C2-00

SPECIAL REPORT FOR SC C2

Yvonne Coughlan[1], Ninel Čukalevski[2]

Special Reporters

1. Introduction

CIGRÉ Study Committee C2 deals with the technical functionalities, structures and competence needed to operate integrated power systems in compliance with the social requirements for security and quality of electricity supply.

The field of activities of SC C2 includes securing the physical integrity of power systems, management of strained systems and capacity shortage situations with controlled risks, restoration strategies, functionalities and reliability of Control Centre and training of System Operators.

SC C2 needs to understand, use and integrate results from studies in other Committees to assure that the technical concepts can be applicable in real time in various contexts and implemented by the System Operators. The SC C2, therefore, embraces a wide range of competence areas and interfaces with other disciplines.

2. Group Discussion Meeting Session 2018

For the Group Discussion Meeting, SC C2 has invited written contributions to provide discussion materials pertaining to two specified Preferential Subjects. As a result of this invitation a total of 45 papers have been accepted, categorized into the following Preferential Subjects:

Preferential Subject No 1:

Ensuring Operating Reliability (33 papers)
Special Reporter: Yvonne Coughlan (Ireland)

Preferential Subject No 2:

Big Data and their Use for System Operations (12 papers)
Special Reporter: Ninel Čukalevski (Serbia)

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3. Important dates

Experts who wish to contribute to the SC C2 Session are required to send their draft **prepared contribution** (presentation and written version) to the Special Reporters (PS1: yvonne.coughlan@eirgrid.com, PS2: ninelc@afrodita.rcub.bg.ac.rs) before Monday **16 July 2018**. For each prepared contribution a time slot of few minutes will be available, depending on the total number. After receiving the draft prepared contributions the Special Reporters will review and inform before **15 August 2018** whether the prepared contribution is accepted. On Wednesday **29 August** during the SC C2 Poster Session all experts with Prepared Contributions need to contact the Chairman, the Secretary and Special Reporters of SC C2 between 15.00 – 18.00 in Hall Ternes with their final contributions.

The **SC C2 Session** is scheduled for Thursday **30 August 2018**, in the Bordeaux Room.

During the Session the Chairman may call for spontaneous contributions. Attendees who provide a **spontaneous contribution**, are allowed to deliver a text for the Session Proceedings. This text is required to be forwarded within a maximum delay of two weeks after the SC C2 Session (thus by Thursday **13 September 2018**) to the Special Reporters.

It is compulsory for all authors to present the results of their studies during the Poster Session in the afternoon of Wednesday **29 August 2018**. If the author(s) cannot attend the Poster Session the National Committee is requested to send a substitute. Draft posters have to be sent in digital format to Vinay.Sewdien@tennet.eu **no later than 1 August 2018**.

Preferential Subject 1

Ensuring Operation Reliability

- **New concepts of system observability, controllability and flexibility.**
- **New solutions for provision of ancillary services: frequency and voltage control.**
- **Wide area control.**
- **System restoration.**

The last decade has brought considerable changes to the electricity sector. Most notable has been the drive towards greater environmental sustainability. As a result, there is a commitment to increase the level of renewable generation on power systems globally. There has been a considerable shift away from a portfolio dominated by conventional generators to a more diverse portfolio which now includes greater levels of distributed generation, renewable generation and demand participation. This growth of alternative generation sources presents a range of operational challenges for the power system. This has meant that the traditional approaches for operation of the power system have needed to evolve and adapt.

The challenge is to continue to ensure power system security, stability and reliability at high levels of renewable energy resources. This is driving innovation in solving a variety of technical challenges which arise in ensuring secure operation. Power system inertia, frequency and voltage control, system stability all have to be carefully considered in terms of technical and commercial requirements. Key to this is having adequate tools to be able to monitor current and future system operating conditions, Static and Dynamic Security Assessment (SDSA), Phasor Measurement Units (PMUs) and Wide Area Monitoring/Control (WAM/WAC).

Papers for PS 1

C2-101 presents an approach to EMS short term studies and real-time system operation in anticipation of the future safety of the power grid.

C2-102 presents the design of a Pumped Storage Power Plant to facilitate integration of large amounts of Renewable Energy Sources on an islanded system.

C2-103 examines what changes need to be made to system restoration plans when you have large system penetration of intermittent renewable generation.

C2-104 discusses the evolution of system restoration procedures and practices.

C2-105 describes a restoration strategy using 380 kV backbone network supplied from a bordering national power system.

C2-106 describes the role of Regional Security Coordinators in a changing environment.

C2-107 describes detailed simulations studying the effect of implementing Fast Frequency Response in Oahu, Hawaii, a Low Inertia Power System and observations from an analysis conducted in South Australia.

C2-108 assesses the Frequency Control reliable operation response against various frequency variations due to demand, fault and outage events.

C2-109 investigates the supplementary inertia technologies that could be deployed to mitigate the rate of change of grid frequency on an island system.

C2-110 presents a study to quantify the amount of instantaneous reserve deemed sufficient to return the system frequency to within the frequency control limits of the ESKOM area for a single contingency.

C2-111 proposes the use of thermal energy storage to improve flexibility of a thermal generator and improve economic operation of an islanded system.

C2-112 presents results from three different types of large scale battery systems.

C2-113 describes the different ancillary services currently considered in the Spanish electrical system and the participation of RES, in particular, wind energy.

C2-114 examines the practices and approaches to active and reactive power management, operational planning, congestion management and system restoration and defence at the TSO-DSO boundary.

C2-115 shows test results for wind and PV technology regarding frequency and voltage control tests.

C2-116 assesses the impact on Transmission and Distribution voltages due to large-scale PV generation.

C2-117 presents the main technical features of a hydropower project in Zambia. It looks at how the project interconnects with the national grid and looks at the results from the voltage stability analysis.

C2-118 describes control voltage on long AC lines using voltage control of hydro generation units.

C2-119 examines the effects on high voltage stability caused by increased decentralized generation on the grid.

C2-121 describes an Energy Management System (EMS) based tool to automatically issue reactive power dispatch instructions to reactive plant operators in order to manage transmission level voltages.

C2-122 presents a case study and proposes a method of encouraging wind generators to provide reactive power support to the gird by the way of incentivising/penalizing depending on the operation mode of the wind generators, that assists the system or otherwise.

C2-123 describes an approach to using existing generation capacity and Wide Area Control to mitigate concerns over reducing system inertia and system stability.

C2-124 summaries experience gained from introduction of PMU-based applications into the Control Room environment.

C2-125 presents the deployment of PMUs along with analytical applications for the Indian Grid and experience gained from integration of these applications into control centres.

C2-126 outlines a Wide Area Monitoring used for Power System Stabiliser (PSS) tuning for damping Inter-Area Oscillations.

C2-127 discusses the introduction of a Wide Area Monitoring System to detect islanding and failures in the power system.

C2-128 discusses the impact of wind power plants on the Chinese power systems with regard to oscillation issues and damping methods on a weak grid.

C2-130 examines the potential of storage systems in reducing generation constraints and improving transient stability and rotor angle stability.

C2-131 presents potential interactions that can occur in multi-feed HVDC systems connecting island power systems to larger mainland grids.

C2-132 Considers the challenges posed by the increasing amounts of Synchronous area HVDC interconnection. The paper looks at vulnerabilities associated with HVDC contingencies in the Nordic Power System.

C2-133 examines the effects on system reliability performance of a new AC cable interconnection from the Crete Island system to the mainland Greek grid. The paper presents a computed probabilistic method for assessing the operational reliability of the project.

C2-134 focuses on network congestion management in the distribution system voltages. This paper describes the modelling of coordinated control of the distribution assets in both the planning time frame and intra-day timeframe.

C2-135 describes development of a planning tool to investigate potential of Power Flow Controllers in optimizing existing transmission network.

Questions for PS1

Question 1.1: Papers C2-113 explains the provision of ancillary service by renewables. C2-108 assesses a method for sharing frequency control reserve among different systems using an interconnector. C2-110 presents a study completed on the South Africa control area, ESKOM, to quantify the required instantaneous reserve for frequency control for a single contingency.

C2-113 discusses how renewable energy sources can provide different ancillary services than those currently in place in the Spanish electrical system. Looking forward, is it expected that new ancillary services will be required in order to achieve higher levels of RES in the generation mix? In the ESKOM control area study, renewable generation has not been considered for reserve provision. That follows traditional procedures to provide system reserve from spinning synchronous generation. Do ESKOM envisage renewable generation providing reserve in the future or do they envisage other sources of reserves if they see the conventional portion of the generation mix shrinks? In C2-108 since the deployment of the frequency control capabilities for the HVDC interconnector in 2015, have there been cases where this control has adversely affected the performance of the interconnector to fast rate of change of frequency events? What new ancillary services are required to facilitate increasing levels of power electronics interfaced generation?

<u>Question 1.2:</u> C2-107 and C2-109 discuss some of the challenges they are seeing with rates of change of grid frequency due to the increased penetration of variable renewable generation displacing inertia-providing conventional generation.

C2-109 assesses the potential of changing the RoCoF grid code standard from 0.5Hz/s to 1 Hz/s to facilitate increase non-synchronous generation. What testing is required of generators to prove their ability to withstand a RoCoF of 1 Hz/s? Has the role of RoCoF been assessed in Oahu as part of a shift towards a lower inertia system? What technologies are expected to provide the Fast Frequency Responses (FFR) service in Oahu?

<u>Question 1.3:</u> Papers C2-102, C2-111, C2-112 and C2-130 discuss the use of various storage strategies to facilitate renewable energy sources.

Are there any concerns around long term reliability and maintenance cycles? How do regulatory issues affect economic feasibility? Are TSOs seeing interest in any other storage technologies? Globally, are there any operational "pilot" projects in this area? Are their issues other than cost competitiveness which may affect battery rollout, e.g. operational concerns, regulatory approval, etc.? Will energy/market management systems require significant modification to facilitate new faster acting storage technologies?

<u>Question 1.4:</u> C2-104 and C2-105 both discuss restoration using Hydro Power Plants. Additionally C2-105 highlights the use of a neighbouring power system in the restoration plan. C2-106 discusses the role of Regional Security Coordinators ensuring coordination and cooperation between the TSO across Europe today.

How static or flexible are the restoration plans? Do the plans account for potential of key stations and lines being out of service? Has any consideration been given to the role of renewable generation and/or storage in restoration strategy development? Has the impact of reduced synchronous conventional generation to support restoration been considered? What is the frequency of updating restoration plans and of repetition of real restoration tests? C2-105 discusses the use of a neighboring power system. Do other TSOs/ISOs have experience in coordinated restoration strategies worldwide? Are there examples of successful coordination between parties? Paper C2-112 presented demonstration of batteries providing ancillary services, has any TSOs/ISOs examined the possibility for using batteries to provide black start capabilities?

<u>Question 1.5:</u> C2-115, C2-116, C2-118 and C2-122 concentrate on voltage control and reactive power provision.

C2-115 discusses new solutions for provision of ancillary services (synthetic inertia and voltage droop control) by wind and PV units. Are these new solutions similar to any solutions deployed in other countries? Is there a charging policy problem regarding wind units providing reactive power in other countries similar to the case in C2-122? In C2-116 and C2-118, new functions and voltage control solutions are discussed. How would these services be deployed?

<u>Question 1.6:</u> C2-114 examines the practices and approaches to DSO/TSO interaction and co-ordination in Ireland. Paper C2-119 examines the effects on high voltage stability caused by increased decentralized generation on the grid. C2-134 focuses on network congestion management in the distribution system voltages.

With significance being placed on Distributed Energy Resources (DER) penetration in C2-114, what infrastructure would be needed to accommodate increasing DER penetration for

operational coordination between TSOs and DSOs? How do TSO and DSO coordinate in other countries with situations like this? For C2-119, the distributed generator controllers targeted modelling of their own buses, was it considered to try control a nodal voltage for a number of DG's? How do you expect to build on this research? C2-134 mentions the use of flexible assets that can help manage network congestion. What do you see as the main stumbling block for DSO's in implementing this method?

Question 1.7: Papers C2-124, C2-125, C2-126 and C2-127 are all related to the application of PMUs and WAMs. Paper C2-123 reviews a Wide Area Control System as part of an Islanding Defence System.

Based on the experience of PMUs in the control room, was there a requirement for change in procedures to react to PMU information? Was there a training requirement for operators on using PMU information? WACs has been applied in Iceland as part of a System Defence Plan. Has any other TSO/ISO considered or applied Wide Area Control Systems?

Question 1.8: Paper C2-135 discusses a method for increasing grid utilisation through Power Flow Controllers (PFCs)

Are current modelling tools sufficiently powerful to handle the added complexity of PFCs on the network? Has the potential interaction between multiple PFCs on network been examined? What are the maintenance requirements for a PFC device? How quickly is it expected a PFC could be moved to a different location in network to facilitate maintenance?

Question 1.9: C2-128 discusses the impacts of Wind power on the Chinese grids with regards to oscillation issues. C2-133 looks at the system reliability performance of new projects involving a cable interconnection from Crete Island to the Greek mainland grid. C2-131 presents potential interactions that can occur in multi-feed HVDC systems connecting island power systems to larger mainland grids.

C2-128 describes examples of sub synchronous oscillations seen in China. Are the next steps for this work to verify the proposed solutions through modelling of the oscillating phenomenon and comparing the performance of the solution options? How would validation of these modelled solutions be carried out? C2-133 have you looked at other similar literature on forecast tool design from other system operators that can help with the implementation of the results of the study as part of this? What other computational methods did you consider along with the Monte-Carlo approach and why did you choose this as a result? In C2-131, did you look at any islands which have both LCC-HVDC and VSC-HVDC interconnections? Were descriptions of control systems available from manufacturers or modelled independently?

Question 1.10: C2-121 discusses an EMS tool to automate the dispatch of Reactive Power in Australia. C2-101 looks at the future of the EMS in short term studies and real-time operation timeframe. C2-103 focuses on what needs to change as part of system restoration plans when you have larger penetration of volatile renewable power.

For the automation of the dispatch of Reactive power set points in C2-121, was a look-ahead voltage tool considered to identify voltage issues in a Control Room environment? C2-101 discusses the Apogée project and is exploring the possibility to offer more proactive and action-orientated tools. What criteria make it acceptable for an operator to implement an action instead of the output of the tool? How was the performance of the tool outputs assessed? C2-103 proposes guidelines to decision making for a restoration process by presenting a number of possible restoration steps. Did you find the prototype implementation uncovered any issues as a result? Based on your discussions, important is it to have support from the DSO for the tool?

<u>Question 1.11:</u> C2-117 presents the main technical features of a hydropower project in Zambia comprising of three power plants. It also looks at how the project interconnects with the national grid and looks at the results from the voltage stability analysis.

How dependent do you feel the results of your study are on the inclusion of other planned projects to be complete by the 2030 study year? Have you assessed iterations where one or more of the planned projects are not implemented and studied how that affects the voltage stability?

<u>Question 1.12:</u> C2-132 considers some of the new risks posed by the increased focus on synchronous system interconnection. The paper looks at vulnerabilities related to HVDC contingencies in the Nordic Power System.

Do you think there is value to be taken for assessment of these vulnerabilities on a European level? Do you think it would raise awareness of the likelihood of these contingencies among other TSO's?

Preferential Subject 2:
Big data and their use for system operations

- **Transformation of data into information for system operators.**
- **Data exchange platforms with other entities: e.g. DSO, DG, among others.**
- **Monitoring, visualization, awareness systems, decision support tools.**
- **Forecasts.**

Numerous changes emerged in the electric power systems during the last 20 years mostly due to the: fast and massive introduction of RES, increase of number/volume of transactions together with the customer role paradigm change as a consequence of industry liberalization. This was accompanied with introduction of power electronic devices and ICT solutions at all levels, from generation and transmission/distribution to customer sites. The need to monitor and control such complex man made systems resulted in the increasing data volumes and broadening of their types and sources. Long lasting progress in AI and machine learning brought many new methods, models and algorithms of big data (BD) and big data analytics (BDA) to different domains, where manufacturing, banking, telecommunication and healthcare are in the forefront, while utility applications and associated benefits has emerged just in the last decade. Today the most promising application areas are: customer behaviour, generation/load forecasting, dynamic phenomena detection and reaction, sensor based asset health monitoring, etc. Still, number of actual real-life implementations in the utility industry has been rather modest so far.
The papers selected for PS2 are humble in total numbers, just 12, and they almost evenly cover all the data related subtopics. Five of them are related with monitoring, visualization, and data exchange platforms, while five other (added to ''balance'' the PS2) deal with balancing and frequency primary regulation. Unfortunately only two of total are the "proper'' big data papers focused on BDA issues (forecasting, asset health).

<u>Papers for PS 2</u>

Paper C2-201 aims to present the current state of automatic Frequency Restoration Reserves (aFRR) approaches in Austria, Hungary, Slovenia and Romania as well as the selection of target model for aFRR energy exchange verified within the research and innovation project FutureFlow.

Paper C2-202 describes the German "SysDL 2.0" project whose goal was to harness reactive power of RES to stabilize local voltage in the distribution grid as well as provide reactive power to the transmission grid in order to stabilize the voltage there as well.

Paper C2-203 deals with primary frequency control in the Nordic synchronous area, called the Frequency Containment Process which consists of two parts, Frequency Containment Reserve for Normal operation (FCR-N) and Reserve for Disturbances (FCR-D). Paper presents the work carried out to design new technical requirements for FCR-D.

Paper C2-204 presents situation in the system with an increased asynchronous generation penetration that has resulted in a lower power system inertia leading to concerning dynamic behaviour in frequency. The aim of this paper is to get a better estimate of the power system inertia during changing network conditions.

Paper C2-205 proposes a data-driven tool that supports generators primary frequency regulation performance evaluation by taking advantage of the existing measurements and operational data collected and gathered in a control centre. The proposed tool employs machine learning techniques to classify the units' primary frequency control performance, emulating the experts' ability to qualify disturbances data.
Paper C2-206 presents the ''GridCloud'' system, designed to leverage scalable and inexpensive cloud computing resources in support of bulk power grid monitoring, control, and coordinated operations where ISO's can share real-time data through GridCloud, streaming PMU data over secure links, and then request state estimation. It was also shown how to bridge from GridCloud's data archive to the Spark/Databricks analytics infrastructure, which offers a mix of classic computational tools, modern machine-learning packages, and big data analytics.

Paper C2-207 presents learning and experience from the application of new WAMS technology, analysis techniques and tools achieved under Project VISOR: visualisation of real-time system dynamics using enhanced monitoring to address challenges (like: visibility and management of oscillatory behaviour below synchronous frequency and higher frequency interaction between generator shaft torsional modes, power electronic converters and network resonant modes) in the Great Britain power system.

Paper C2-208 describes a large-scale project within the UPS of Russia to integrate in the dispatch centres new innovative development – system for monitoring the margins of load ability and stability, i.e. sustainability (SMMS) of power systems. The system calculates the acceptable active power flows in full compliance with the requirements of regulatory documents in a real time mode.

Paper C2-209 describes the project performed by the French TSO and DSO with the goal to identify which new data exchanges were deemed necessary to tackle new challenges in the TSO-DSO coordination, to carry out their mission, and to define the relevant IT/OT tools.

Paper C2-210 presents a system for estimating the current and short-term future PV output based on satellite sensing and processing and used them at the central load-dispatching centre. To improve the estimation accuracy of the current and short-term future PV output, company has employed methods to analyse sizable data from approximately 260,000 smart meters.

Paper C2-211 describes Central Dispatch control centre modernization project where data from the several (6), different vendor Area Dispatch and CC, should be ''harmonized'' and migrated to the Central Dispatch Control Centre (CDCC). For that, a specified-form document for the new system was created as well as program to convert it into XML file to be imported to the new CDCC.

Paper C2-212 provides a brief description of future asset management needs in Statnett and some of the supporting use cases (related to: building up a transformer health index, temperature sensing in cables, estimation of residual life, etc.) developed in project SAMBA. It also describes the company's future ICT architecture focused on asset management.

<u>Questions for PS 2</u>

Question 2.1 Paper C2-201 aims to present the current state of aFRR approaches in Austria, Hungary, Slovenia and Romania, while paper C2-202 describes German "SysDL 2.0" project whose goal was to harness reactive power of RES.

(201): What potential savings to customers or TSO's can bring all the proposed approaches to cross border balancing services integration? (202): What was the size of the networks used in real-time tests? To coordinate real time work with TSO what RES data/set-points should be available at TSO CC?

Question 2.2 Paper C2-203 deals with design and new technical requirements for primary frequency control in the Nordic synchronous area, while Paper C2-205 proposes a data-driven tool that supports generators primary frequency regulation performance evaluation.
(203): Is there any on-line demonstrated performance of the FCR-D service provider measurement used, and how it is performed? Within the design approach used in Nordic country is customer provided for FCR-D used, if yes how is their work verified? (205): What is a primary intended use of the proposed data-driven tool: for after the fact PFR performance evaluation or for real-time to warn operators that some units are under performing? For the effective real time use of the tool is there some minimal number of PMU's to be used?

Question 2.3 Paper C2-204 has the aim to get a better estimate of the power system inertia during changing network conditions.

Is the proposed method for system inertia estimation applicable also to integrated power systems? (All): What approaches are used in other countries to manage system inertia when getting low? Is there need for a new functionality of contingency analysis application in systems with high RES penetration and low inertia, especially in isolated systems? What methods exist for monitoring and forecasting the system inertia? How does the accuracy of these methods change when synthetic inertia is provided through non-conventional measures?

Question 2.4 Paper C2-206 presents the ''GridCloud'' WAMS based system, designed to leverage cloud computing resources in support of bulk power grid monitoring, control, and coordinated operations, while Paper C2-207 presents experience from the application of new WAMS technology, analysis techniques and tools achieved under Project VISOR.

(206): Apart from using LSE and making estimates available from cloud level or to use CNN during a period with degraded observability, what other BDA applications are the probable next candidates? Is there a conceptual difference between Grid cloud data storage and Data warehouse? (207): Was the usability of the new application for system disturbance detection and characterization practically tested during the VISOR project, what are the advantages over SCADA? Is it possible to base power system emergency control on WAMS for a realistic system where just a modest fraction (10-20%) of nodes is equipped with PMU's? (All): With regards to data quality (data latency, corrupted data, etc.), how robust can one expect BDA applications for System Operations to be?

Question 2.5 Paper C2-208 describes a system for monitoring the margins of load ability and stability. Paper C2-209 describes the project performed with the goal to identify which new data exchanges are necessary to cope with challenges in the TSO-DSO coordination, while Paper C2-211 describes Central Dispatch control centre modernization project.

(208): Does the term ''sustainability'' used to characterize operation of the system SMMS differs from the term stability (static, dynamic)? (209): How are the data (consumption, RES generators, and capacitor) that relate to source substations (SS) and to be supplied in real time from DSO to TSO, collected from the MV, LV networks, by DSO SCADA or by other means? (211): After replacement of 6 existing ACC with new CDCC, will Area Control Centre operators continue their work as remote users of the relevant area network within the CDCC? Is

communication architecture such that existing RTUs will be rerouted to CDCC instead towards ACC? (All): How often is today standard (IEC) data model CIM used in SCADA/EMS/GMS/DMS systems? Are the benefits more obvious than before? What are the obstacles in its introduction in industry?

Question 2.6 Paper C2-210 presents a system for short-term future PV output estimation based on satellite sensing and processing, involving BDA methods.

How the PV generation forecast error is calculated in your area, based on comparison with actual (historic) generation, or compared with potential (max) generation as reported in the paper? (All): In light of growing importance of RES generation forecast, are there similar approaches in other countries to employ satellite imaging and processing to forecast levels of solar radiation and wind speed? Are there other innovative solutions to improve RES generation forecast in operational timeframes?

Question 2.7 Paper C2-212 provides a description of future asset management needs in Statnett and some of the supporting use cases (related to: building up a transformer health index, temperature sensing in cables, estimation of residual life, etc.).

Will future EAM system be based on equipment data base that is CIM compliant? Is the project approach, where defined use-cases are tested before implementation, restricted by their nature to the problems that are already solved? (All): How often is sound orientation to existing ICT standards (especially in the segment of system architecture, like TOGAF) used during the early design of new complex OT/IT systems, applied in other countries and companies?