POSITION PAPER

Transition of the Electricity System from conventional generation to a dispersed and/or RES system

Prepared by Joachim Vanzetta, Chairman SC C2, on behalf of the Technical Committee

Motivation

Currently electricity systems are facing a transition caused by several different reasons, e.g. a growing trend in renewable generation development which most of them have intermittent nature, a change of transmission systems from pure AC to hybrid AC/DC-Systems, the development of special protection schemes, overhead lines with partial undergrounding and others. This paper focuses on the transition of the electricity system caused by the ongoing penetration of RES.

The debate on climate change has led to significant efforts in different countries to minimize the carbon footprint in energy supply. Beside all sectors of energy production and consumption, these efforts impact the electricity system as well. More and more conventional power generation in thermal power plants is replaced by renewable and dispersed generation in order to lower carbon dioxide (CO2) pollution e.g. by reducing the carbon footprint. Especially in Europe, the transition towards a power generation structure dominated by renewable and dispersed generation to reduce the carbon footprint is one of the preferred options.

For example, the EU targets [1] for sustainable growth include:

- reducing greenhouse gas emissions by 20% compared to 1990 levels by 2020. The EU is prepared to go further and reduce by 30% if other developed countries make similar commitments and developing countries contribute according to their abilities, as part of a comprehensive global agreement;
- increasing the share of renewables in final energy consumption to 20%; and
- moving towards a 20% increase in energy efficiency.

Compared to 2011 the global emissions of CO2 – supposedly the main cause of global warming – increased only by 1.1 % in 2012 (3% in 2011) but still reached an all-time high of 34.5 billion tons in 2012 [2]. Nevertheless the growth of renewable generation in the electricity system is remarkable. The share of renewable energy sources (RES) such as wind, PV (Solar) and Bio fuels is increasing with accelerated speed, e.g. in 2012 more than 20% of the global electricity production was already covered by RES [3].

The incident in Fukushima in 2011 may foster the development of renewable energy as some countries have now decided to no longer use nuclear power plants for electricity generation (e.g. Germany) which will lead to negative effects on CO2 production if the nuclear power plants which are shut down are not replaced by RES.

This shows that the transition of the electricity system from conventional generation to a dispersed generation system including RES has already started and is speeding up. To give an illustration of this development Fig. 1 shows an example of the development of installed wind generation capacity in different countries over the last years.

In this context, an important question is the definition of the adequate mix of sources to supply the electricity demand considering security, efficiency and environmental issues •••

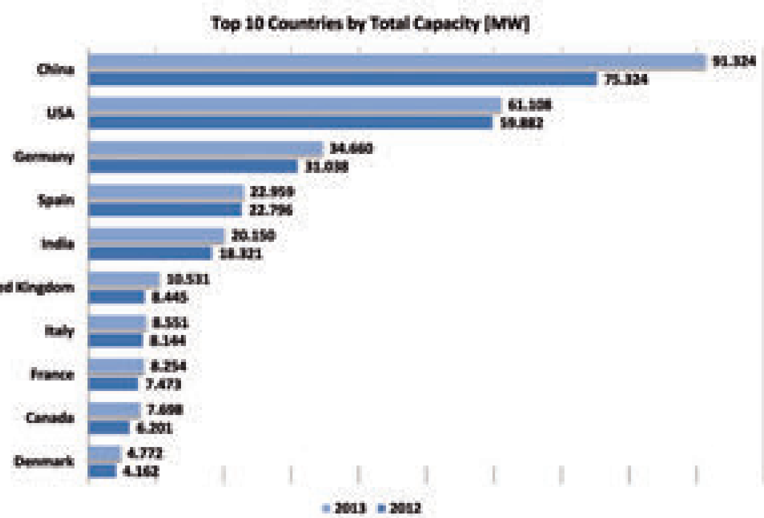

Fig. 1: Installed generation capacity in Wind [4]

including all the sources available: hydro with and without reservoir, thermal (gas + coal + nuclear) and renewable (wind + solar + biomass). The adequate mix of sources should be maximizing the technical and economic benefits that can be obtained considering the characteristics of all the energy sources available in the electric system.

Many stakeholders are discussing these very important issues and have different opinions and experiences of the challenges, threats, opportunities and weaknesses of this on-going process. The issue is complex: on the one hand people want to have cheap and reliable energy and a stable security of supply but on the other hand the process of transition and the changes caused by it are not fully transparent today. For example, there are many challenges for balancing supply and demand which are requiring new or enhanced technical solutions. Most of the impacts, e.g. to the Internal Energy Market (IEM) due to enhanced subsidies in renewable generation, are not yet considered sufficiently. In addition, the stakeholders are looking for independent and unbiased information sources which are not motivated by specific political or economical interests. In particular this need for unbiased information is very high for political stakeholders and decision-making bodies.

Cigré as an independent association has produced this paper on different aspects of the transition to enrich the discussion amongst the public and political decision-makers.

Challenges

Most countries of the world have decided to fight against global warming, but many controversial aspects have to be considered which leads to different questions about the outcomes of this transition.

This paper addresses the following questions:

1. What are the key challenges for a transition from conventional generation to a dispersed generation and/or RES system; in particular:
   - 1.1. What are the technical impacts on the generation system (conventional power plants, storage, PV/Wind installations …)?
   - 1.2. What are the technical impacts on the transmission/distribution grid (security of supply, network extension, system operation, control centres, stability problems, balancing power, ancillary services, quality of supply …)?
   - 1.3. What are the economic impacts on both sectors (cost of generation, costs of transmission/distribution grids, new concepts in energy regulation, effects of different subsidy schemes …) and the impact on the IEM if more and more generation is renewable?
   - 1.4. What are the operational challenges (managing congestions, keeping the power/frequency balanced …)?
2. Can we afford a different speed in different countries with interconnected systems in this transition?
3. What are the needs for further research in transmission/generation assets and new technologies?
4. What are the impacts on social welfare?

1. What are the key challenges for a transition from conventional generation to a dispersed and/or RES system?

Based on the rapid penetration of RES – with all their different characteristics – integrating RES into the electrical power system is a major challenge for all involved parties. In particular, variability and predictability/uncertainty of RES impacts on scheduling and dispatch in the electrical power system. The location of RES influences the planning, design and operation of electrical networks and capacity factor, capacity credit and power plant characteristics of RES are quite different to more traditional generation such as thermal generation. [5] This impacts on the interactions between the various generators and affects the overall planning and operation of the power system.

1.1. What are the technical impacts on the generation system?

An important characteristic of RES (especially PV and wind) is its diurnal and seasonal variation (e.g. peak generation of wind energy may occur in the morning or evening and may have higher outputs in spring or fall). These RES in particular are very variable and only partially dispatchable: generation can be reduced if needed, but maximum generation depends on the availability of the RES (e.g. sun or wind). The availability for RES often does not positively correlate with electricity demand, either in terms of time of use/availability or location, making it difficult to predict the availability of generation. In addition, the variability of RES increases the burden on dispatchable generation or other resources to ensure balance between supply and demand. In this context it is important to state that electricity generation and demand have to be balanced at any time. This particularly means that reliable thermal generation has to be available if there is a lack of RES generation. Therefore more flexibility is required from the generation mix. Generation provides most of a power system's existing flexibility to cope with variability and uncertainty through ramping up or down as needed. Greater need for flexibility can imply either investment in new flexible generation or improvements to existing power plants to enable them to operate in a more flexible manner. Control of demand (e.g. by use of smart meters) can also help to manage the variability of RES but the technology and systems for widespread and large-scale application are still evolving.

Another impact on generation is the possibility of over-generation during low-demand periods when base-load generators must stay on line and are dispatched to their minimum levels. In this situation, system operators must have the ability to limit the output of variable generation to •••

maintain system stability. Owing to the dependency on environmental conditions, it is highly unlikely that the maximum production of all renewable generation in the system or in a general location will occur at the same time. By storing electrical energy (e.g. using pump storage, batteries or flywheels) when renewable generation is high and the demand low, and generating when renewable output is low and the demand high, the curtailment of RES can be reduced and the base-load units in the system will operate more efficiently. But storing of electrical energy is still a very limited option due to high costs and low density of electric energy e.g. in batteries. Also dispatchable renewable sources (including hydropower with reservoirs, bioenergy, geothermal energy, etc.) can in many cases offer extra flexibility for the system to integrate other renewable sources and to regulate the balance between supply and demand.

It is clear that this scenario causes the following immediate and strategic consequences:

- changes in the traditional approach and tools to plan and operate the interconnected power system;
- improvements in methods and tools to forecast the generation of RES.
- changes in operational procedures and requirements of grid codes in face of deep and fast variations of the intermittent generation; and
- a strategy how to include RES and conventional generation into a common electricity market and how to incentivise investments in reliable generation.

As stated the main problem concerning RES is the poor predictability. Therefore flexible conventional power plants are necessary to cover the times without generation from RES and to be able to cope with rapid changing ramps. One step to be better aware of the influence of RES on the system is improvement of forecast tools and procedures for generation dispatch.

1.2. What are the technical impacts on the transmission/ distribution grid?

Raised penetration of dispersed generation has increased operational uncertainties which system operators must consider when making operating decisions. How much renewable generation can be depended upon is less certain compared to conventional generation whose fuel availability and dispatchability is more controllable. This uncertainty also causes an increase in the generation ramping range that must be covered for load pick-up and drop-off, and in the size of operating reserve a system must provide. In general the output of RES is characterized by steep ramps as opposed to the controlled and gradual ramping of conventional generation. Managing these ramps can be challenging in real time operations, particularly if "down" ramps occur as demand increases. Insufficient ramping and dispatchable capability on the remainder of the integrated power grid may complicate these challenges.

Enhancing the dispatchability and certainty of RES is necessary to support more accurate resource adequacy planning and enhance market efficiency. Development of more sophisticated tools to evaluate resource adequacy is needed. To ensure a desired amount of intermittent generation is available for reliable operations, it may be advisable to influence, or mandate through regulations or market rules, more generation capacity than the needed amount to be installed at a particular substation or on the system.

A sudden loss of large amounts of RES may give rise to transmission congestions that are otherwise not predicted from the traditional N-1 contingency analyses. Operators must be able to respond to the sudden change in power flow that causes transmission congestions, constraints and even emergency situations. Sudden increased intermittent generation may also add to potential power quality problems such as harmonics and lamp flicker. This places a further burden on the operator who will now require additional and more flexible control actions to handle this type of "contingency".

Strengthening connections within an electrical power system and introducing additional interconnections to other systems can directly mitigate the impact of variable and uncertain RES. A general challenge for most RES, however, is that renewable generation is location specific, therefore concentrated renewably generated electricity may need to be transported over considerable distances and require network expansion although the level is dependent on the resource and location relative to existing network infrastructure.

Concerning system stability, changes in reactive power support and inertia are challenging tasks referring to a secure level of the grid. The grid needs a certain amount of rotating mass to compensate frequency and voltage deviations. With the on-going penetration of RES into the electricity system rotating mass of conventional power plants may become inadequate. The penetration level also affects the need for system reserves. It is common practice to establish reserve obligations based on the loss of the largest generating unit or a particular transmission contingency. However the change in renewable output not only imposes higher reserve needs, but also can occur so rapidly that it leaves little time to start up other units to refill the reserve. For this situation new kinds of reserves and activation schemes may be needed.

The lack of data and control of distributed generation (especially for TSOs) represents a particular challenge. Provisions of online information from small generators as well as legal and technical support for system operators to control generation and make use of the flexibility of small generators have to be achieved. Therefore the role of DSOs will expand and, since significant levels of RES are located and connected to low voltage grids, communication and cooperation between TSOs and DSOs will have to be strengthened since interdependencies between them will increase. •••

In addition, e.g. the operation of wind power plants can cause impacts related to power quality and harmonic penetration at the connection point and overvoltages by electromagnetic transient (EMT) phenomenon. The deep and fast loss of RES generation can cause also the following operational impacts on the power system:

- Surpassing the operational limits of transmission lines and equipment;
- Surpassing the power system limits in an area or region;
- Decreasing the performance of voltage stability and control;
- Decreasing the performance of dynamic stability and power system frequency control.

The ongoing transition towards a more and more unpredictable generation structure makes it inevitable to strengthen the transmission and distribution system. Besides this additional power reserves have to be analysed and integrated into the system.

1.3. What are the economic impacts on both sectors?

In general, major changes will be required in the generation plant mix, the electrical power systems' infrastructure and operational procedures to enable the transition to increased renewable generation while maintaining cost and environmental effectiveness. These changes will require investments far enough in advance to maintain a reliable and secure electricity supply.

The intermittent nature of RES and the difficulties in forecasting its output create a need for storage and load control to manage the challenge for both system operation and market design. Current market designs lack consistent economic signals for investment and the facilitation of asset replacement. This may lead to long construction outages while still using the system that is in service for increasing higher transfers and this can lead to increasing levels of unplanned outages. As a result, a number of issues need to be addressed such as:

- difficulties justifying investment when usage is intermittent;
- lack of consistent price signals;
- differing policies and levels of subsidy across borders;
- design criteria for the grid in areas with large demand and intermittent generation: Possible trade-off between local generation and grid capacity to provide sufficient security of supply;
- long term uncertainty about local or regional requirements as a result of changing energy policies;
- production from e.g. wind power far away from load centres leads to higher transmission losses that may need to be evaluated from an environmental perspective and not just conventional economic costs;
- use of additional generation reserves from other sources;
- implementation of System Protection Schemes (SPS) in critical areas; and
- reinforcement of the transmission grid.

The development of advanced communications technology, with smart electricity meters linked to control centres, offers the potential to access much greater levels of demand flexibility. Hence the impacts of different price signals, subsidies and certain market rules need to be examined in relation to renewable generation. Incentives to modify and/or reduce electricity users' consumption (e.g. pricing electricity differently, such as higher prices during higher demand periods) can mitigate the impact of the low capacity credit of some types of variable generation. Furthermore, demand that can quickly be curtailed without notice during any time of the year can provide reserves rather than requiring generation resources to provide this reserve. Demand that can be scheduled to be met at any time of the day or that responds to real-time electricity prices can participate in intra-day balancing thereby mitigating operational challenges that are expected to become increasingly difficult with variable generation.

From a regulatory perspective, a need for a less complex and less bureaucratic approach to control RES is required. In addition, technical regulation (e.g. Grid Codes) is needed to ensure reliable connection to the integrated power grid and assure acceptable system performance. Connection requirements for intermittent generation must include requirements for the frequency and voltage ride through capability to ensure intermittent generation does not trip unnecessarily. Clear definition of connection requirements will lead to standard designs and a lower long term cost to the design and operation of the power system.

Current market entry incentives and the immunity provision for non-delivery for RES put the conventional generation participants at a disadvantage and the rising share of renewables causes a decrease of full load hours of the conventional power plants and a decrease of the energy price. Due to the fact that electricity markets are driven by energy-only prices conventional power plants become more and more unprofitable because the costs of renewable energy generation are highly subsidized in many countries. Nevertheless gas prices are changing remarkably due to the exploitation of shale gas which has a significant impact on renewable economics.

For a smooth integration of RES into the energy system from an economical point of view it is indispensable that regulation and market design have to be adapted. Common rules are necessary especially in neighbouring countries to provide a certain amount if security for investments.

1.4. What are the operational challenges?

In a dispersed and /or RES dominated power system the technical changes impact the operation in real time already during the transition phase. Operational solutions of today might no longer be applicable tomorrow. To operate the entire power system according to the commonly agreed operational criteria delivers challenging tasks to the operators in the control rooms. The constantly decreasing conventional generation being replaced by RES results in less potential operational options and new challenges:

- maintaining the voltage profile within dedicated limits •••

while RES usually do not contribute to dynamic voltage/reactive power control;

- keeping the short circuit power within predefined values for sufficient selective protection functioning while especially rectifier coupled RES do usually not support short circuit currents;
- avoiding overloads due to missing controllability of especially micro and small generation (e.g. PV installed in low voltage systems);
- managing congestions due to priority of RES injections;
- keeping the power/frequency balance within dedicated limits while RES are usually not involved in load/frequency control and reserve management;
- guaranteeing the appropriate response from manageable resources;
- dispatching and controling of a large number of small renewable generators across both the transmission and the distribution networks;
- creating adequate tools for Supervisory Control and Data Acquisition (SCADA) and network models;
- defining and implementing more significant technical requirements e.g. thresholds for disconnection of renewables at off-nominal frequency and voltages (e.g. 50.2 Hz problem in Germany);
- defining and implementing additional requirements for power system frequency and voltage control, including SPS, as well as preventive measures to be carried out rapidly in real time;
- defining new requirements in the grid code in order to guarantee power system security; and
- establishing standardisation in data exchange and operation processes to allow cost effective integration in system operation.

Control room operators in transmission and distribution grids have to cope with these challenges and have to provide commonly coordinated actions despite the systems visibility covering all involved voltage levels and generation types.

To manage the system security appropriately the coordination of remedial actions which involve actions from diverse control rooms has to be increased dramatically. Due to the uncertainty of RES an increasing need for operational planning in the day-ahead and intraday time domain is seen.

Since physical laws do not stop neither at national borders/control areas in interconnected systems nor at borders between the transmission and distribution grids a close cooperation of the acting system operators (TSO-TSO/TSO-DSO) is required to cope with the overall system security comprising the operational planning and the real time operation. Bilateral and multilateral remedial actions may be executed to solve congestions instead of moving congestions through the interconnected system.

The unsatisfactory predictability and the low grade of controllability of RES lead to a higher risk of unforeseen system situations and therefore an increased risk of abnormal system situations. Emergency procedures and restoration plans have to be adjusted to the specific nature of RES.

It is clear that the increase of RES leads to dramatic changes in the operational procedures and to new requirements for tools and SCADA systems. Furthermore the change of the generation pattern fosters the closer cooperation between system operators at all voltage levels. The operational planning and the real time domain are affected and operators in the control rooms have to be prepared and trained to cope with these changes.

2. Can we afford a different speed in different countries with interconnected systems in this transition?

Not all locations have the same ability to use renewable generation systems (e.g. a wind farm in the desert or a solar park in the Antarctic). Some locations may have a lower economic justification compared to locations where the renewable resource is optimum. Therefore a different speed in the transition of the system when caused by RES cannot be avoided.

Different growth in different countries may lead to inefficient investment due to the lack of regional standards for compliant design. The increased uncertainty regarding long-term scenarios (e.g. energy storage) may also lead to inappropriate infrastructure investment and higher costs.

Where multiple power systems are interconnected across country borders, as in Europe, the lack of consistent economic signalling across all boundaries may lead to unwanted cross border transmission and technical solutions to stop the power flows (e.g. phase-shifter transformers) rather than appropriate investments to facilitate the most economic outcomes. Examples of this already exist for some countries in Europe.

Different priorities and policies of investment in interconnected network will cause heterogeneous network charges. An appropriate regulatory framework is necessary to allow a common market and trading of energy.

Integration of RES at different speed cannot be avoided due to the different environmental situations in different countries. Nevertheless consistent signals (economic and regulation) are needed to ease this problem.

3. What are the needs for further research in transmission / generation assets and new technologies?

To be able to handle the future challenges of a RES integrated •••

electricity system the current methods of planning, designing and operating the system as well as the common ways of maintaining the system have to be changed and enhanced. New technologies such as in the fields of cable and HVDC are seen as promising developments to help with this challenge. Because of the different load flows in the AC network there may also exist an increasing requirement for shunt and series reactive power control devices (Flexible AC Transmission System (FACTS) devices), to control the load flow on lines and the AC voltage throughout the AC network.

If the number of HVDC schemes embedded in an AC network increases significantly the concept of forming an HVDC Grid, e.g. interconnection on the DC side of the HVDC schemes, may become economically attractive, as the number of converter stations would be smaller [7]. Both cable and HVDC can help to solve the problem of enhanced power transportation and community resistance to grid enhancement. Research into cable and HVDC Grids is in progress in academia, within manufacturers and in research institutions.

Since engineering and project management is a significant (but not major) part of the cost of an HVDC scheme some cost reduction may be achieved by using "standard" or preferred ratings. Further cost reductions of HVDC schemes may be achieved through further research and development of semi-conductors, converter arrangement and HVDC converter components, e.g. DC breakers. By proving that cable as well as HVDC can help to smoothly integrate RES into the electricity system a higher rated view can be achieved. HVDC schemes perform differently to an AC line or a generator during faults and dynamics in the network and this different performance need to be taken into account in the design of the overall system protection. Furthermore, if multi-circuit AC overhead lines are partly converted to HVDC use, the steady state interaction between the circuits as well as the consequences of an unintended connection of the AC and DC circuits need to be understood and taken into account in the protection and design of the HVDC scheme and AC network. To successfully integrate more HVDC schemes within the AC network system, protection engineers will need to have a better understanding of the performance of HVDC schemes. In real-time operation new concepts for Hybrid-systems have to be developed, aligned and implemented. This again needs a close cooperation of the involved TSOs.

But research should not be limited just to transmission/ generation assets. To be able to securely operate the future electricity network several other areas have to be researched (e.g. communication, IT-security …). In the electricity system of the future the management of large volumes of data in a "smart grid" environment will be obligatory. The major problems of a "smart grid" are related to the huge amount of additional data that has to be collected, saved and turned into useful information. The introduction of RES accompanies with the need to develop new protection models and schemes. These will also require larger data volume and controllability of large number of distributed devices. One important issue is an appropriate level of security in this data exchange. Due to the interaction between a huge number of "smart grid" devices serious impacts to the electricity system can occur in case of coordinated cyber-crime attacks.

Another challenge of the integration of RES in the power system is the longer time required to build new transmission lines compared to the time required for installing RES plants. Where the enabling facilities are not mandated, transmission planners face more uncertainties. They need to respond to proposed plans for wind power plant installation, but face the uncertainty that the plans may not materialize. This puts the transmission providers at risk for possible stranded costs and potential transmission constraints if a significant amount of new energy sources surface elsewhere. There are two proposals to mitigate this risk and solve the problem with the objective of collecting and transmitting wind generation to the load centres:

- using the existent margins in the transmission system; and
- anticipating the planning and implementation of the new transmission system in sites/areas with high potential to install RES plants especially wind.

Research is needed in different areas to better integrate RES in the energy system. One major topic is seen in HVDC technology. Therefore a lot of research and development is needed in this field. But other areas like communication, security and handling of data should be reflected as well.

4. What are the impacts on social welfare?

One barrier for a smooth transition is the high investment cost of RES. Some countries provide investment subsidies that involve fixed price power purchase agreements. This skews the mechanism and behavior in a competitive market. In other situations when other financial incentives are used, the RES are free to participate in competitive bidding. However, owing to the intermittent nature of renewable generation, provisions are made in the market rules to exempt these resources from penalty for non-delivery. This puts the conventional generation sources at a disadvantage, and sets up the need for backup capability that might further erode market efficiency.

The reduction in the level of dependable generation increases the operating reserve requirement. This exerts an upward pressure on the energy market price, increases the market operating costs, and evokes a need for a new kind of reserve requirement.

The coordination of lots of different, independent actors related to the transition and the penetration of RES is a major difficulty for securing investments in an uncertain environment. This problem is reinforced by the low public support when costs are imposed on those who can least afford it. The resulting political pressure can lead to inconsistent policy positions that can have the effect of delaying the transition or increasing the long term costs.

Due to the different supporting mechanisms in the country an unbalanced situation in the market occurs. The increasing penetration of RES leads to a steady decreasing energy price which puts conventional power plans at a disadvantage and makes several of them unprofitable.

5. Conclusion and Summary

Increased penetration of RES occurs all over the world at various stages of maturity and different levels of market share. RES can be integrated into all types of electrical power systems from large interconnected continental-scale systems to small autonomous island-systems. System characteristics including the network infrastructure, demand pattern and its geographic location, generation mix, control and communication capability combined with the location, geographical footprint, variability and predictability of the renewable resources determine the scale of the integration challenge.

As the installed capacity of RES increase, additional electricity network infrastructure (transmission and/or distribution) will generally have to be constructed. Integrating variable RES, such as wind, with increasing levels of capacity, makes maintaining reliability more challenging and expensive.

These challenges and costs can be minimized by deploying a portfolio of options including electrical network interconnection, the development of complementary flexible generation, larger balancing areas, intraday and sub-hourly markets, demand that can respond in relation to supply availability, storage technologies, enhanced forecasting, system operating and planning tools. Finding the cost-minimal portfolio is a substantial challenge.

In summary there are three key messages in this paper:

- in the past with growing dispersed generation it was assumed that transmission lines would be a relic of the past. As we know today the opposite is true. There is now a need for more lines and transmission assets (such as FACTS, HVDC, Hybrid systems) than before due to the need to locate of RES in areas of sun or wind that are often some distance away from the existing infrastructure;
- to eliminate the existing obstructions for the transition of the system the multiple impacts of RES on system operation, grid development and generation pattern have to be clearly understood and communicated to decision makers and the public; and
- Grid codes and technical standards as well as regulatory rules have to be adapted and need to take into account the impact of RES on the whole energy system.

Acknowledgement

The C2 chairman Joachim Vanzetta especially wants to thank Prof. Klaus Fröhlich, President of CIGRE, Mark Waldron, Chairman of Technical Committee, Philippe Adam, Secretary General of CIGRE and all members of the technical committee for their support, their thoughts, knowledge and fruitful discussion during the drafting phase of this paper.

A special thank for their detailed and valuable contributions to B. Andersen, T. Carolin, S. Cisneiros, N. Cukalevski, P. Dumarquez, P. Gomes, S. de Graaff, J. Jacobs, B. Li, S. Nilsson, K. Papailiou, T. Papazoglou, M. Power, T. Ringelband, P. Roddy, H. Sarmiento, C. Schneiders N. Singh, P. Southwell, U. Spanel. ■

BIBLIOGRAPHY

[1] SEC (2008) 85 - Joint impact assessment on the package of implementation measures for the EU's objectives on climate change and renewable energy for 2020 (2008)

[2] EC JRC, Trends in global CO2 emissions (2013)

[3] Fifteenth Inventory - Edition 2013, Worldwide electricity production from renewable energy sources, Stats and figures series (2013)

[4] The World Wind Energy Association (2014)

[5] Renewable Energy Sources and Climate Change Mitigation IPCC, 2011 - Ottmar Edenhofer, Ramón Pichs-Madruga, Youba Sokona, Kristin Seyboth, Patrick Matschoss, Susanne Kadner, Timm Zwickel, Patrick Eickemeier, Gerrit Hansen, Steffen Schloemer, Christoph von Stechow (Eds.) Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1075 pp.

[6] Challenges in the control centre due to distributed Generation and Renewables – Michael Power, Nisheeth Singh, Maria Sanchez, Carsten Roggatz, Eamon Garrigan, Igor Aronovich, Vivek Pandey and George Ivkovic - CIGRE Smarts Grids: Next Generation Grids for New Energy Trends – Lisbon April 2013

[7] HVDC Grid Feasibility Study – Cigre Technical Brochure 533, Working Group B4.52, 2013