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SPECIAL REPORT FOR SC C1 (System Development and Economics)

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Special Reporters

GENERAL INTRODUCTION

Across the world, power systems are expanding at different rates, utilising a range of evolving technologies and embracing the need to reduce carbon output to varying degrees. The resulting increase in the level of uncertainty attached to long term decisions make system planning, infrastructure investment and asset management particularly challenging.

The three preferential subjects chosen for this special report are specifically aimed at addressing these challenges. Thirty-three papers have been received on these subjects. The report identifies several common themes and poses questions to test and stimulate debate on the various ideas and solutions put forward by the authors. These questions are intended to stimulate contributions and discussion from the broader audience and not just those who have written papers.

- **Preferential Subject 1:** Improvement in system and asset performance through application of enhanced Asset Management methodologies, Eric Rijks, eric.rijks@tennet.eu
- **Preferential Subject 2:** New system solutions and planning techniques, David Alvira, dalvira@ree.es
- **Preferential Subject 3:** Securing investment in transmission networks with increasing RES, Olivier Herz, olivier.herz@rte-france.com

PS1: IMPROVEMENT IN SYSTEM AND ASSET PERFORMANCE THROUGH APPLICATION OF ENHANCED ASSET MANAGEMENT METHODOLOGIES

The asset management business model gained rapid popularity through the 1990's as many utilities responded to liberalization of electricity markets and associated de-regulation and re-regulation. As a result organisational changes were implemented to focus on asset management issues. In parallel with this, looming problems associated with large fleets of aging infrastructure became apparent.

The challenge for asset managers of electricity utilities is to balance performance, risks and costs. As a result utilities have been motivated to develop more rigorous and quantitative methods for business case analysis to justify investments in assets.

The high penetration of RES is causing an increase of load cycling of conventional power plants. The load cycling is having a great impact on the aged power plants. How does this impact aged transmission assets? Do the changes in load aggravate the deterioration of aged assets? Do asset managers change their replacement strategies because of the lower loads on the aged assets?

Nine papers were accepted in response to this preferential subject and are grouped as follows:

- Aging infrastructures
- Delivering customer value
- High penetration of RES

1.1 Aging Infrastructure

The following papers present new approaches to and experiences with risk based modelling and investment planning for aging asset bases.

Paper C1-104: A framework for asset replacement and investment planning in power distribution networks (United Kingdom). The paper presents a framework to analyse the effect of asset replacements on the future overall risk level of an asset base. The framework predicts future risk by modelling the deterioration of assets with a semi-Markov model. The output of the framework is a future risk profile of the asset base given a certain asset replacement rate.

Paper C1-105: Asset management methodology for optimization of long term replacement plan of age facilities (Japan). The paper describes the methodology applied by Kansai Electric Power Co. for long term investment in replacement of aged assets. The maintenance management system for the transmission system is introduced and resulting asset strategies are presented.

Paper C1-109: Predictive modelling of overhead lines reliability and lifetime (Portugal). The paper presents a methodology for risk based optimization of maintenance of OHL. With the methodology a risk based differentiated inspection policy was set up combining data from heterogeneous sources such as airborne inspections, dispatch event records and third party data. The methodology is discriminative regarding contingencies related to the outages of OHL's and a non-stationary approach for vegetation modelling is used.

In the methodology the root causes of the outages of OHL's are discriminated and a non-stationary approach for vegetation modelling is used.

Question 1.1: *The papers present frameworks and methodologies for the development of asset strategies. Can the authors or others give examples and share recent results and experiences with these or similar frameworks and methodologies and how these can be or have been applied in the practice of DNOs and TSOs?*

Question 1.2: *Paper C1-105 presents a maintenance management system. Paper C1-109 presents risk based maintenance and inspections. Can the authors elaborate on the data input at the workplace? Which types of data are collected? How is this data input minimized?*

Question 1.3: *Can others give comments on risk evaluation of asset strategies and maintenance optimization? How would other DNOs and TSOs make use of frameworks and methodologies as presented?*

1.2 Delivering Customer value

The papers in this topic present new methodologies and approaches for assessing customer value by evaluation of operational efficiency, KPI's, data envelopment analysis and power system reliability.

Paper C1-101: A method of full-scale comprehensive evaluation on operating efficiency of electric power networks (China/ United Kingdom). The paper presents a method for evaluation of the operational efficiency of electrical power networks. An index system is developed including indices of the electrical system and economical indices. The evaluation is based on the Project-Pursuit Principal Component Analysis.

Paper C1-102: Introducing the integrated evaluation procedure of T&D utilities' asset management efficiency (Russia). The paper presents a procedure to conduct comparative studies of various T&D companies, estimate their asset management efficiency and issue strategic development recommendations. The procedure combines a set of KPI's, such as functional reliability, financial condition, investment prospects.

Paper C1-106: Circuit impact measurement in the face of a distribution network reconfiguration for asset management (México). The paper introduces the basic concepts of Data Envelopment Analysis and its application for benchmarking studies on the distribution circuits of a distribution zone in México. Based on these benchmarking studies technical and scale efficiencies in the distribution circuits were identified.

Paper C1-107: Consideration of transmission protection system response in reliability of electricity supply analysis – case study (Norway). The paper is one in a series of papers published earlier presenting an integrated approach for analysis of the reliability of electricity supply. This paper discusses how the effect of the protection system (dependent failures) can be included in the reliability analysis, without using Markov models.

Question 1.4: *Papers C1-101, C1-102 and C1-106 present evaluation procedures for TSO's and DNO's. Can the authors or others comment on the applicability of the evaluation procedures presented? To what extent would they make use of these methodologies in their AM processes? Which strategic development recommendations follow from the evaluation performed?*

Question 1.5: *Paper C1-107 presents an integrated method for reliability analyses. Can the authors elaborate on the application of this method to consider the impact of substation configurations in the backup system coordination?*

Question 1.6: Can others comment on how power supply reliability analysis in their systems is conducted and how the impact of the protection system is accounted for?

1.3 High penetration of RES

Two papers present strategies to reduce increased asset load cycling and low load transfers due to high penetration of RES.

Paper C1-103: ALMACENA Project. Electrochemical Electricity Storage for System Operation (Spain/ USA). The paper describes the ALMACENA R&D project by REE, where electrochemical electricity storage is investigated as a means to face the challenges that intermittent generation such as wind and solar energy bring.

Paper C1-108: Improving the cross-border transmission capacity of Polish power system by using phase shifting transformers (Poland). The paper describes the study performed for installation of phase shifters to face the loop flows introduced by high penetration of RES.

Question 1.7: Paper C1-108 presents the analysis performed for the decision to install the phase shifters. Can the authors or others comment on the use of this or alternate technology to help address load cycling, intermittent generation and loop flows in the transmission and/or distribution system?

Preferential Subject 2: New System Solutions and Planning Techniques

Cost Benefit Analysis (CBA) studies are done on the basis of some given data regarding new generation, including renewable, conventional and storage, where renewable generation is driven by Government incentives. CBA studies that take into account renewable generation driven by markets is more intricate because very high levels of RES penetration can only be reached with new high capacity and long distance transmission which will not be decided without very clear signals about new RES generation.

Eleven papers were accepted in response to this preferential subject, and they have been grouped as follows:

- 2.1 Flexibility of generation, load and grid facilities to enable high penetration of RES.
- 2.2 Power systems evolving into supergrids or microgrids.
- 2.3 Changing technologies. This subtopic is embedded in the former two subtopics

2.1 Flexibility of generation, load and grid facilities to enable high penetration of RES

RES integration is considered in almost all papers, being the main issue in papers 201, 202, 205, 210 and 212. In these papers facilitating RES integration is investigated through means such as flexible generation or the use of FACTS.

Paper C1-201: Higher integration of RES is expected in Germany for the next several years. Transmission grid development is mainly driven by wind energy and distribution grid development by PV. Very flexible thermal generation and higher capacity of storage are necessary for compensating the volatility of RES, but some RES curtailment seems to be unavoidable. After 2020 storage technologies other than pumped storage should be competitive with flexible thermal generation.

Paper C1-202: This paper considers optimization of transmission network expansion by using FACTS and D-FACTS (distributed FACTS) to help integrate RES. The study is done in Brazil, where hydro and wind generation are volatile but have opposite mean seasonal values. The study focuses in the Northeast region dispatching generation technologies through a multi-stage stochastic optimization methodology depending on its price and taking into account exchange limits between different areas.

Paper C1-205: This paper studies challenges for integrating short term (2012-2017) and long term (2030) RES objectives in India. Short-term objectives imply around 20 GW of new wind generation and around 10 GW of new solar generation. This makes the RES penetration reach 17% (in power capacity) and 9% (in energy). The challenges of the short-term objective are mainly related with new flows and congestions with lack of transmission network and generation far from consumption centres, lack of ancillary services providers and difficulties to maintain security of supply during disturbances. A number of mitigation measures are proposed for the short and long term.

Paper C1-210: The increasing level of renewable power integrated in the Irish transmission network has forced the TSO to develop methods and tools for investment decision-making. In the past, a DC tool has been used in order to be able to handle a great number of calculations and make a techno-economic optimization based on flows. In this paper an AC tool is presented. An example of application of the methodology and tool is presented in the paper.

Paper C1-212: The authors of this paper have investigated the capability of an offshore wind power plant, connected through a VSC-HVDC link, for providing the grid with certain services necessary for operating the system. The VSC-HVDC link could also connect two asynchronous AC systems. Although technical studies that address the security of supply by analysing the network behaviour during disturbances continue to be of crucial importance, investment efficiency assessment measured through cost benefit analyses (CBA) is becoming increasingly important.

Question 2.1: *Are technical studies correctly being incorporated into the CBA? Are all major technical issues benefits quantifiable?*

Question 2.2: *Are there benefits in standardizing the CBA methodology (like it has been done in Europe)? Is there any other experience in the world in relation to standardisation?*

Question 2.3: *How should long distance high capacity transmission expansion plans be done for very high levels of RES penetration? Should they be closely linked with market driven RES generation expansion? Are present CBA methodologies still valid for these kinds of investments?*

2.2 Power systems evolving into supergrids or microgrids

Integrating different systems has benefits, as can be seen in papers 203, 204, 206, 208, 211 and 213. Sustainability, competitiveness and security of supply are the main drivers for connecting different systems.

Paper C1-203: This paper describes the philosophy and objectives of smart grid development in China. Smart grid development is seen as the key solution for avoiding massive blackouts, energy and environment conflicts and to better endure an international financial crisis. China's philosophy on smart grids is based on:

- Building a strong UHV backbone grid
- Coordinating the development of the grid at various voltage levels

- Using IT based technology to develop a more automated and interactive grid

Paper C1-204: In this paper the members of e-Highway 2050 project describe a methodology for the development of the pan-European Electricity Highways System for 2050. The objective of the project is the development of methods and tools for planning a European Highways System, based on scenarios that take into account macro-economic data, optimize grid architecture out to 2050. The scenario development is based on the assumption that GHG emissions should be reduced between 80-95% by 2050 compared to 1990 levels.

Paper: C1-206: Development of offshore networks raise several complex issues. Coordinated development can bring important economical, environmental and operational benefits. This paper considers the value of coordination and regulation, and the uniqueness of offshore grid design in addressing these issues.

Paper C1-208: This paper describes the defence plan of Oman in regard to its connection to the UAE system. Two issues are investigated:

- Frequency instabilities that lead to under frequency load shedding
- Actions against loss of synchronism

Paper C1-211: This paper investigates the transmission network needs of the southern part of Africa. A Strategic Network Framework is proposed to develop the South African Power Pool.

Paper C1-213: The European GridTech project aims to assess new grid-impacting technologies and their implementation in the European Electricity System. A future European electricity grid should enable a clean, efficient and secure electricity system in line with the three pillars of the European Energy System: sustainability, competitiveness and security of supply. Within the 2020, 2030 and 2050 time horizons, the goal of the project is to assess where, when and to what extent different innovative technologies could effectively contribute to the further development of the European transmission grid.

Question 2.4: *Is CBA an adequate methodology to decide investment in these type of facilities as referred to in papers 203, 206, 208 and 213? Are all types of benefits appropriately quantified? How is flexibility taken into account and measured?*

Question 2.5: *Are the various technologies discussed in papers 203, 206 and 213 complementary or competitors? I.e. should one be preferred over the other or should some or all be deployed?*

Question 2.6: *Which technologies are real solutions today and which are to be developed for the medium or long term? Are there any other known technologies not mentioned in the papers that may become viable in the medium or long term?*

Preferential Subject 3: Securing investment in transmission networks with increasing RES

This preferential subject deals with methodologies and gained experience in securing investment in transmission networks with increasing intermittent generation.

A total of eleven papers were accepted under this preferential subject. They have been grouped in three general categories:

- 3.1 Technical potential for a massive development of RES – Papers C1-302, 305 and 311.

- 3.2 New planning approaches for a better grid integration of increasing RES – Papers 301, 304, 308, 309 and 310.
- 3.3 Opportunities of HVDC technologies for a secure development of RES – Papers 303, 306 and 307.

3.1 Technical potential for a massive development of RES

Paper C1-302: Hydropower technology roadmap – A pathway for doubling hydroelectricity production worldwide by 2050 (Brazil, France)

The Hydropower technology roadmap, jointly elaborated by IEA and Brazil, is one of the technology roadmaps issued by IEA in regard of 2050 CO₂ targets. The paper presents its main outcomes and highlights a considerable undeveloped technical potential, most of it in emerging economies and developing countries, although it's a fully mature and competitive technology. Major issues are financing for new projects, given a decrease in public funding and electricity market liberalisation, and sustainable development. The paper presents key actions necessary to achieve the targets, including a doubling of the global capacity by 2050.

Paper C1-305: Transforming Desertec vision into quantitative scenarios – simulations and optimisation analysis for a decarbonised EUMENA power system (Italy, Germany)

The mission of Desertec Industrial Initiative (Dii) is to enable large scale exploitation of solar and wind power Middle East and North African deserts, viewing the whole EUMENA region as an integrated power system. Dii has developed a system model to optimize the overall system costs, having 2050 as a horizon year. Given the potential of solar and wind power in the MENA region, the paper describes the model and presents assumptions and constraints.

Paper C1-311: A 100% renewable scenario for Venezuelan Power Generation Sector in 2050 and its costs (Venezuela)

Being rich in energy sources, oil and gas as well as RES, Venezuela is questioning which technologies to support. Furthermore, its high growth rate of electricity demand calls for demand side management. The paper presents an ongoing research study analyzing the present and future situation of the Venezuelan power generation sector, based on six scenarios by 2050 (two demand groups: low and high efficiency and three supply matrixes: business as usual, sustainable and 100% renewable scenarios). It concludes Venezuela has all the resources to achieve a 100% renewable power generation by 2050, depending on policy and economic considerations.

Question 3.1: What can be said about the feasibility of massive development of RES generation having regard to power system constraints? (cf. papers 302 and 311, which present RES potential regardless of grid issues, while 305 shows the role of the transmission grid for RES potential's integration)

Question 3.2: Concerning the Mediterranean region (cf. papers 305 and 303), how could huge interconnection capacities from southern deserts to Europe be implemented having in mind the issue of acceptability and permitting procedures? As far as Europe's security of supply is concerned, is this approach robust considering the expected economic development of North African countries and the associated local growth in electricity demand?

3.2 New planning approaches for a better grid integration of increasing RES

Paper C1-301: Justifying transmission investment with large-scale RES (Australia).

Having regard to the dilemma among the general public between the desire to cease using coal-fired generation and the concern about the rate of electricity prices increases, the paper presents a brief examination of a mechanism proposed in 2011, the Scale Efficient Network Extension (SENE), based on geographic generation clustering. From a comparison of two cases involving large-scale RES with substantial network investment, it shows that significant network augmentations can be successfully realised within the existing regulatory framework

Paper C1-304: Energy transition in Germany and its impact on investment costs based on the example of the AÜW distribution network (Germany)

Electricity distribution networks are experiencing more and faster changes than in the past, especially because of the increasing amount of distributed RES. In the Allgäu region, the total installed RES generation is approaching the peak demand. The paper describes the methodology and shows the results of a comprehensive study to assess the consequences of this large share of RES and to estimate the necessary investment for the distribution network of AÜW. The study shows that an excessive share of RES leads to high investment costs only necessary for a few days/hours per year. Adapted planning criteria and innovative Smart Grid technologies, including measurement based network planning, are very effective to highly reduce investment.

Paper C1-308: New methodology of transmission system planning in Poland based on economic and market approach (Poland)

Fast growth of RES in Poland and Europe requires a change in approach to the long-term planning of the transmission grid. The paper proposes a new approach in Poland, not only in technical terms, but also in terms of economic and market conditions in order to optimize choices based on economic criteria. It mentions the most important results, among them the optimisation of transmission congestions and costs reductions.

Paper C1-309: A spatial framework for strategic investments to enable RE IPP integration (South Africa)

Given the enormous potential of RES sources in South Africa, the grid integration of Independent Power Producers (IPP) requires a strategic study to determine the necessary network strengthening. The purpose of the study is to produce geospatial least-cost IPP integration solutions. The paper describes the study methodology, starting with the identification of IPP clusters, and the case study of a cluster in the Western Cape Province.

Paper C1-310: Transmission investment evaluation in the Chilean electricity market (Chile)

In countries like Chile, with high growth rates of electricity demand and law obligations leading to significant investments in RES, transmission expansion is a huge challenge that needs evaluation methodologies. The paper describes the planning process for the three segments of the Chilean transmission system (Trunk, Subtransmission and Additional Transmission).

Question 3.3: *One interesting idea is the economic value of flexibility (cf. papers 301 and 308, which propose methods to face uncertainty in RES development). How should we address the recognition of this value in grid planning methodologies?*

Question 3.4: *Can we consider joint planning studies between transmission and distribution operators in order to optimize investments and reduce the global cost for the*

networks' customers? (cf. paper 304, which shows the impact of increasing distributed RES on a distribution network)

Question 3.5: When implementing methods to anticipate transmission projects (cf. papers 309 and 310), what can be said in terms of optimization of the transmission network and/or stranded costs if the expected RES potential doesn't realize?

3.3 Opportunities of HVDC technologies for a secure development of RES

Paper C1-303: Opportunities and solutions for the development of a Mediterranean grid (France)

The Medgrid industrial initiative is producing a study to quantify the technical, economic and environmental impact of new transmission lines across the Mediterranean by 2020-2030. The paper describes the approach and models used by Medgrid and presents its first qualitative results. An increase of RES capacities in the South would lead to a higher and more balanced use of these new lines. The allocation of the collective gain between stakeholders will depend on regulations and policy mechanisms regarding the development and the operation of these new interconnection lines.

Paper C1-306: Economic assessment of HVDC grids (United States, Sweden)

The recent advances in VSC technology enables development of HVDC grids (i.e. multi-terminal systems), which can become a viable technical solution to permitting problems for new transmission lines while the growth of power generation from RES requires a massive new transmission network. However, a number of challenges remain to be solved. Using energy market simulation and analysis tools with a HVDC grid model, the paper shows the results of a case study, which demonstrate the economic benefits of HVDC grids over isolated DC connections. New modelling features, including DC/DC converters, will allow more advanced studies.

Paper C1-307: Operation of the electrical system of Crete in interconnection with the mainland grid: a stability study (Greece)

Crete is the largest Greek autonomous electrical system. Interconnection with the mainland system is an option to reduce costs and to allow further development of the vast RES potential in the island. The dramatic increase of annual demand and peak load and recent evolutions in HVDC technology allows the goal to achieve this interconnection by 2020, which has to be carefully investigated given its cost. The paper presents a study made by the Greek TSO, focusing on system security in terms of transient stability and converter stations.

Question 3.6: Are there technical and economic assessments of deep submarine power cable technologies and multi-terminal HVDC grids (cf. papers 303, 306 and 307), as well as a time horizon for their commissioning? What level of confidence can be given to the costs used in economic assessment studies?

Question 3.7: The final results of Medgrid's study are now available (cf. paper 303). Regarding these results can the authors update or precise their conclusions? Do we have a vision of the future regulatory mechanism concerning trans-Mediterranean interconnections?