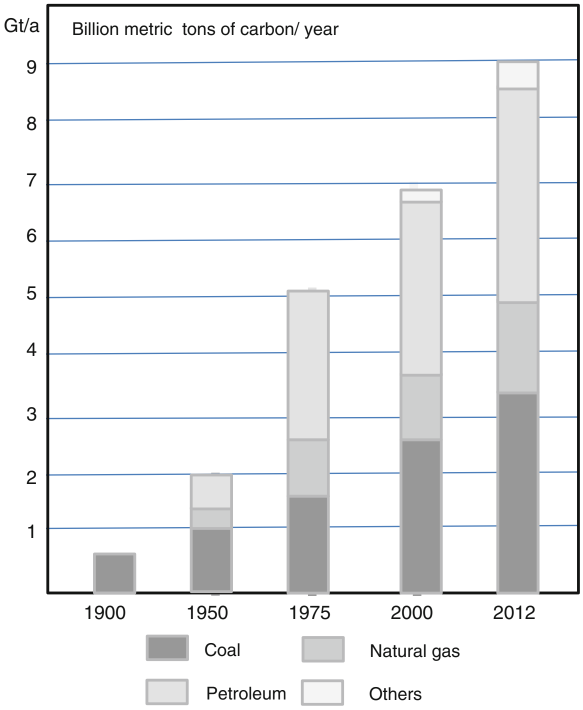


Fig. 1.1 The reserve expectations for primary energy and the annual world demand (*Sources* **a** [2], **b** [3])

Fig. 1.2 The global annual carbon emissions by fuel types (*Source* [4])



toward the generation of renewable energy is therefore the optimum way to meet the increased energy needs of the future.

Consequently, the European Union has set ambitious objectives for the year 2020 to:

- lower energy consumption by 20 % by enhanced efficiency of energy use,
- reduce CO_2 emissions by 20 % and,
- ensure that 20 % of the primary energy is generated by renewable energy resources (RES).

Table 1.1 Potential of RES and CHP for Europe [5]

SET-plan	2020		2030	
Plant type	Energy, %[a]	Power, GW[b]	Energy, %	Power, GW
Wind	11	180	18	300
Photovoltaic	3	125	14	665
Concentrating solar thermal power	1.6[c]	1.8	5.5[c]	4.6
Hydro (large plants)	8.7	108	8.3	112
Hydro (small plants)	1.6	18	1.6	19
Waves	0.8	10	1.1	16
Bio fuel	4.7	30	5.3	190
Cogeneration heat and power	18	185	21	235
Sum	59.4	657.8	75.8	1542

[a] Related to the annual consumption

[b] Installed power

[c] Partly imported from Northern Africa

In the European Union, about 40 % of PES that is used is currently applied for the generation of electricity. (The other 60 % is used for transportation, heating, etc.).

Electric energy offers the best opportunity to be produced by renewable energy sources like wind power, solar energy, bio fuel and hydro power. Consequently, electric energy has to carry the main part of the renewable energy production by having an annual share of >30 % in 2020. All of the member states of the European Union have set their individual targets in support of the common strategy for 2020.

In 2006, the European Commission published the "Strategic Energy Technology Plan" (SET plan) [5] underlining the potential of the various categories of RES and of cogeneration of heat and power plants (CHP), which are also favoured to increase energy efficiency. In Table 1.1 the data of the SET Plan is summarized. This plan also contains figures regarding the importation of energy from solar-thermal power stations in Northern Africa, which corresponds with the Desertec vision [6]. In 2020 the installed RES and CHP power will exceed the currently installed power capacity of the Continental European interconnected transmission system (former UCTE—Union for the Co-ordination of Transmission of Electricity). The rate of dependency of the power production from RES on the weather is considered in the ratio of energy (E) and installed power (P), and it is the worst for Photovoltaic (PV) and the best for biofuel and CHP plants.

The need to modernize the European electricity networks is based first of all on the integration of more sustainable generation resources, especially the partially volatile renewable sources, and secondly, on the growing electricity demand and the establishment of trans-European electricity markets. The context of all these aspects presents major challenges, highlighting the essential need of innovations in this area.

Common vision
April 2006

Strategic research agenda
February 2007

Strategic deployment document
October 2008

Fig. 1.3 The fundamental smart grid documents of the European Advisory Council

The vision for electricity networks of the future was developed by a European group of experts in the framework of the technology platform "Smart Grids" [7] between 2005 and 2008, and three fundamental documents were published as a result (Fig. 1.3).

The Smart Grid definition is presented in the strategic deployment document [8] as follows:

A Smart Grid is an electricity network that can intelligently integrate the actions of all users connected to it—generators, consumers and those that do both—in order to efficiently deliver sustainable, economic and secure electricity supplies.

A Smart Grid employs innovative products and services together with intelligent monitoring, control, communication and self-healing technologies to:

- enable the network to integrate users with new requirements;
- better facilitate the connection and operation of generators of all sizes and technologies;
- enhance the efficiency in grid operations;
- allow electricity consumers to play a part in optimizing the operation of the system;
- provide consumers with more information and choice in the way they secure their electricity supplies;
- improve the market functioning and consumer services;
- significantly reduce the environmental impact of the total electricity supply system;
- deliver enhanced levels of reliability, quality and security of supply.

Consequently, a Smart Grid supports the introduction of new applications with far-reaching impacts: providing the capabilities for safe and controllable integration of more renewable, especially volatile energy sources (depending on the weather conditions) as well of new categories of network users like electric vehicles and heat pumps into the network; delivering power more securely, cost efficiently and reliably through advanced control automation and monitoring functions providing self-healing capabilities after faults and finally, enabling consumers to be better informed about their electricity demand and to actively participate in the electricity market by Demand Side Response on dynamic tariffs.

This vision will lead to new products, processes and services, improving industrial efficiency and the use of cleaner energy resources while providing a competitive edge for Europe in the global market place. At the same time, it ensures the security of the infrastructure thereby helping to improve the daily lives of ordinary citizens. All this makes Smart Grids a milestone in support of the European strategy for achieving the largest knowledge-based economy in the world.

1.2 The Core Elements of the European Smart Grid Vision

The electricity supply of the future will be shared by central power stations and distributed energy resources (DER). Both concepts may contain renewable energy sources (RES), some of which may be volatile or intermittent in their output (for example wind power plants, which may occur as DER or may build their own central power stations as well). DER tends to have a much smaller output than the traditional forms of generation, but large scale deployment will counterbalance this. In addition, placing sources of generation closer to the users will reduce the energy losses that are due to transmission of power over long distances. Figure 1.4 presents a picture of how the power supply of the future may be imagined [7].

Ultimately, the Smart Grids will combine existing technologies—improved and updated—with innovative solutions. The future grids will be based on the existing grids but will also allow to implement new system concepts, such as “Wide Area Monitoring and Protection”, “Microgrids” and “Virtual Power Plants”. Centralized generation will still play an important role, but many more actors will be involved in the generation, transmission, distribution and operation of the system, including the end consumers.

Based on these considerations, the core elements of the vision are defined in [7] as follows:

1. Create a **toolbox of proven technical solutions** that can be deployed rapidly and cost-effectively, enabling existing grids to accept power injections from distributed energy resources without contravening critical operational limits (such as voltage control, switching equipment capability and power flow capacity);

pp – power plant, 1– large hydro pp, 2– wind farm on-shore, 3–small hydro pp, 4–concentrated solar thermal pp, 5 –biofuel pp, 6- wind farm off-shore, 7–low emission fossil pp, 8 – high voltage DC transmission, 9– control center, 10 – micro- grid, 11 – wave pp, 12 – photovoltaic plants, 13 – underground power transmission, 14 – solar heating, 15 – hydrogen filling station, 16 – small electric batteries, 17 – thermal storage, 18 – electricity storage, 19 – cogeneration of heat and power, 20 – fuel cells

Fig. 1.4 Power supply of the future—the vision [7]

2. Establish **interfacing capabilities** that will allow new designs of grid equipment and new automation/control arrangements to be successfully interfaced with existing, traditional grid equipment;
3. Ensure **harmonization of regulatory and commercial frameworks** in Europe to facilitate cross-border trading of both power and grid services (such as reserve power, for instance Nordic hydropower), ensuring that they will accommodate a wide range of operating situations;
4. Establish shared technical standards and protocols that will **ensure open access**, enabling the deployment of equipment from any chosen manufacturer without fear of lock-into proprietary specifications. This applies to grid equipment, metering systems and control/automation architectures;
5. Develop **information, computing and telecommunication** systems that enable businesses to utilize innovative service arrangements to improve their efficiency and enhance their services to consumers.

The creation of the first core element, namely the "toolbox", is possible only in conjunction with the other four core elements. The toolbox presents the overview of the innovative solutions which make up the top priority of the Smart Grid concept.

Two major trends in the development of the power system can be observed:

More transmission

Increasing transmission demands in liberalized markets caused by free energy trading activities, and in some countries, by an unlimited in-feed of volatile wind power are stressing the power systems and causing frequent congestions of the transmission capacity. The existing transmission lines need to be loaded higher than in the past.

Active distribution

A growing share of electricity will be generated in the distribution level. Distribution networks will become active and will have to accommodate bi-directional power flows. Partially, these aspects will lead to a lower utilization of the transmission grids. However, both trends will lead to extremely volatile load flows on all levels of the power system.

The toolbox has to provide means that allow a response to the related challenges in an economic and flexible way, and two different toolboxes have to be established, one for transmission and one for distribution as depicted in Figs. 1.5 and 1.6, respectively.

On the transmission level advanced technologies are requested to enhance the transfer capability of the network and to ensure a flexible and smart operation management in the case of congestions. A situation is called congestion if the N-1 criterion (see below) cannot be satisfied according to the observed load flows through the network.

The majority of changes will take place on the distribution level. The significant growth of the distributed energy generation will significantly impact the network loading and the power quality parameters. In accordance with the Smart Grid definition an interaction of network operations and market activities will become necessary to optimize the distribution network enhancement. Consequently, a communication infrastructure has to penetrate all networks down to the low voltage consumer level to make this kind of interaction possible. Advanced Information and Communication Technologies (ICT) will be the key for:

- advanced distribution automation to enhance the quality of supply,
- a coordinated energy management covering generation, storage and demand in the framework of virtual power plants (VPP),
- provision of new metering services to the consumers including motivation methods for efficient use of electricity
  - by dynamic tariffs,
  - by the real-time communication of information to the end consumers,
  - to visualize the current tariffs, their demand and the related costs.

The other two aspects—the VPP and the Smart Metering—are means to generate flexibility for:

- the adaptation of the demand to the available low cost energy,
- the adaptation of the load flow to the available network capacity.

These aspects are market related but they may support the network operations. In the Smart Grid context the market and grid operations will influence each other mutually. In the environment of large scale volatile power production it will become mandatory to coordinate the network and market operations in a smart way.

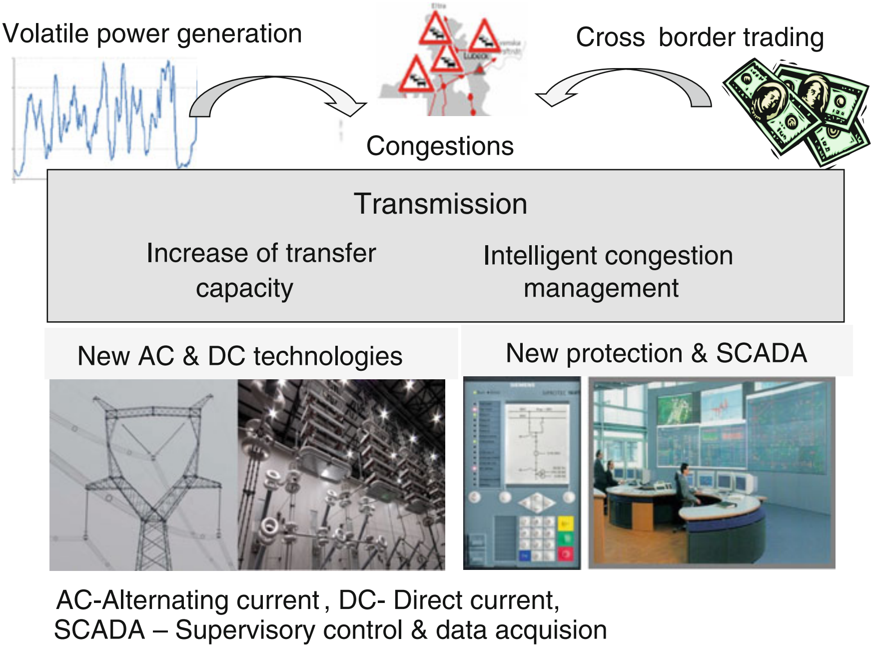


Fig. 1.5 Smart grid challenges, toolbox and solutions for transmission networks

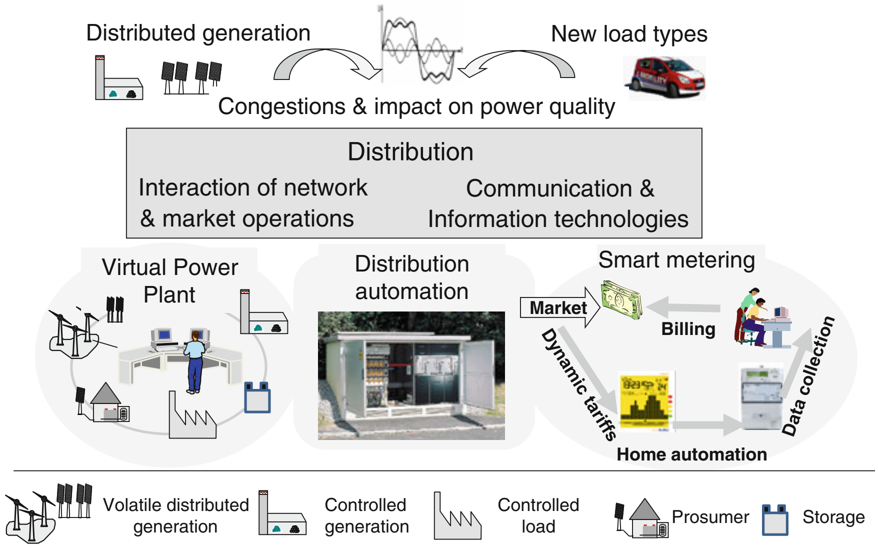


Fig. 1.6 Smart grid challenges, toolbox and solutions for distribution networks

The main goal of these solutions is to integrate the volatile RES into the network operation without any loss of voltage quality, reliability (N-1 criterion) and security of supply.

The current approaches for fulfilling the N-1 criterion presented in Fig. 1.7 have to also be ensured under the prospective changing operational conditions of the networks. The N-1 criterion is defined as follows: A network always meets the requirements of the (N-1) criterion if it survives the failure of an operating device with no inadmissible restriction to its function for an accidental, technically possible and operationally reasonable initial situation.

Figure 1.7 presents the overall power system from left to right with the indication of the voltage levels. However, the High Voltage HV and Extra High Voltage EHV are defined differently in different regions of the world. In most of the countries the HV is defined in the interval between 100 and 220 kV. However, in Japan the 66 kV level is defined as HV. Voltage levels from 230 kV up to 765 kV belong to the EHV level.

On the other hand, the rated voltages of the transmission system used in Continental Europe are 220 and 400 kV (or 380 kV) where they are both defined as EHV. Consequently, the EHV level in Continental Europe is defined beginning with 220 kV below the threshold used, for example, in the USA. The ultra- high voltage UHV level is declared as ±800 kV DC and 1000–1200 kV AC. The voltage levels according to Table 1.2 are used in the considerations of this book.

According to Fig. 1.7 the power flow is described as follows:

- The bulk power plants feed into the transmission network which operates normally on
  - the EHV level e.g.

    220, 400 (380) kV in Continental Europe, (also 275 kV in UK),
    220, 330, 500 and 750 kV in the the Unified Power System of Russia/Integrated Power System (UPS/IPS),
    230, 345, 500 and 765 kV in the USA,

  - the ultra-high voltages with ±800 kV DC and 1000–1200 kV AC are new technologies which have been developed and are ready for the global markets.
- The transmission network transports the energy to the regional distribution or sub-transmission networks operating on the HV) level (66–110–150 kV). Large industrial networks may be directly connected to the transmission networks. Continental Europe uses the rated HV of 110 kV.
- The HV network substations perform three tasks:
  - transforming the HV into Medium Voltage (MV—6, 10, 20, 30, 35 kV) for local energy distribution,

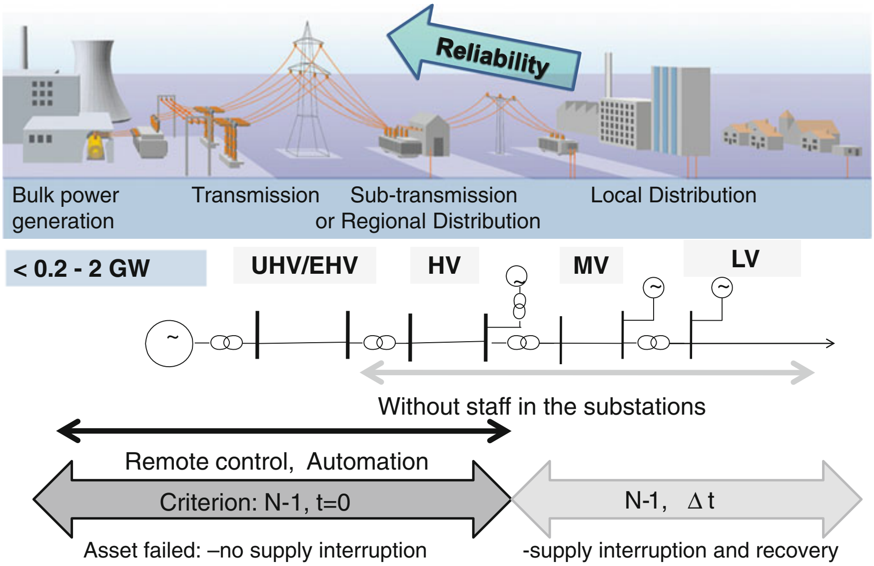


Fig. 1.7 The power system and the operational conditions

Table 1.2 Voltage level specifications applied

Ultra high UHV	Extra high EHV	High HV	Medium MV	Low LV
>800 kV	≥220 to <800 kV	>65 to <220 kV	≥1 to <65 kV	0.1 to <1 kV

- feeding industrial networks and
- connecting regional power plants in the range of ∼20–200 MW.

- The MV networks perform similar tasks, but here the range of the power plants is lower from tens of kW up to 10–20 MW.
- The MV/LV transformer terminals feed directly into the low voltage (LV) networks, whereby the worldwide standard for the rated LV is 400 V, although in a small number of regions 200 V is still in use. The LV networks supply households, small enterprises, administration, trade and other business buildings in rural and urban areas. Furthermore, the LV networks are obliged to connect small power producers. Often these producers are also consumers, and in this sense the new term “prosumer” was introduced.

As shown in Fig. 1.7, the network reliability has to grow as the level of the power system increases.

The HV, EHV and UHV networks are completely remote controlled and supervised, and their protection schemes contain the main and the reserve protection.