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IEA Implementing Agreement ENARD

Annex IV: Transmission Systems

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Zusammenfassung

Die Internationale Energie Agentur (IEA) lancierte 2006 ein Implementing Agreement zu „Electricity networks analysis, research and development (ENARD)“. Ziel von ENARD ist es, Ansätze aufzuzeigen, wie die Leistungsfähigkeit von Stromnetzen verbessert werden kann mit Blick auf liberalisierte Strommärkte, die Integration von erneuerbaren Energien und die erforderlichen die Netzerneuerungen. Die Resultate von ENARD sollen insbesondere verwendet werden als Entscheidungsgrundlage für Netzbetreiber und die technologiespezifische Industrie, aber auch für die Beratung von Regulatoren und Regierungen. Damit soll auf politischer Ebene ein Bewusstsein geschaffen werden für die zentralen Herausforderungen und Lösungsansätze im Bereich der Stromnetze.

Der im vorliegenden Jahresbericht dokumentierte IEA ENARD Annex IV nahm im Frühling 2009 seine Arbeit auf und befasst sich im Sinne eines Teilprojekts mit dem Gebiet der Übertragungsnetze bzw. Transmission Systems. Der Annex IV ist auf zwei Jahre bis Mitte 2011 ausgelegt. Teilnehmende Länder sind die Schweiz, Norwegen, Schweden, Finnland, Dänemark, Italien, Belgien und die USA.

Projektziele

Ziel des ENARD Annex IV ist es, eine langfristige Vision aufzuzeigen für die Entwicklung von Übertragungsnetzen bis nach 2020. Dabei sollen Brücken gebaut werden zwischen der politischen Agenda und den Aufgaben von Stromnetzbetreibern. Die drei „R“ umschreiben den Fokus von ENARD: Network Renewal (Netzausbau und –erneuerung), Renewables Integration (Integration erneuerbarer Energien) und Network Resilience (Widerstandsfähigkeit bzw. Ausfallsicherheit des Stromnetzes). Im Vordergrund stehen die Rolle des Stromnetzes als Wegbereiter eines funktionierenden und nachhaltigen Energiemarktes, die Identifikation von Hürden beim Netzausbau, Herausforderungen bei der Netzplanung, der Beitrag neuer Technologien zu einem sicheren Netzbetrieb oder die Integration von CO2-armer Energieproduktion.

Der Annex IV ist aufgeteilt in zwei parallele Aufgabengebiete (tasks) mit je drei sequentiellen Aktivitäten:

Task 1: Netzausbau und Marktanalyse

1.1. Übersicht über verfügbare Methoden und Technolgoien zur Netzausbauplanung und Marktanalyse

1.2. Einschätzung des Potentials neuer Methoden und Technologien zur Leistungssteigerung von Stromnetzen und zur Analyse von Strommärkten

1.3. Identifikation von notwendigen neuen Methoden und Technologien

Das erste Aufgabengebiet umfasst unter anderem den Zusammenhang zwischen Netzplanung und Marktregeln, Undergrounding (Verlegung von Hochspannungskabeln anstelle von Freileitungen), Anreize zur Finanzierung von Investitionen, Voraussetzungen für eine verstärkte Windintegration, Weiterentwicklung des Engpassmanagements.

Task 2: Netzbetrieb und Netzsicherheit

1.1. Übersicht über verfügbare Methoden und Technologien zur betrieblichen Netzüberwachung und –kontrolle

1.2. Einschätzung neuer Methoden und Technologien um die Überwachung und Kontrolle von Stromnetzen zu verbessern.

1.3. Identifikation von notwendigen neuen Methoden und Technologien

Das zweite Aufgabengebiet umfasst unter anderem regionale Regelenergie- und Echtzeitmärkte, flexible Regelenergie bei verstärkter Windintegration, eine aktive Nachfrageseite, grossräumige Monitoring-Systeme (WAMS), Technologien zur aktiven Steuerung von Stromflüssen (z.B. FACTS und HVDC), ein regional koordiniertes Krisenmanagement.

Durchgeführte Arbeiten und erreichte Ergebnisse

2010 fanden zwei Workshops im Rahmen des Annex IV statt. Der Workshop vom 11.-12. Januar 2010 in Leuven (BE) wurde genutzt, um das Papier mit den Zwischenresultaten des ENARD Annex IV zu finalisieren, welches im August an der CIGRE Session 2010 vorgestellt wurde (vgl. Anhang). Beim zweiten Workshop vom 20.-21. Mai 2010 in Washington DC lag der Schwerpunkt auf den Programmen des U.S. Department of Energy (DOE) im Bereich Netzausbau, Netzerneuerung und Smart Grid. Die Arbeit von Annex IV wurde zudem an zwei ENARD Workshops im April und September vorgestellt.

Internationale Zusammenarbeit

Vertrag Nr. 154037 betreffend das Projekt „IEA IA ENARD Annex IV – Teilnahme und Mitarbeit."

Bewertung 2010 und Ausblick 2011

2010 konnten die Zwischenergebnisse von ENARD Annex IV im Rahmen der CIGRE Session präsentiert werden. Zudem erlaubte der Workshop mit dem U.S. Department of Energy (DOE), die amerikanischen Ansätze bezüglich Netzausbau, Netzerneuerung und Smart Grid in die Arbeit miteinzubeziehen. Bis Juni 2011 soll der Annex IV abgeschlossen und ein Schlussbericht gemäss Deliverables vorgelegt werden.

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CIGRE 2010

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IEA Enard:- International Collaboration On Developments In Transmission Systems R&D

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SUMMARY

This paper reports the ongoing activities in IEA ENARD's Annex IV "Transmission Systems". The Annex was formally adopted by the ENARD Executive Committee in September 2008, with the aim to establish a long term vision for developments in transmission systems beyond 2020. On this background the objective is to address the main barriers towards the necessary development of transmission systems and to identify the most promising solutions related to the various operational, planning, technological, and market aspects, including the need for development and application of new methods and tools. Finally the Annex is expected to address the specific R&D activities needed as a result of the vision.

There is a need for new solutions to deal with variable and less controllable generation and to cope with the distance between generation and the main load centres. The solutions rely on development of transmission capacity and storage, taking advantage of further technological developments such as VSC-HVDC. In order to enable necessary investments it is equally important to establish a suitable regulatory framework and market design, allowing close coordination among the involved entities and reducing the investment risk. Further, more refined methodologies and tools need to be adopted to identify the best options for grid expansion.

The future development will require significant changes in the way power systems are operated and controlled. A main barrier is the uncertainty related to management of reserves and balancing control, ranging from secondary control in the minute range to tertiary control and intra-day markets. A key message is that there is a need for a better understanding of the various challenges related to balancing the increasing variability in power generation and load demand on this time scale. New tools and analysis techniques must be developed to properly address these issues.

KEYWORDS

Transmission system developments, Power system operation, Power system planning, R&D needs.

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1. INTRODUCTION

The crucial role of electricity transmission and distribution (T&D) networks in the delivery of energy policy objectives was recognized via the establishment of ENARD, the IEA Implementing Agreement on Electricity Networks Analysis, Research & Development [1]. The International Energy Agency (IEA) acts as energy policy advisor to its twenty seven OECD and associated member countries in Australasia, Europe and North America. Energy technology collaboration is pursued via a framework of more than forty "Implementing Agreements", which enable experts from different countries to optimise R&D investment by working jointly on information collation, research, analysis and dissemination.

The aim of this paper is to report the ongoing activities and main findings in IEA ENARD's Annex IV "Transmission Systems". This Annex was formally adopted by the ENARD Executive Committee in September 2008, with the aim to establish a long term vision for developments in transmission systems beyond 2020. Annex IV aims to address the main barriers towards the necessary development of transmission capacity and to identify the most promising solutions related to the various operational, planning, technological, and market aspects, including the need for development and application of new methods and tools. Finally the Annex is expected to address the specific R&D activities needed as a result of the vision. The Annex is meant to take an overall system view, considering transmission in the overall system context and as a key enabler in allowing operation of generation in a well functioning electricity market [2].

The work is organised in two main activities:

- Expansion Planning and Market analysis
- System Operation Management and Security

This paper describes the status of work within the Annex during its first year, with main focus on information collation and the assessment of available methods and tools for transmission system operation and expansion planning. The paper is organised as follows: Chapter two provides a general background and motivation for the work describing the main objectives and tasks in planning and operation of power systems and transmission networks. Chapter three introduces the long term vision for transmission system developments that serves as a starting point for the further work of the Annex. The two main activities of the Annex work, focusing on planning and operation of power transmission systems are addressed in Chapters four and five, respectively, and finally some preliminary recommendations are presented in Chapter six.

2. OPERATION AND PLANNING OF POWER SYSTEMS AND TRANSMISSION NETWORKS

Transmission networks are key enablers to achieve important targets in the energy sector. The Lisbon Treaty [3] states that the European Union policy on energy shall:

(a) Ensure the functioning of the energy market,
(b) ensure security of energy supply in the Union,
(c) promote energy efficiency and energy saving and the development of new and renewable forms of energy,
(d) promote the interconnection of energy networks.

The US Department of Energy report [4] describes and analyses a 20% wind energy penetration scenario by 2030. It is concluded that this will require continuing evolution of transmission planning and operation, in addition to expanded electricity markets in USA.

These overall policy goals and scenarios are all very much related to the development of transmission systems regarding operation as well as planning aspects. A properly functioning electricity market and better interconnection of energy networks are essential in order to achieve renewable energy targets.

The transmission network is the main transport level for bulk electrical power. Transmission systems were originally made to interconnect regional and national power systems for better utilisation of generation capacity and reserves. Nowadays, the transmission networks are additionally more and more utilised for bulk power exchange between regions and countries [5], [6]. On the interconnected electrical network there must always be a balance between total generation and consumption. In this way the transmission grid can also be viewed as the main market place for electrical energy as this is the highest level where generation meets the load demand. As for all transport systems there will be congestions that must be managed as part of the market solutions and operating procedures. In order to reduce congestions, thus allowing an efficient market and a reliable integration of renewable generation, transmission planning plays a strategic role. To this aim, the transmission planning process must be coordinated and effective, driven by a regulatory framework that encourages the most useful investments.

Transmission system operation is in most countries the responsibility of a dedicated system operator. Normally this is a company regulated by national authorities, and the system operator task is very often executed by the same company that is also the main transmission grid owner. In Europe these companies are usually referred to as TSOs – Transmission System Operators. In other countries, e.g. in USA, they are termed ISOs (Independent System Operators) or RTOs (Regional Transmission Organisations). In this report we will use the term TSO throughout, but mainly referring to their responsibilities as (independent) system operators.

The main task of a TSO is to ensure secure and efficient operation of the power system by maintaining the continuous balance between power generation (supply) and consumption (demand). More specifically this means:

- Ensure security of operation: Monitoring and control of the power system to maintain overall balance (frequency and voltage control on different time scales) and security margins are the main tasks. The provision of sufficient primary and secondary controls (and reserves), either by own resources or through grid connection requirements and management of ancillary services, are important responsibilities.
- Ensure efficiency of operation: Provide fair and transparent conditions for all power market participants to ensure proper functioning of the energy markets[1]. Congestion management and determination of available transmission capacity / transfer limits (ATC, NTC) are key operational tasks.
- Ensure sufficient transmission capacity by promoting cost effective network development and the interconnection of energy networks. Transmission expansion planning and market analysis are the key tasks.
- Coordination of maintenance schedules can also be important tasks of TSOs in order to optimise efficiency and security of operation.

In order to perform the operational and planning tasks, there is a need for analytical tools and controls. These include:

- Off-line analysis tools and models for planning purposes
- Off-line and on-line analysis tools for operation planning purposes
- On-line operation monitoring and scheduling tools
- Equipment and controls to manage the system operation

[1] Note that it is no longer necessarily a TSO task to ensure long term adequacy of energy generation.

Power system operation is becoming an increasingly complex task with higher penetration of variable generation and with more interconnections and cross-border trade. Thus, the need for new tools and controls to address the future challenges is apparent and a main subject to be investigated further in IEA ENARD's Annex IV.

Reliability and security of operation have a price. In both operation and planning there is always a trade-off between security and reliability on one side and the efficiency of operation on the other side. Security of supply can be measured in terms of expected costs of interruptions, while the market efficiency can be measured by the price differences and total costs of congestions resulting as a consequence of re-scheduling or sub-optimal dispatch of generation.

The challenge in operation planning can therefore be viewed as an optimization problem where the goal is to determine power transfer limits (ATCs, NTCs) that minimize the total expected costs. This is illustrated in Figure 1. By comparison, in transmission investment planning, a similar optimization problem can formulated where the level of reliability is seen as a trade-off between cost of interruptions and the cost of network investments.

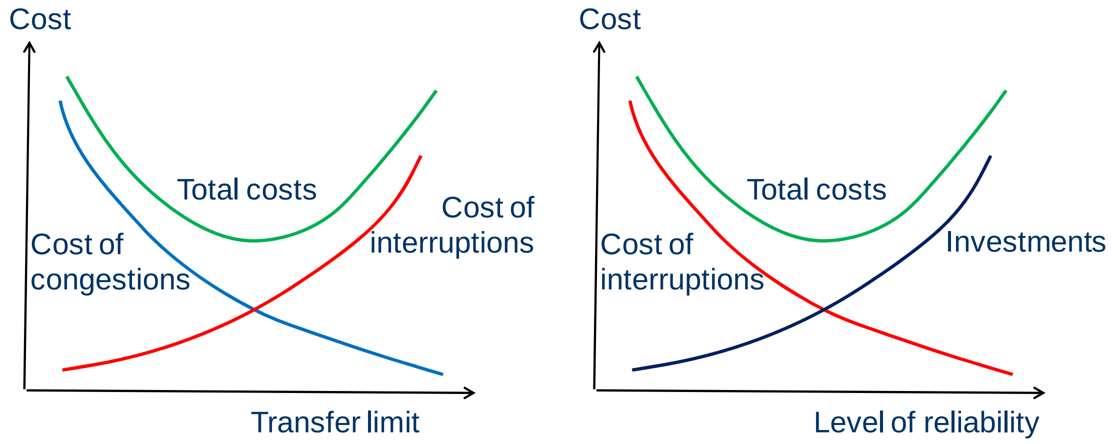

Figure 1. Expected operational costs as a function of transfer limit (left figure) and Expected costs as a function of reliability in transmission planning (right figure).

3. VISION FOR TRANSMISSION SYSTEM DEVELOPMENTS

The future transmission systems will undergo a shift in paradigm brought forward by changes in electric power generation and consumption. These changes of the future power system define the basis for addressing the main barriers towards a necessary development of transmission capacity. The overall vision is characterised in the following:

- ► Paradigm shift:
  - The paradigm shift is a consequence of the increasing penetration of large scale integration of variable renewable energy sources and distributed generation. In this scenario variable generation, such as wind power, will constitute a main part of what could be called the base power generation.
  - Fossil fuel generation, on the other hand, and other sources that are previously referred to as "conventional" generation will have a less dominant role, and to a larger degree these become peaking units that are necessary for balancing purposes.

This development will require significant changes in the development of transmission networks and the way the power systems are operated and controlled:

- ► In general there will be an increasing need for power transmission and energy storage.

- ► Large capacity (multi-GW) connections will become more common. This is needed both to strengthen the existing networks, and to accommodate more power exchange between the present interconnected power systems. New high capacity networks are also needed to transfer and exchange power from large offshore and other remote wind farms to consumption areas.

- ► This development will challenge present security standards such as the deterministic n-1 criterion. It will not always be possible to maintain n-1 security as applied today without additional system protection solutions. In other circumstances the n-1 criterion may not provide sufficient security, and there will be a push towards development and application of additional risk based security standards.

- ► Flexibility and controllability becomes increasingly important. This creates a need and opportunity for "smart solutions" both in distribution and transmission. Developments towards a more active demand side participation will be particularly important in order to cope with variability at a lowest possible cost.

- ► An evolution of the power markets is necessary to adapt to the changes. There will be implications on market design towards a larger degree of integration and harmonisation to reflect the stronger interconnection of transmission networks. Intra-day and real-time markets will become increasingly important in order to manage variable generation and to accommodate the increasing mix of power generation in a non-discriminatory way.

4. TRANSMISSION EXPANSION PLANNING AND MARKET ANALYSIS

The main goal of the first activity within ENARD Annex IV is to assess available methods and tools for transmission expansion planning, and to identify the need for new tools that integrate market modelling, network analysis and security assessment, also including the possible contribution of emerging transmission technologies. Based on Annex IV input, collected at the meetings and by a questionnaire set up purposely, the following remarks can be pointed out.

4.1 Methodological challenges with transmission planning

As a result of the vision, the following key issues can be pointed out regarding methods and tools.

1) Probabilistic approaches. Transmission expansion planning has changed much since the restructuring of the power sector. With vertically integrated utilities, transmission planning and generation planning were closely coordinated. The overall objective was to supply the demand (obligation to serve) as economically as possible with an acceptable degree of reliability and quality. Major uncertainties regarded the load development and fuel prices. Classical probabilistic methods for evaluation of generation and transmission system adequacy have been known for decades [7]; in many cases, however, deterministic worst-case analyses have been enough to recognise the need for transmission expansion and to define suitable solutions.

For many TSOs, the practice adopted to define the transmission developments is essentially based on deterministic analyses even today, with little or no support from probabilistic methods [8]. However, TSOs have to plan network development under greater uncertainties of the future power flows. In particular, the uncertainties of future power flows depend on the location of generation and consumption, which in turn are affected by policy measures and other factors. Increasingly important generation sources, such as wind generation, are intrinsically stochastic. As a consequence, the adoption of probabilistic approaches and tools becomes more and more relevant than in the past[2]. In some countries, like Belgium, the real driver for probabilistic analyses is the scenario variability brought about by the electricity market: the emphasis lies in the issue of transit flows crossing the country [9].

2) Cost-benefit analyses. In today's competitive market, TSOs have to plan the expansion of their own networks by pursuing maximum social welfare, while meeting reliability constraints. Identifying the transmission investments leading to maximum social welfare is a complicated task which is faced in different ways by the TSOs. The analysis must take into account multiple factors such as investment cost, operation and maintenance cost, improvement in market efficiency, losses reduction etc. These elements participate in the cost-benefit analyses. By such analyses it is possible to "objectively" compare and prioritise different transmission planning solutions. A major challenge for the TSOs is to respond properly both to the short-term market-based needs and the longer-term policy-based and security of supply needs.

The new paradigm for transmission expansion planning approach calls for increasingly comprehensive cost-benefit analyses, including e.g. emission policies, environmental impact costs etc. As many relevant factors as possible should be included in the decision process, in order to justify the investments before the institutions and provide clear motivations to gain public consensus. Along these lines, for instance, there have been attempts to quantify into monetary values some "subjective" features such as the visual impact of overhead transmission lines, by carrying out public surveys (e.g. in Norway). However, developing accurate cost-benefit analysis models is complex, firstly from the methodological standpoint; accordingly, tools should be able to integrate the different features [10].

3) Combine grid and market models. As a first step towards more exhaustive cost-benefit analyses, it is important that the benefits of transmission investments be evaluated at least by enhanced models integrating grid simulations and market mechanisms. According to the results of the questionnaire carried out, most countries use, in their planning process, tools combining models of the grid and of the market. Most system operators in USA combine grid and market models, too. They usually require a nodal network and market representation to obtain accurate price signals, see e.g. [19].

4) Transmission and Distribution interaction. Simulation of future scenarios should integrate the models of evolving factors, such as distributed generation and the demand flexibility offered by the smart grids concepts. Distributed generation has traditionally had an impact limited to the distribution level, but it may acquire relevance up to directly affecting the transmission system. The same applies when considering the smart grids concepts (cf. [11], [12], [13]). Within the smart grids framework, the issue of communication, control, and storage will be crucial.

5) Power system modelling and tool interplay. More cooperation among TSOs would require market and dynamic model exchange opportunities between different software packages. Efforts should be devoted to increase the interplay and data exchange capabilities of different tools and their user-friendliness [11].

4.2 Organisational challenges with transmission planning

Besides methodological aspects, the following key issues can be pointed out regarding the organisation of the power industry aimed to foster investments in generation and transmission, thus allowing an efficient, reliable, and sustainable power market.

1) Technical coordination. The issue of coordinated planning and market is very important from the technical and market standpoints. Traditionally, TSOs consulted the bordering counterparts only in case of new interconnection projects. Because of the increased power transfer over the

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[2] It is worth mentioning an ongoing CIGRE WG C4.601 activity aimed to evaluate the needs for, and challenges of, probabilistic methods for transmission planning.

interconnections, and the variability and complexity of operation, coordinated planning should be carried out for all projects that may affect the interconnected system operation. In Europe, the new organisation European Network of Transmission System Operators for Electricity (ENTSO-E) was founded in 2008 to improve the needed coordination [14].

2) Market design and policy/regulatory issues. Transmission projects require high investments and the life-cycle of the power assets is in the order of decades, hence care should be taken to make the right choices. Proper coordination should exist in particular between transmission planning and generation development. However, there are critical interactions that may or may not lead to grid developments that are really required: inadequate regulatory regimes may prevent from adopting the best solutions. In Europe, an Agency for Cooperation of Energy Regulators (ACER) was established in 2009 to improve coordination of the regulatory regimes.

There are several factors bringing risk in transmission investment. The planning process should be coordinated, and the time from decision to implementation should be reduced [5], [6]. A proper coordination between transmission planning and generation development is particularly important. This need refers to the permission issues, existing both in Europe and in the US: The time to build new transmission infrastructures is usually longer than the time required to build generation facilities, owing to the public opposition and the complex series of permits required.

A significant example of coordinated transmission planning is provided by the offshore site of Kriegers Flak. It involves three countries (Denmark, Sweden, Germany) where several solutions for the connection of the park to the three countries are explored, either AC or DC (VSC-based) or combinations. Different solutions imply different interconnection capabilities between the onshore grids of the involved countries. The Nordic Grid Master Plan [15] is an example of best practice in the direction of cooperation in transmission planning aimed to ensure a well functioning regional electricity market.

5. SYSTEM OPERATION MANAGEMENT AND SECURITY

The aim of the second activity is to assess available methods and tools for operational monitoring and control, and in particular to identify the need for new tools and methods to manage future challenges in balancing control also accounting for the potential of new transmission technologies. This also includes market design and management of balancing services, as well as methods for provision and distribution of operational reserves and other ancillary services.

An initial assessment is made based on Annex IV input, and the following remarks point to the most important challenges.

5.1 Operation planning and monitoring tools

The main challenge is related to management of risk in operation. The increasing variability in power generation makes it more difficult and more important to continuously monitor the state of the transmission system. The operators must be provided with accurate and sufficiently detailed information about the state of the system, including power flow and stability information. An area of great potential is Wide Area Monitoring Systems (WAMS) and control centre applications that are based on the use of synchronised phasor measurements. Together with developments in ICT this technology provides for a number of new applications and functions within control centres related to state estimation and improved monitoring. Further development and implementation of WAMS applications that improves the situational awareness from a system operation point of view is needed.

Another challenge is related to development and implementation of probabilistic (risk) based methodologies, including risk indices, to be applied in control centre tools for monitoring and operation planning.

5.2 Transmission technology and controls

A key issue to be addressed is the operational challenges related to massive development of offshore wind power. One example to illustrate this problem area is the visions of a North Sea "supergrid" to harness the potential of deep water offshore wind and tidal energy. Development of the necessary transmission capacity to tap into this potential and its control is a huge task. This requires new thinking about the management and exchange of balancing services, and the possibilities and impacts of enlarged control areas (across borders and interconnections) need to be thoroughly analysed.

For future management of large scale wind power the critical time scale is within minutes to hours, as illustrated in Fig. 2. A particular focus is the need for tools to properly understand and analyse the operational challenges related to power balance management, secondary/tertiary control and the need for reserves.

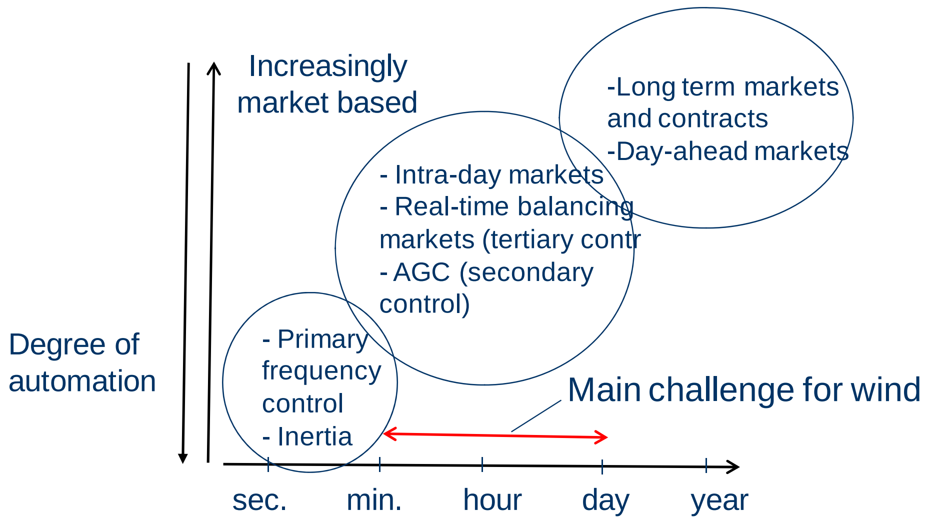

Figure 2. Main control tasks in power system operation, indicating the main future challenges with increasing amounts of wind energy.

Possible solutions that need to be further developed include:

- Development of flexibility (e.g. frequency response capability) of low carbon generation plant including renewables to ensure adequate balancing reserves under rapidly varying generation mix.
- Co-ordinated and optimised application of power flow control in the grid (phase shifting transformers, FACTS and HVDC).

5.3 Markets and organisational challenges

Fig. 3 illustrates how the variability and uncertainty in wind power generation in combination with a relatively inelastic demand potentially lead to large price variations. Larger variations and uncertainties about future prices may further reduce the efficiency and functioning of the electricity markets.

New electricity markets must be developed and existing markets must be adapted to the future system. Development of new balancing and real time markets is also necessary to make use of wind power forecasts that are continuously updated and improved closer to the operating hour.

More flexible loads are needed to increase the demand elasticity. Increased Demand Side Participation (DSP) and the use of loads are also needed as a resource in balance management [16].

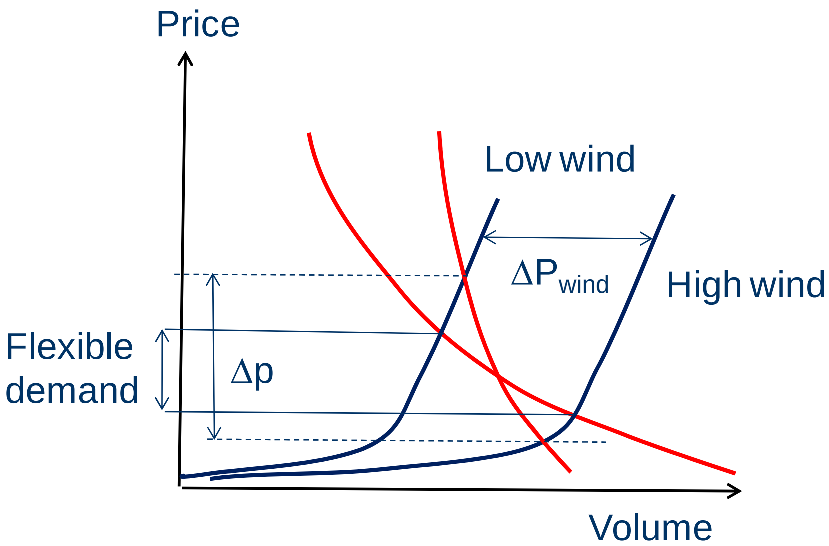

Figure 3. Supply and demand curves illustrating how the variation (or uncertainty) in wind power and the degree of elasticity in demand influences price variations in the market.

Improved communication and cooperation between TSOs is important for several reasons, including the need for better observability of neighbouring networks and closer cooperation in crisis management. Security of operation, balancing and congestion management in one area of a network often depend on the operating condition in the neighbouring areas or in the neighbouring networks. There are many examples that transmission congestions locally within one network are the reason for limited reserves or transfer capacities in a neighbouring network. The ability to get sufficient information about the state of the surrounding networks is thus important for the overall security of operation, and in particular to be able to perform congestion management in the most cost effective way. Modern communication tools such as interactive video conferencing systems may support operational cooperation among TSOs.

6. RECOMMENDATIONS TOWARDS FUTURE DEVELOPMENTS

This work has started out with a vision of a future power system that is characterised by a larger mix of generation sources and greater uncertainty about system loads as seen from a transmission system point of view. New generation comprises multi-GW power plants, including offshore wind farms and nuclear power plants (having entirely different operating characteristics) and a larger penetration of smaller generators largely embedded in distribution networks (distributed generation). Adding to the complexity of power system operation is also the development towards more active distribution networks. However, the “SmartGrid” concepts open up possibilities for increased demand side participation and flexibility that can be utilised for overall power system control purposes.

As a consequence there is clearly a need for increased transmission capacity to deal with the variability in generation and the distances between generation and the main load centres [17].

The transmission planning process should be accomplished with close coordination among the TSOs of the interconnected systems. This requirement also implies exchanging data on the forecast scenarios. New data exchange solutions should be investigated, comprising data for both market and network simulation models.

Market mechanisms should be more extensively integrated into network simulation tools. Accordingly, the adoption of advanced probabilistic planning approaches is required to evaluate and compare alternative solutions for transmission investments. Simulation tools and data models should be able to deal with large systems (i.e. including neighbouring countries) and consider a wide range of possible operating scenarios. This is necessary in order to properly identify the system-wide benefits of transmission investments and thereby avoid sub-optimal solutions [20].

The challenge with respect to operation and control is different depending on the time scales in question. The instant balance between generation and load in the second to minute range is maintained by automatic control systems referred to as primary controls (frequency and voltage control). Existing technical solutions can be further developed and more widely applied to maintain sufficient security and power system stability. Good power system models exists and tools are available, however further developments and improvements are necessary (but possible) in order to properly analyse the more tightly interconnected power systems of the future.

It is also anticipated that technical and market based solutions exist to manage power balance in the longer time scales, ranging from day-ahead markets to seasonal energy balances. Better market models and planning tools that integrate the market models with network simulations are necessary developments.

In operation and operation planning a main uncertainty is related to management of reserves and balancing control ranging from secondary control in the minute range to tertiary control and intra-day markets. A key message is therefore that there is a need for a better understanding of the various challenges related to balancing the increasing variability in power generation and load demand on this time scale.

A lot of research and development work is being performed in this area, but still there is a lack of available tools and generally approved analysis techniques to provide answer to the main questions:

- What degree of variability can the existing power systems and transmission networks cope with?
- What is the potential of new monitoring and control technologies (WAMS, WACS, FACTS)?
- What is the potential of demand side participation and demand side control?
- What is role and potential of new energy storage technologies?

Inherently, there is a trade-off between the need for increased transmission capacity and energy storage on one hand and on the other hand the potential of improved operation through better monitoring and control, larger and more coordinated balancing areas. More research is needed to understand the impact of the different technical and operational solutions.

Applications must be developed to improve the situational awareness and observability of power networks. Promising solutions are expected to emerge from developments of Wide Area Monitoring Systems that are well integrated with existing SCADA/EMS systems. As the system becomes more integrated, there will be an increasing need for system –wide controls based on real-time information from advanced telemetry (PMUs) and the use of activating controls in real-time. This requires more research and development [18].

Transmission congestions need to be managed in a co-ordinated manner on wider geographical regions than today. On the technology side the future research must concentrate on developing more cost efficient transmission solutions, requiring a minimum of maintenance. Increasing the capacity and efficiency of HVDC solutions will be particularly important to realise offshore transmission grids.

7. ACKNOWLEDGEMENTS

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