CIGRE WG "Network of the Future" Electricity Supply Systems of the future

On behalf of the Technical Committee

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Introduction

The mission of modern power systems is to supply electric energy satisfying the following conflicting requirements:

– High reliability and security of supply
– Most economic solution
– Best environmental protection

The first requirement of reliability and security of supply has always been and still remains a key objective and has shaped the design and operation of power systems from the very beginning of their formation. In the last few decades, the need for a more efficient operation of the system with the aim to reduce prices and increase the quality of service has led to the **unbundling of the power system and to the liberalization of the energy markets.** It is fair to say that these actions are probably the *last decade's landmark* of the electric electric power systems framework. In more recent years, the increasing concern about climate change and the effects energy production may have on greenhouse gas (GHG) emissions have led to the wide integration of Renewable Energy Sources (RES) and Dispersed Generation (DG) in the power system with obvious advantages for the environmental behaviour of the power systems. Aggressive targets for the increased share of renewable generation in the overall power supply have been set, e.g. the EU Commission target known as 20-20-20 for 2020. Similar targets are set in US, Canada, Japan, and most parts of the developed and developing world. The efficient integration of large shares of RES and DGs imposes the need to revisit the current ways of thinking in respect of the planning, management and control of the power systems both at transmission and distribution level, with the introduction of higher intelligence to help further improve efficiency. These aims, which are primarily driven by the **environmental concerns** are the landmark of this decade and will certainly shape **the Energy Supply Systems of the Future.**

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CIGRE is in a unique position to provide an independent and highly specialized vision of the Energy Supply Systems of the Future, since its membership includes a very large number of experts within the electric energy sector from all over the world, who are ideally positioned to express the views of industry and academia. The aim of this brochure is to:

– identify the key parameters, which in these experts opinion will shape the Networks of the Future in a time horizon of a couple of decades,
– to highlight the relevant activities which have been and are still taking place within the various Working Groups of CIGRE
– to identify missing activities, which could be the objectives of future Working bodies,
– to identify synergies within and outside CIGRE.

The over reaching aim is to contribute to the vision and the development of the future Energy Supply Systems in a global, co-ordinated way.

Driving factors, network development scenarios and relevant activities

The driving factors for the transition to the Future Energy Supply systems are generally identified as:

– Increased customer participation
– International and national policies encourage lower carbon generation, the use of RES and more efficient energy use
– Integration of RES and DG into the grids
– Need for investment in end-of-life grid renewal (ageing assets)
– Necessity to handle grid congestion (with market based methods)
– Progress in technology including Information and Communication Technology (ICT)
– Environmental compliance and sustainability of new built infrastructure

These factors suggest that two models for network development are possible, and not necessarily exclusive:

– An increasing importance of Large Networks for Bulk Transmission capable of interconnecting load regions, large Centralized Renewable Generation resources including offshore, and to provide more interconnections between the various countries and energy markets.

– The emergence of clusters of small largely self contained Distribution Networks, which will 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.

These two models lead to the three scenarios shown in Figure 1. The CIGRE WG has debated several options ranging from choosing only Scenario 2, as the most realistic, or to choose scenarios 1 and 3 which give the extreme situations revealing particular issues that would not otherwise be obvious and eliminating scenario 2.

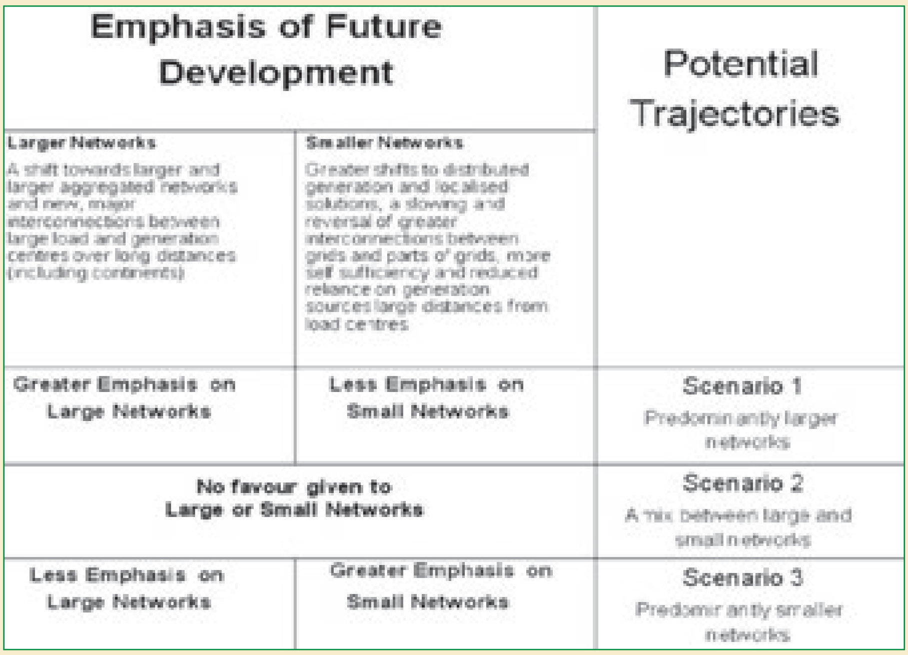

Fig. 1: System Models of Future Development

It was agreed that the most likely shape of the Future Energy Supply Systems will include a mix of the above two models. The quantitative composition of Future Systems is not possible to predict, but this is not considered to be very important. The WG considers that both models are needed in order to reach the ambitious environmental, economic and security targets sought. Therefore, CIGRE has decided to deal with all technical issues relevant to both models including the study of isolated systems.

The electricity supply of the future: CIGRE's role

CIGRE does not undertake specific system or equipment development work, but is an independent and critical analyser of different solutions and the provider of high quality, unbiased publications and other contributions to the electrical supply industry.

CIGRE adds value by:

- *expressing its view on the different conditions/ solutions which exist and are appropriate in different regions of the world,*
- *identifying new issues and challenges to be investigated,*
- *providing information about the development of new techniques, indicating the challenges for new development or for new applications of existing techniques,*
- *supporting and/or collaborating with associations like CENELEC, IEC, IEEE, etc. for the development of new technical standards.*

The key technical issues

The WG considers that the main drivers for the power system evolution can be summarized as follows:

- Massive integration of RES and DER
- Active customer participation
- Increasing end-use of electricity and non acceptability for building new infrastructure

The evolution of today's power system towards the new models as described above is based on the following technical issues (TIs), that should be considered in detail:

TI1. Active Distribution Networks resulting in bidirectional flows within distribution level and to the upstream network

TI2. The application of advanced metering and resulting massive need for exchange of information

TI3. The growth in the application of HVDC and power electronics at all voltage levels and its impact on power quality, system control, and system security, and standardisation

TI4. The need for the development and massive installation of energy storage systems, and the impact this can have on the power system development and operation.

TI5. New concepts for system operation and control to take account of active customer interactions and different generation types

TI6. New concepts for protection to respond to the developing grid and different characteristics of generation

TI7. New concepts in planning to take into account increasing environmental constraints, and new technology solutions for active and reactive power flow control

TI8. New tools for system technical performance assessment, because of new Customer, Generator and Network characteristics

TI9. 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

TI10. An increasing need to keep Stakeholders aware of the technical and commercial consequences and keeping them engaged during the development of the network of the future.

Relevance to CIGRE SCs key challenges

Each of the Technical Issues listed above may need the involvement of different CIGRE Study Committee experts, since many issues have different facets and involve different technologies working together. The WG has performed a preliminary assessment of which SCs might be involved in addressing each TI, and a preliminary list can be found in the table below. It should be noted that each TI is likely to be handled by a number of separate WGs, some of which will have members from a single SC, and some of which will be Joint WGs involving members from 2 or more SCs.

KEY TECHNICAL ISSUES	CIGRE SCs
TI1. Active Distribution Networks resulting in bidirectional flows within distribution level and to the upstream network	**C6,** C3, C4
TI2. Massive need for exchange of information	B5, C6, **D2**
TI3. Massive integration of HVDC and power electronics at all voltage levels	B1, **B4,** B2, C4, C6, C1, D1
TI4. Massive installation of storage	**C6,** C4, C1, D1
TI5. New concepts for system operation, control	**C1, C2,** B5, C6, C5
TI6. New concepts for protection	**B5, B4,** C4, C6
TI7. New concepts in planning	**C1,** C3, C4, C6, B2, B4, B5, C5
TI8. New tools for system technical performance assessment	**C4,** C6, B3, B4
TI9. Increase of right of way capacity and use of overhead, underground and subsea infrastructure	**B1, B2, B3, B4,C1, C3, C4**
TI10. Need for stakeholders awareness and engagement	**B1, B2, B3, B4, C1,** C3, C6, C5

Future areas of CIGRE contribution

TI1. Active Distribution Networks resulting in bidirectional flows within distribution level and to the upstream network

The activities of **SC C6** are mainly driving TI1. Protection issues are an important challenge and are dealt with by **SC B5 in TI6**.

Future work

Modeling and analysis of active networks is important and should be dealt with by **SC C4**. Environmental issues are not yet covered and will be developed in cooperation with **SC C3**.

Indicative activities

- Smart buildings
- Smart cities
- DC distribution networks
- Potential ancillary services from distribution
- How to protect islanded electronically dominated distribution systems?
- How to address the micro grids issues?
- High renewable penetration in islanded communities

TI2. Massive need for exchange of information

The activities of **SC D2** are mainly driving TI2. Coordinated protection is an outstanding issue dealt with by **SC B5 in TI6**. The operation of active networks with increased DG and customer participation requires has increased exchange of information and this is dealt within **SC C6**.

Future work

Effects on power system operation and control are an important issue to be pursued by **SC C2**.

Indicative activities

- Evolution of existing telecommunications infrastructures to cover the new needs
- Cyber security
- New techniques and applications for maintenance of communication equipment
- How to cope with and best utilise the information from intelligent monitoring?

TI3. Massive integration of HVDC and power electronics at all voltage levels

The activities of **SC B4** are mainly driving TI3. The increased integration of power electronics requires new advanced modeling and analysis techniques, this is developed in co-operation with **SC C4**. Impacts on system development are dealt with in co-operation with **SC C1**, and the HVDC cable components by **SC B1**. Impacts on materials are dealt with by SC D1.

Future work

The penetration of power electronics at medium and low voltage levels is an important outstanding issue that should be pursued in cooperation with **SC C6.** •••

Indicative activities

- Power electronics at lower voltages including within generators
- FACTS applications for active and reactive power control
- New HVDC technologies
- Enabling of multi-vendor HVDC Grids
- Coping with multiple harmonic sources with the networks.

TI4. Massive installation of storage

TI4 is expected to be an important future activity, which is currently partially covered by **SCC6** at the distribution level only.

Future work

Issues not covered include the developments in storage technologies, in material and devices or methods, which could be developed by **SC D1** and **SC A1,** respectively and storage analytical models that could be developed by **SC C4**. Storage solutions which are connected to the network via Power Electronics will provide opportunities for reactive power management, and potential integration with HVDC Grids, and this aspect will be analysed by SC B4. The effect of large scale storage in the development and operation of the power system are important future issues to be pursued by **SC C1** and **SC C2**, respectively.

Indicative activities

- Storage techniques overview and selection
- Integrating energy storage in HV grids
- Influence of bulk energy storage
- Dual utilisation of power electronic converters associated with energy storage
- Maximise the value of energy efficiency measures by using energy storage to allow demand reduction to occur when it has the highest value.

TI5. New concepts for system operation and control

The activities of **SC C2** are mainly driving TI5. **SC C6** develops work on operation of active distribution networks and control of DER. **SC C4** develops models of specific components (gas turbines, wind parks, etc.) and risk-based and probabilistic tools.

Future work

TI5 is closely linked with the activities of **SC C2** and also **SC C1**, joint work is in progress and should be developed further. Protection is another relevant activity that should lead to joint work with **SC B5**.

Indicative activities

- Challenges in control centres due to renewable generation
- How much conventional generation is necessary in the future?
- Critical infrastructure protection against cyber attacks from outside
- ICT convergence
- Providing ancillary services from intermittent generation
- Harmonisation of grid codes for wind farms connecting to the grid
- Harmonisation of grid codes for connection of power stations to the network
- Impact of instrument transformers on substation concept
- Planned and unplanned outage management in a controlled and efficient manner

TI6. New concepts for protection

The activities of **SC B5** are mainly driving TI6. **SC B4** develops joint work on the impact of HVDC networks.

Future work

Modeling of protection devices and consideration of protection in analytical tools is an activity to be pursued by **SC C4**. Protection of active networks including low voltage networks is an outstanding activity to be pursued jointly with **SC C6**.

Indicative activities

- New protection , automation and communication for distribution networks
- Synchrophasors for system wide protection
- IEC 61850 Process bus and beyond the substation
- Advanced protection algorithms

TI7. New concepts in planning

The activities of **SC C1** are mainly driving TI7. **SC C4** develops probabilistic models for assessing network capability; **SC C1** is exploring how best to integrate these tools in making planning decisions on justifying network augmentations. **SC C6** develops work on planning active distribution networks.

Future work

Planning is closely related to environmental effects and the functioning of electricity markets.

These are issues that can be the focus of joint work with **SC C3** and **SC C5**, respectively. The effects of protection should be considered by **SC B5**. The integration of HVDC Grids and AC Networks can be the focus of joint work with SC B4.

Indicative activities

- Demand forecasting recognising the changing nature of supply and demand
- Manage strong need for re-investment and new investments for future demand in the context of current and future technologies and growing uncertainty
- Future of reliability in terms of what the customer needs and the future system can deliver
- How can markets give incentives for improving the generation portfolio
- System flexibility for accommodating variable intermittent generation
- Impact of smart technologies on market designs
- More dynamic coupling between the markets and the infrastructure investments recognising the changing investment risk
- Integration of renewables potential from remote areas such as the North sea and African desert
- "Investigate tools" and approaches for planning networks which integrate HVDC networks and HVAC networks solutions
- Future use of new unconventional generation technologies including Super conducting machines

TI8. New tools for system technical performance assessment

The activities of **SC C4** are mainly driving TI8. **SC C1** has also developed work on modeling complex networks.

Future work

The development and operation of active networks requires new tools for their technical performance, especially their dynamic behavior, islanding and power quality effects. Work should be developed in cooperation with **SC C6**. Models will be required for HVDC converter stations, HVDC Grids and for FACTS devices, and these can be developed jointly by B4 and C4.

Indicative activities

- Simulation tools for distribution levels
- Models for dynamic performance of PV, and wind mill generation
- Islanding
- Phasor Measurement Units use at distribution level
- Peer to peer approaches with multi agent techniques
- More transients and higher harmonic content in the network means to review test programmes

TI9. Increase of right of way capacity and use of overhead, underground and subsea infrastructure

The activities of **SC B2** and **SC B1** are mainly driving TI9. **SC B4** has also developed work on HVDC and FACTS, which can increase the right of way capacity. **SC C4** has developed models on long AC cables and HVDC cables jointly with **SC C1**. The effect of the transmission infrastructure on the environment is an important activity considered by **SC C3**.

Future work

The increased use of interconnections is a key component of the network of the future, as far as the supergrid is concerned. This development will have major implications on planning, operation & control and the establishment of electricity markets covering wider areas. Relevant activities could be developed in cooperation with **SC C1**, **SC C2** and **SC C5**.

Indicative activities

- Smart components for transmission lines
- Cost optimisation in new transmission lines
- Transmission interconnections
- Integration of superconducting transmission and distribution elements/lines
- Integration of power stations to the load centres by superconducting cables
- Off shore platform connection to the grid (reliability issue)
- Towards fluid free components (dry type)

TI10. Need for stakeholders awareness and engagement

The activities of **SC C3** are mainly driving TI10. The effects of cables and overhead lines on the environment are considered by SC B1 and SC B2.

Future work

Public opposition to new construction is a key problem impeding power system development. This issue concerns networks, substations, HVDC converter stations and generating stations. Relevant activities should be pursued by **SC B1, SC B2, SC B3 and SC B4**. Public opposition also affects power system development and should be ●●●

considered in cooperation with **SC C1**. The facilitation of distributed generation (including renewable generation) and of active customer participation, are important relevant activities that should be developed in cooperation with **SC C6. SC C6** is also responsible for rural electrification, a subject very relevant to TI10. Finally, the development of electricity systems of the future in the new context requires extensive engagement with key stakeholders to ensure the required investments receive government and community support and gain access to scarce capital. These investments are required to both enable the new energy solutions and enhance the power system to deal with more extreme weather events.

Indicative activities

- Improve and make more efficient the Stakeholders engagement, in order to smooth the public acceptability of power system infrastructures
- Leveraging CIGRE activities into developing countries
- Developing education tools together with methods to value the true cost of energy, thus strengthening the awareness of Stakeholders and general public
- Producing simple public documents that promote key messages that are customer focused

Conclusions

CIGRE is in a unique position to provide an independent and highly specialized vision of the Electricity Supply Systems of the Future. In this brochure the two characteristic models of development ranging from the Supergrid to the Microgrid have been reviewed, as the two are likely to form the basic components of the Future Electrical Energy Systems. Ten key technical issues have been identified and described in detail. The priorities of the Study Committees have been contrasted to the key technical issues and the recently completed or in progress CIGRE working groups have been aligned to the technical issues. This comparison has revealed new activities that can form the basis of future working groups, some of which will require collaborative work amongst a number of Study Committees. This ensures a more strategic approach to examination of these critical areas by minimising overlaps, addressing gaps and ensuring strong connection of the various activities. It should be noted that this work is based on the recent and current Study Committee activities and is therefore subject to constant evolution. ■

Appendix I. Study Committee Short Descriptions

A1	Rotating Electrical Machines	● Life management ● Machine monitoring and diagnosis ● Renewable generation ● Large generators ● High efficient electrical machines
A2	Transformers	● Design and manufacture ● Application of material ● Utilization, e.g. maintenance and operation, condition monitoring, life management, repair and refurbishment, disposal ● Safety and environmental aspects, e.g. noise, oil spill, fire hazard and explosion ● Economic/commercial aspects ● Quality assurance and testing
A3	High Voltage Equipment	● Design and development ● New and improved test techniques ● Maintenance, refurbishment and lifetime management ● Reliability assessment and condition monitoring ● Requirements presented by changing networks
B1	Insulated Cables	● Power cables in all phases of life ● Submarine, underground, ducts, tunnels....... ● HVDC and HVAC Cable Systems
B2	Overhead Lines	● Increase Acceptability of OHL ● Increase Capacities of existing OHL ● Increase Reliability and Availability of OHL
B3	Substations	● New substation concepts ● Substation management issues ● Life cycle management and maintenance ● Impact of new communication standards and smart grids on existing and new substations

B4	HVDC and Power Electronics	● Responsible for HVDC systems and Power Electronics for AC systems ● Its members are International Experts from Manufacturers, Operators, User Engineers, Consultants and Academics. ● Provides unbiased and balanced documents concerning economical, technical and environmental matters associated with its area of responsibility. ● The target audience includes engineers in the Electrical Supply Industry, Standardisation bodies, investors and regulators
B5	Protection and Automation	● Improved concepts of Substation Automation Systems ● Technical recommendations for IEC 61850 ● Application of numerical protections and substation automation systems ● Methods to improve the performance of protection systems ● Protection implications of new generation technologies.
C1	System Development and Economics	● Planning for rapid development, uncertain generation and desired reliability (newly and rapidly developing countries, system performance, contingency planning, mass penetration of renewables, a greenfield approach) ● Investment drivers, decision processes and tools (investment drivers, planning criteria, grid codes and the role of new technology, new investment decision processes, new tools and methods for increasing uncertainty) ● Asset management practices including risk assessment now and in the future (risk management, broad trends and practices, new solutions for changing power system designs)
C2	System Operation and Control	● Control and switching for reliability: voltage,frequency and capacity limits ● Reserves and emergency strategies ● Management of fault and restoration situations ● Short term planning and coordination of system capacity needs ● Requirements and use of power system analysis and security assessment functionalities ● Requirements, methods, tools for training of operators ● Impact on system operation from institutional structures: regulators,trading and contracted ancillary services.
C3	System Environmental Performance	● Environmental impacts of Power System development and operation; ● Global environmental changes and Power System; ● Public acceptance of Power System infrastructures; ● Stakeholders engagement and communication; ● Power System efficiency and environment.
C4	System Technical Performance	● Power Quality ● Electromagnetic Compatibility/Electromagnetic Interference (EMC/EMI) ● Insulation co-ordination ● Lightning ● Advanced Tools for the analysis of power system performance ● Power systems dynamic/transient performance models and analysis.
C5	Electricity Markets and Regulation	● Consequences of regulatory changes for the electric power sector ● Regulatory incentives for investment ● System implications of new generation technologies ● Markets design's impact on transmission system operation ● Market design for integration of intermittent generation
C6	Distribution Systems and Dispersed Generation	● Dispersed Energy Resources connection and integration ● Dispersed Energy Resources concepts in distribution systems operation and planning (Microgrids and Active Distribution Networks) ● Demand management and Active Customer Integration ● Rural electrification
D1	Materials and Emerging Test Techniques	● Electrical insulating materials ● Electrical conducting materials ● High voltage and current test and measuring techniques ● Diagnostic tools
D2	Information Systems and Telecommunication	● ICT applied to the networks of the future. ● Telecommunication networks in Electric Power utilities (architectures, media, protocols…) ● New ICT architectures to control the bulk power systems (smart meter, smart grid, intelligent grid, control centres EMS, MMS etc…). ● ICT governance within utilities – in-house versus outsourced. ● Information security within the Electric Power Utilities