ELECTRICITY SUPPLY SYSTEMS OF THE FUTURE

cigré
INTERNATIONAL COUNCIL
ON LARGE ELECTRIC SYSTEMS

A variety of factors are driving the transition, world-wide, to the energy supply systems of the future with remarkably different challenges, tasks, management, coordination, resource mix and market models:

- International and national policies that encourage lower carbon generation, the use of renewable energy sources (RES) and more efficient energy use;
- Integration of RES and distributed generation (DG) into the grids;
- Increased customer participation and thereby new needs especially for the distributions grids;
- Progress in technology including information and communication technology (ICT);
- Need for investment in end-of-life grid renewal (ageing assets);
- Necessity to handle grid congestion (with market based methods);
- Evolution of market design and regulatory mechanisms to manage the transformation in an equitable, cost-effective manner;
- Environmental compliance and sustainability of new built and existing infrastructure;
- The need to address the large number of people with no access to electricity in the world.

These factors suggest that two models for network development in the years 2020 and beyond (up to 2040) are possible, and not necessarily exclusive:

- An increasing importance of large networks for bulk transmission capable of interconnecting load regions and large centralized renewable generation resources including offshore, as well as to provide more interconnections between the various countries and energy markets;
- The emergence of clusters of small, largely self-contained distribution networks, which include decentralized local generation, energy storage and active customer participation intelligently managed so that they are operated as active networks providing local active and reactive support.

The most likely shape of the energy supply systems of the future will include a mixture of the above two models, since additional bulk interconnections and active distribution networks are needed in order to reach the ambitious environmental, economic and security-reliability targets sought for.

The evolution of today's power system towards the models described above is based on the following ten technical issues and the associated technical challenges. This summary paper [1] provides CIGRE's views on the know-how needed to manage the transition towards the electricity supply systems of the future. Different systems in the world may need to put more emphasis on some points and less on others, but we see relevance to all parts of the world from these technical issues:

1 ACTIVE DISTRIBUTION NETWORKS RESULTING IN BIDIRECTIONAL POWER AND DATA FLOWS WITHIN DISTRIBUTION LEVELS AND TO HIGHER VOLTAGE NETWORKS

- Distribution systems need more intelligence or 'smartness' - the massive penetration of smaller units (generation and intelligent loads) imposes the need for their control and coordination.
- The coordination of a large number of small resources imposes a technical challenge that requires application of decentralized, intelligent control techniques in interaction with wholesale markets and transmission system management.
- Massive implementation of smart metering and demand-side response - metering that is used as information collectors for distribution networks automation, home energy management and electric vehicles.
- Potential evolution of market and regulatory arrangements to manage efficiency, equity and cost recovery
- Distribution network architectures that support local energy balancing including microgrids.
- New market-oriented control of distributed generators, such as virtual power plants, interacting with distribution grid operation, as well as transmission grid operation.

[1] CIGRE WG "*Network of the Future*", on behalf of the TC, *Electricity Supply Systems of the future*, conv. Nikos Hatziargyriou , ELECTRA, N° 256- June 2011, pp. 42-49

2 THE APPLICATION OF ADVANCED METERING AND MONITORING AND THE RESULTING MASSIVE NEED FOR EXCHANGE OF INFORMATION

- New measured parameters, architectures of information, communication technologies and algorithms for system operation, protection, maintenance, life management, etc.
- Identification of the data to be exchanged and its requirements (volume, frequency, availability, security etc.);
- Disaster recovery and restoration plans.
- Cyber security and access control. It is noted that as modern power systems rely more and more on ICT technologies, the issues around communications, cyber security etc are becoming increasingly important and they will become a focus area in their own right in the future development of this work.

3 THE GROWTH IN THE APPLICATION OF DC AND POWER ELECTRONICS (PE) AT ALL VOLTAGE LEVELS AND ITS IMPACT ON POWER QUALITY, SYSTEM CONTROL, SYSTEM SECURITY, AND SYSTEM STANDARDISATION

- Study of AC network performance with appropriate control models of high-voltage DC (HVDC) and PE systems.
- Harmonic distortion due to the operation of HVDC and PE can be managed with AC and DC harmonic filtering. Harmonic pollution caused by increased use of consumer electronics.

- DC and PE-based generation has significantly different dynamic response and performance than conventional generation and AC lines during faults in the AC network; in many cases, if applied with judicious and properly coordinated design and controls, these technologies can provide great benefits and performance enhancements to overall system reliability.
- HVDC Grids are a new and different application of HVDC and require standards and grid codes to enable the grid to be built gradually, and with the flexibility of utilizing equipment from different manufacturers, similar for AC applications.
- The expected increased use of DC at end-use premises (i.e. in home and commercial buildings etc.).

4 THE NEED FOR THE DEVELOPMENT AND SIGNIFICANT INSTALLATION OF ENERGY STORAGE SYSTEMS, AND THE IMPACT THIS CAN HAVE ON THE POWER SYSTEM DEVELOPMENT AND OPERATION

- Construction: Advanced materials, reduction of installation and construction costs, reduction of environmental impact, improvement of efficiency of charge/discharge cycles, decrease weight and increase of size density, development of lifetime estimation models.
- Operation and network issues: Impact of storage within all voltage levels, modeling for steady state and dynamic simulations, management of charging-discharging, sizing of storage devices, co-operation with RES for hybrid systems, management in island systems, ability to reduce peaks, co-operation with demand side management (DSM) techniques.
- Development of pump storage and battery storage applications.

5 NEW CONCEPTS FOR SYSTEM OPERATION AND CONTROL AND MARKET /REGULATORY DESIGN TO TAKE ACCOUNT OF ACTIVE CUSTOMER INTERACTIONS AND DIFFERENT GENERATION TYPES

- Operational challenges by combination of stochastic generation and modified loads due to flexible loads and energy storage: Power balancing, congestion management, evolution of market design and regulatory mechanisms to promote market participation of RES and consumer involvement, active and reactive power reserves, risk management.
- The integration of power electronics based technology in the transmission system, e.g. including HVDC links inside meshed interconnected system, which creates challenges regarding reliability, market integration and control and impacts the dynamic behaviour of the power system.
- Evolution of power system control at continental, country, regional and local level: The need of common and coordination activities among transmission system operators (TSO) and distribution system operators (DSO), market operators, energy service providers and other stakeholders. Awareness of overall system status, boundaries between systems, information exchange and operational interfaces between TSO, DSO and other actors, i.e. production and load centres.
- Increased level of automation - New software tools to quickly determine the status of the system over wide areas, providing decision support and increasing the awareness of system operators, automated configuration and electrical parameters adjustment, automated service restoration and adapted disaster recovery.
- Ensure competencies and adapt training of system operators.

6 NEW CONCEPTS FOR PROTECTION TO RESPOND TO THE DEVELOPING GRID AND DIFFERENT CHARACTERISTICS OF GENERATION

- New wide area protection systems (WAPS) for transmission, to overcome limitations of special protection schemes in terms of reliability, flexibility and maintenance cost.
- Impact on the protection system of new generation technologies (decreasing short circuit power and causing flows reversal).
- Capabilities for fault ride through (FRT), i.e. capabilities of new generators to withstand low voltages due to faults without disconnecting - coordination between protection and new generators capabilities.
- Inadvertent islanding detection and intentional islanded operation, i.e. situations when part of the distribution network operates without connection with the higher voltage network as a physical island.
- New protection and automation functions for distribution networks using powerful communication networks.
- Innovative technologies, e.g. DC circuit-breakers.

7 NEW CONCEPTS IN PLANNING TO TAKE INTO ACCOUNT THE NEW TRANSMISSION/DISTRIBUTION INTERFACES, INCREASING ENVIRONMENTAL CONSTRAINTS AND NEW TECHNOLOGY SOLUTIONS FOR ACTIVE AND REACTIVE POWER FLOW CONTROL

- Higher community awareness of environmental factors: This drives many of the developments, e.g. for transmission line approvals, technology or equipment choices and design such as switchgear insulating gas.
- Planning and approvals under increasing uncertainty: The changing role of the power system and changing nature of supply and demand impact the ability to plan to minimize asset stranding, while maintaining reliability and quality. Uncertainties are very high and affect so many economic and technical factors that taking them into account in the planning environment is a major need and challenge.

- Best use of existing assets: By extending asset useful life and by adapting assets to new requirements (e.g. bi-directional power flows), by asset updating or upgrading (e.g. new control systems), and if possible by their redeployment. Example techniques are reliability assessment, end-of-life management of ageing assets including T&D equipment and “big data” analysis for asset management.
- Network investment planning: Given demand response, possible electrification of heating, cooling and transport, and distributed generation, and given the much higher aggregate length of distribution lines compared to transmission lines, the interaction of transmission and distribution expansion investment needs to be addressed.
- Changes in technology: Need to understand costs, capabilities and lead times of each solution to enable comparison between options.
- Changing economic drivers: This impacts availability of funding and investment risks and can have major impacts on investments especially in market-based systems.
- Changing market and regulatory environment (impacts on level of central planning vs. market solutions).

8 NEW TOOLS FOR SYSTEM TECHNICAL PERFORMANCE ASSESSMENT, BECAUSE OF NEW CUSTOMER, GENERATOR AND NETWORK CHARACTERISTICS

- Advanced numerical techniques and numerical methods for the solution of dynamic problems in integrated timeframes and multiphase power-flow problems.
- Bridging the gap between 3-phase and positive sequence modeling.
- Advanced tools and techniques for power balancing and reserve requirement evaluation.
- Planning and operational tools which can optimise the overall performance of the network and help to manage uncertainty based on monitoring data and the application of failure mode and effect analysis (FMEA) to characterise the actual network performance of new and existing technologies
- Advanced load modeling techniques.
- Techniques to model decentralized control applications, i.e. functions with a limited perception of the environment able to take intelligent decisions, such as multi agent techniques.
- Modeling of active and adaptive control strategies (centralized control systems, grid-friendly appliances, demand side management, etc.).
- Models for new and advancing technologies
- Hardware in the loop (HIL) simulation tools that can interface physical hardware equipment with real time digital simulators (RTDS) in order to (potentially reduce performance demonstrations.
- Tools and techniques for assessing the harmonic performance of the grid in light of greater DC and PE penetration at all voltage levels
- Co-simulation platforms that can integrate the simulation of both transmission systems and distribution systems
- Bridging the gap between electromagnetic transient (EMT) and positive sequence simulation tools.

9 INCREASE OF RIGHT OF WAY CAPACITY AND USE OF OVERHEAD, UNDERGROUND AND SUBSEA INFRASTRUCTURE, AND ITS CONSEQUENCE ON THE TECHNICAL PERFORMANCE AND RELIABILITY OF THE NETWORK

- Technologies for uprating existing overhead lines: replacing old conductors by high temperature conductors and re-tensioning of existing conductors at overhead lines, upgrading voltage level, using real time monitoring.
- Conversion of AC to DC lines, considering hybrid lines (DC & AC), compact lines and aesthetic supports for overhead lines.
- Use of overload capacity and thermal transient calculations of underground (UG) systems, and thus impacting on the design criteria of UG Sections.
- Following the development of new insulated AC or DC submarine and underground cables for high voltage applications, such as offshore wind farms. Consideration of “on-sea” infrastructure with off shore developments in wind farm solutions for substations and cables including both transmission and distribution (T&D). Use of wind-load data for design criteria for submarine cables.
- Design criteria and installation technologies for deep water cables to enable relevant interconnections.
- Requirements for T&D equipment in changing network conditions
- Incorporation of intelligence into T&D equipment.

10 AN INCREASING NEED FOR KEEPING STAKEHOLDERS AWARE OF THE TECHNICAL AND COMMERCIAL CONSEQUENCES AND KEEPING THEM ENGAGED DURING THE DEVELOPMENT OF THE NETWORK OF THE FUTURE

Environmental aspects (nature, fauna flora, EMF, audible noise, visual impact, etc.) are among the main drivers, but also main objections against energy projects worldwide (production, transmission, etc.). Environmental considerations (nature, human being) are a main driver for the development of the sustainable energy systems of the future. This is now increasingly understood by the electricity sector, also driven by the "outside world": politics, NGOs and other stakeholders, like the financial world.

The following measures need to be taken by the industry:
In the planning phase:

- to demonstrate the benefits which will result from the project,
- to guarantee that sustainable development principles and issues are being incorporated,
- to take into account public views, consultation and needs already in the system planning and design and options (e.g. the choice of alternatives).

In the construction and operation phases:

- to demonstrate the compliance with environmental standards,
- to obtain support for the necessary actions (e.g. maintenance).

These ten technical issues, already intersect the 16 CIGRE Study Committees demonstrating how the CIGRE work supports development of the electricity supply systems of the future. Through the products CIGRE is creating, and will continue to create in future years, governments, regulating authorities, system planners and operators, equipment designers, vendors, academics and consultants and other stakeholders (like investors, general public, NGOs) will be equipped with valuable published resources on these very diverse technical aspects of the future system. We hope and anticipate it will guide their decisions towards optimal reliability, security, economy, sustainability and environmental & customer-friendliness of the future systems.

INTERNATIONAL COUNCIL ON LARGE ELECTRIC SYSTEMS
Conseil International des Grands Réseaux Electriques
21, rue d'Artois - F 75008 Paris
Tel : +33 (0)1 53 89 12 90 - Fax : +33 (0)1 53 89 12 99
www.cigre.org

©CIGRE 2016