# C1 - 00

## SPECIAL REPORT FOR SC C1
## (System Development and Economics)

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## GENERAL INTRODUCTION

SC C1 aims to support electricity system planners worldwide to make the best of change – of the paradigm shift brought about by rapid evolution in generation patterns and economics, demand response, ICT, and in social, environmental and regulatory frameworks and expectations. The system needs to be planned to deal with the changes, needs to be built taking into account economic and public acceptance difficulties, and needs to be maintained well. These changes often imply a stronger grid with more large-scale interconnections and unprecedented interdependence between transmission and distribution.

SC C1's current work and three preferential subjects address these needs and uncertainties:

**PS1: Expanding Role of Social Factors and Transparency in Transmission Investment Decision Approaches:** With climate change and sector coupling tying electricity, heating and mobility systems closer together, it becomes clearer to citizens how strongly our daily lives are affected by electricity system decisions. We exert our influence on these decisions through our choices in the energy markets, but also through transparency and participation in investment decision processes. System planning needs to provide transparency and participation effectively and efficiently, and the papers under this PS show how the state of the art of that is evolving. Examples of questions are new elements in multi criteria evaluation; new stakeholders in the decision making process; and management of the scope of highly uncertain investments.

**PS2: Impact of Changing External Factors on Asset Management:** Asset management has evolved a long way from maintenance planning on individual assets towards a holistic management of sustaining and developing the system's assets with interactions among assets, risks, economic impacts, probabilistic analyses. Examples of questions are political, economic, regulation, weather, cyber and physical security factors; within-company strategy on grid modernization, e.g. monitoring, Big Data, asset analytics, security; asset usage and longevity effects from highly variable/non-schedulable generation.

**PS3: Coordinated Planning between Grid Operators across all Voltage Levels:** As generation and storage become more distributed and demand more responsive to price signals, coordinated planning between transmission and distribution becomes necessary to manage power flows frequently changing direction both across voltage levels and between neighboring systems. Examples of questions addressing more coordinated planning are methodologies for planning multiple interconnected transmission grids and for transmission-distribution interaction; how cost sharing and/or company organization and strategy can improve or impact coordinated planning principles; and the evolution of planning methods to account for smart grids, distributed generation, demand response.

The number of papers accepted and included in the C1 session is 38.

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## PS1: EXPANDING ROLE OF SOCIAL FACTORS AND TRANSPARENCY IN TRANSMISSION INVESTMENT DECISION APPROACHES

This section describes the 13 papers responding to PS1 in two categories: The first group explains how investment decisions are made more transparent. This aims to satisfy stakeholders who wish to understand why decisions are made, and also to gain comfort that these decisions are the right ones. The second group addresses how social and environmental factors can be taken into account in the decision-making process. The maturity of these processes varies across the globe but they are applied in many different countries.

### 1.1 Making investment decisions more transparent

C1-101 Multiple criteria data envelopment analysis for ranking of investments in transmission systems
The paper explains how in Brazil, analysis of qualitative and quantitative components of decision making, relating to auction bids for future transmission investment can be analysed to show how these components affect investment decisions.

C1-102 Project portfolio management for a transmission investment portfolio
The paper details how Statnett as the Norwegian TSO prioritises investments in a consistent way in order to make this process more transparent for stakeholders. It is an internal process with no explained external input.

C1-103 Assessing the impact of transmission investments on the Italian Ancillary Services Market using MODIS Simulator
In the case of increasing balancing service costs due to renewable generation, and how a TSO can use CBA to explain why an investment is in the best interest of stakeholders.

C1-105 Flow-based transmission capacity calculations for investment analyses - a novel approach for network development
This Dutch paper sets out an improvement to the flow-based capacity calculation model: The flow-based for investments model looks more closely at the network impact of investments to identify where bottlenecks can be reduced, focussing investments in the right area.

C1-106 A bottom-up approach for the development of Qatar long term load forecast
The paper proposes a new approach to LV load forecasting to prevent over-investment due to over-estimation of load growth. It uses high quality GIS data to inform the baseline.

C1-109 Planning process of Polish transmission grid under non-deterministic conditions
This paper explains how the public in Poland are consulted on the high-level development plans of the TSO, prior to these being agreed with the regulator. This limits illegitimate investment due to these increased levels of stakeholder engagement.

C1-110 Managing future uncertainties in the Ireland power system through the implementation of scenario planning
This paper explains how in Ireland stakeholders have an input into the development of scenarios which are then used to determine the future development of the transmission system. It explains a robust process of learning from other countries and developing a fit for purpose methodology for Ireland.

C1-111 Transpower's transmission asset investment approach and methodology for Waikato and upper North Island
This paper from New Zealand suggests a probabilistic approach to network standards to cope with network insecurity in a decentralised market where the TSO is a natural monopoly.

C1-112 Paradigm shift in transmission planning and regulatory changes approved in Chile in 2016
This paper describes the process in Chile of introducing new regulatory law. It includes the use of stakeholder groups and experts to gain consensus for the future direction of the electricity system in Chile.

C1-113 Stakeholder participation in the development of the electricity grid: the INSPIRE-Grid project
The paper sets out how in Germany and Europe a stakeholder engagement process is proposed on individual build projects to reduce the likelihood of opposition to projects.

**Questions**

Q1-1: In those papers and countries where different criteria are used, how explicitly are those traded off against each other, e.g. economic benefits vs. visual impact vs. $CO_2$ reductions? What is international experience with differences in value placed on different criteria by TSOs, regulators, governments and interest groups?

Q1-2: In which examples has public consultation changed the development plan? How has it changed, and how much has this helped reduce opposition to the new infrastructure?

Q1-3: Different papers address different information the TSO is transparent about, e.g. business plans, scenarios, network plans, line routings, cost-benefit analyses. What is international experience with how much stakeholders and citizens appreciate the different kinds of transparent info, and how this affects public support for new infrastructure?

Q1-4: What is international experience with the danger that investments cost more due to transparency and ensuing planning adjustments, but stakeholder opposition continues and further delays occur?

### 1.2 Taking into account Social Factors in the decision making process

C1-104 Trends in transmission planning uncertainty and the impacts and value of leveraging flexible investment strategies and technologies
This US-American paper proposes a scorecard approach to measure the benefit of quicker more flexible transmission solutions over traditional large build options. The impact on the environment can be reduced which has a big social benefit.

C1-107 Optimisation of the Burkina Faso electricity mix at the 2030 horizon
The paper addresses the increasing social unacceptability of thermal generation (e.g. oil) by assessing how PV generation can meet the increasing demand in Burkina Faso.

C1-108 The Mediterranean Master Plan
All TSOs from around the Mediterranean Sea have together produced a coherent plan for investment in transmission to address economic growth and the 'green' agenda.

**Questions**

Q1-5: What are the range of social factors that can be catered for in multi-criteria scorecards or analyses, in addition to environmental? How easy was it in international experience to agree on the different criteria? How stable are the different non-economic criteria over the past years? For example, has the value placed on environmental criteria compared to economics increased or decreased, and why?

Q1-6: In international experience, how much have non-economic criteria impacted actual project plans?

## PS2: IMPACT OF CHANGING EXTERNAL FACTORS ON ASSET MANAGEMENT

The eight papers under this asset management preferential subject address extreme weather, automated reliability tools, future strategic grid expansions, evaluation of surveys, optimization of maintenance and renewal strategies, managing uncertainties of power flow, power flow control improving transfer capacity and efficient facility renovation, consistent evaluation of failure consequences, historical statistical information to estimate economic end of life, and integration of sustaining and planning activities.

The papers are classified into PS2's three subtopics, namely:

1. Political, economic, regulation, weather, cyber and physical security factors, etc.
2. Within-company strategy on grid modernization, e.g. monitoring, Big Data, asset analytics, security
3. Asset usage and longevity effects from highly variable/non-schedulable generation

### 2.1 Political, economic, regulation, weather, cyber and physical security factors, etc.

C1-206 Experiences and procedures in dealing with typhoon situation to coal-fired power plant
This paper from Thailand considers the impact of severe weather, such as tropical storms and typhoons, on a coal-fired power plant, and provides clear rules to follow or strict guidelines for unforeseen events. The rules / guidelines consider storm severity level index, storm category criteria, individual responsibilities of employees, safety rules. The paper provides a case study of an application.

**Question**

Q2-1: Impacts of climate change and extreme weather conditions are increasingly a consideration for network security and resilience. Can the author and others provide their experience of requirements from the political, economic or regulatory environment to mitigate these impacts (from an asset management and/or planning perspective, e.g. microgrids)?

### 2.2 Within-company strategy on grid modernization, e.g. monitoring, Big Data, asset analytics, security

C1-201 On developing automated tools for reliability planning
This paper discusses how to value automated tools outside of commercial software for transmission planning, to address increased uncertainty and an increased number of technology solutions. It proposes that automated studies save time, enable more complex analysis, improve the quality of results. It identifies tools that are candidates for automation. It further describes key automation traits to be considered and provides an example within California Independent System Operator's (CAISO) Transmission Planning Process (TPP).

C1-203 Strategic planning of the Egyptian transmission system under a strong increase of the installed generation capacity
This paper discusses the Egyptian Electrical Transmission Company (EETC) development of the transmission network 2015 – 2025. It presents the overall methodology and key findings.

C1-205 Valuation approaches to risk in asset management in Australia
This paper explores utilities' risk valuation processes including the use of asset health and asset criticality. Results of a survey of Australian utilities' valuation approaches to risk management, and approaches to high impact low probability event risks are presented.

C1-208 Optimization of maintenance and renewal strategies for towers in France
The numerical tool MONA combines complex system modelling and risk analysis to simulate the behaviour of the whole asset management system of a TSO for optimized maintenance

and renewal strategies. MONA considers 4 main subsystems: physical assets including their degradation curves, renewal and maintenance strategies, the network's electric constraints, and the corporate organization and resources. An example for painting towers is provided.

**Questions**

Q2-2: What is the international experience with the standardization and commercialization of new kinds of IT tools for the grid planning and asset management process, especially related to analysing large numbers of scenarios?

Q2-3: What is the international experience with system expansion planning and asset management using the same models and valuations, and explicit risk valuations?

### 2.3 Asset usage and longevity effects from highly variable/non-schedulable generation

C1-202 Managing uncertainty in the power flow studies of South Australian transmission network

The paper proposes an alternative to Monte Carlo analysis, namely Sparse Grid Interpolation (SGI), and provides a test case on historical and forecasted power system data for the South Australia transmission grid. It further discusses the increased value of probabilistic vs. traditional deterministic power flow model analysis, with increasing penetration of renewable generation. The model quantifies uncertainties of bus voltages and line flows resulting from uncertainties in demand, generation, network structure and parameters.

C1-204 Using modular power flow control elements to improve transfer capability, reduce constraints on renewable generation, and alleviate congestion

This paper investigates modular power flow control devices to alleviate congestion on transmission lines resulting from new generation dispatch patterns which cause transmission constraints (as a result of large amounts of solar and wind energy in South Australia). It describes the economic application of improving the power transfer capability of transmission corridors by improving average utilisation of transmission lines.

C1-207 Efficient facility renovation using asset information

This Japanese paper presents a three step asset management plan, namely "data collection", "data analysis and prioritization of replacement" and "planning and practice of replacement", within limited time, budget, skilled workforce and planned outages. Data from substation facilities and online monitoring systems is collected automatically, and linked with inspection results and accident information. Data analysis and prioritization tools include transformer failure risk, transmission line corrosion estimation map, remaining lifetime of lines.

**Questions**

Q2-4: Faster simulation tools are an alternative approach to the automation of large numbers of scenarios discussed above. What is the experience of statistical validity with methods such as in C1-202 as changing input data (e.g. PV penetration, demand response, weather conditions) can change parameters?

Q2-5: What is international experience with modular power flow control devices with respect to network reliability, especially if many controllable devices are installed on one line or in the overall system? What is experience with failure mechanisms and consequences of failure?

Q2-6: How to decide which and how many substations to monitor? What is the current percentage of substations being monitored for automatic data collection in Japan and other countries? Does the information feed into system expansion planning?

Q2-7: What is international experience on the potential risk reduction or value of embedded generation, microgrids and distributed energy storage systems within the optimisation of maintenance and renewal strategies?

## PS3: COORDINATED PLANNING BETWEEN GRID OPERATORS ACROSS ALL VOLTAGE LEVELS

PS3 includes three subtopics:

- Methodologies for planning multiple interconnected transmission grids and for transmission-distribution interaction; we address this in two subtopics of impact of HVDC & HVAC technologies on planning (4 papers), and of planning criteria and methods especially under uncertainty (5 papers).
- How cost sharing and / or company organization and strategy can improve or impact coordinated planning principles; the 4 papers (incl. 1 also addressing the first subtopic) focus especially on cases of international interconnections of continental scale.
- The evolution of planning methods to account for smart grids, distributed generation, demand response; the 5 papers focus especially on the coordination of planning of transmission and distribution system operators.

### 3.1 Impact of technologies on planning – HVDC & HVAC

C1-302 Converting regional EHV AC transmission to HVDC (USA)

C1-303 Improving the electric interconnection between the grids of Mexico and United States by using HVDC systems (Mexico)

C1-304 Planning a meshed HVDC offshore grid in the North Seas (Belgium)

C1-312 TCSC Application to increase transmission cmpacity and ensure SSR Mitigation in Korea Power Grid (Korea)

Evolving from HVDC links to HVDC grids is one of the challenges of the paradigm shift in energy systems, driven by the need of long distance bulk transport of renewable energy generation to load centers. HVDC grids can be either embedded into existing AC grids or newly developed for off-shore wind farms. An intermediate step for HVDC grids, multiterminal links, some already in operation, require special modelling and analysis: in particular for fault analysis, control & protection strategies. Standards, procedures, and tools need to evolve to account for these needs. Moreover, there is very little operational experience with fundamental components, e.g. DC breakers. For off-shore grids, where HVDC often is the only option, an important issue is the definition of a set of technical criteria which may be different from planning criteria for onshore. For a cross-border offshore grid, several strategies are possible, which could lead to very different offshore grid structures (topologies).

**Questions**

Q3-1: Which are the most challenging aspects for design and planning of HVDC grids? Is the HVDC grid option already cost-effective? In particular, what is the state-of-the-art of DC breakers and how does it affect the HVDC grid business case?

Q3-2: Which are the most promising “concept” grid topologies and structures with HVDC and HVAC, and why?

### 3.2 Planning criteria and methods, dealing with growing uncertainties

C1-301 Managing risk: recommendations for new methods in system development planning (UK/Belgium)

C1-308 Application of PTDF methodology to exchange capacity calculation and contingency analysis (Spain)

C1-310 Enhanced transmission expansion planning strategy with penetration of renewable energy resources for Egyptian grids

C1-311 Transitional refinements in Point of Connection Transmission Pricing Implementation Plan India

C1-317 Optimal asset planning based on actual demand trend (Japan)

The traditional approach to address uncertainties in system operation/planning is to build and analyse a set of snapshots representing a limited number of "worst conditions/combinations" of contingencies in grid elements, load spikes or generation outages; the weak point here is the somewhat subjective selection of snapshots. New methodologies are being introduced (e.g. PTDF = Power Transfer Distribution Factor), exploiting higher computational capacities and stochastic generation values; their aim is to provide a comprehensive screening of e.g. every hour in a year and to pinpoint in a fast and automated manner the critical snapshots to be further investigated in dynamic or stability studies.

More and more, planning of future power system requires careful consideration of the risk dimension and relevant metrics. Risk assessment is an important feature for a system planner to be added to the Cost/Benefit Analysis as a necessary tool for completing the techno-economic analysis. These include the need for better data to quantify likelihoods of unplanned outages and key dependencies, to study a range of credible future operating conditions, to adequately model control responses and operator decisions pre- and post-fault. Failure to address the full range of potential operating conditions can result in over- or under-investment.

**Focus on fast growing/downsizing markets**

In fast growing and largely meshed power systems, an important issue is how to optimise the subsequent steps of developments in order to achieve the overall optimisation of system costs and performance. Artificial Intelligence, self-learning techniques and sophisticated mathematical models are being developed and introduced in grid operators' planning toolbox. Downsizing power systems face an opposite problem, but with similar recommended solution, and requiring tight coordination among the affected different grid operators.

**Question**

Q3-3 In the direct experience of authors and contributors, are the risk management and planning under uncertainty approaches described in the papers general consensus and being implemented for decision making step by step worldwide (in operations, planning, and asset management), or are there cases where very different approaches need to be used?

### 3.3 Interconnections

C1-303 Improving the electric interconnection between the grids of Mexico and United States by using HVDC Systems (Mexico)

C1-305 Research on African transcontinental power grid interconnection planning for large-scale clean energy integration and transmission (China)

C1-307 Connecting South Asia with HVDC (Sweden)

C1-309 Impact of Adriatic submarine HVDC cables to South East European Electricity Market Perspectives (Croatia)

Planning interconnections of power systems is complex, with technical and economic analyses. They have benefits for reliability, security, resiliency, efficiency, economy and environment.

Both costs (investment and operational) and benefits depend on the technology employed. UHV technologies enlarge the possibilities of interconnecting systems on a continental or even cross-continental basis; SC C1 has a WG (C1.35) on global network feasibility (tutorial on 28 Aug.)In macro-regional planning, the combined effects of several interconnection projects create a sequencing issue in the project-by-project economic analysis and suggest an overall coordinated planning approach across countries.

### Questions

Q3-4: In the cases described in the papers, how much are the relative contributions to the benefits of the new interconnections, relating to: energy market transactions, complementarity of load/generation profiles, reserve sharing, increase in stability, increase of security of supply/resilience, local particular conditions?

Q3-5: For already interconnected large synchronous areas, which are the conditions to select among AC, DC or back-to-back architectures a further interconnection to a new country?

## 3.4 Coordinated planning between grid operators, especially transmission-distribution

C1-306 Integration of large scale renewable through co-ordinated system planning in India

C1-313 Dealing with conflicts between DSOs and TSOs in procuring ancillary services (UK)

C1-314 Coordinated planning of ENWL distribution network and NG transmission network in Cumbria area for the Moorside Project (UK)

C1-315 Coordinated TSO and DSO network development plan on the islands of Cres and Lošinj (Croatia)

C1-316 International experiences on subtransmission network planning and delivery: A proposal for Chile

For effective utilization of resources in different parts of the power supply value chain, network infrastructure needs to allow seamless flow of power across voltage levels. If different entities operate distribution and transmission, DSO service requirements might be negatively impacted by the operation of the transmission network, and vice versa, especially if there is congestion in distribution due to electric vehicle charging or distributed resources.

Coordination of TSO and DSO planning is becoming more beneficial and needed for efficiency of investments, the more distributed resources and distribution congestion there may be. In case that investing by one network operator provides significant reduction of costs for the other network operator, the network operators could jointly request from the regulator special treatment of the investment. Additional options of this kind are created through “non-network” (e.g. storage, demand response) alternatives to network capacity expansion.

### Focus on a grey area: subtransmission

Treatment of subtransmission is scarce and not homogenous in the literature; some operators do not define the segment, while others do not define a detailed treatment, with the identification mostly made by voltage level and/or by grid architecture/topology; by its nature, subtransmission can become the laboratory for pilot projects of tighter collaboration TSO-DSO.

### Question

Q3-6: What is the best international experience with TSO/DSO coordinated planning, and with “non-network” or “third party” solutions to match security criteria most efficiently? Are there especially good examples on the subtransmission level ?