CIGRE Study Committee C4

PROPOSAL FOR THE CREATION OF A NEW WORKING GROUP[1]

WG C4.49	**Name of Convenor:** Łukasz Kocewiak (Denmark) **E-mail address**: lukko@orsted.dk	
Strategic Directions #[2]: 1	**Technical Issues #[3]: 3 and 8**	
The WG applies to distribution networks[4]: Yes		
Potential Benefit of WG work #[6]: 2, 3 and 4		
Title of the Group: Multi-frequency stability of converter-based modern power systems		

Scope, deliverables and proposed time schedule of the Group:

Background:

Electrical infrastructure is becoming more complex due to the introduction of long HVAC cables, HVDC connections, widespread penetration of renewable energy sources (e.g. PV plants, wind power plants) and offshore electrical network development. The number of power electronics and grid-connected converters (PV-systems, wind turbines, STATCOMs, HVDC transmission systems etc.) in modern power systems is rapidly increasing. In the past, devices like wind turbines or PV-systems were mostly connected to the medium and low voltage grids. However, with the greater availability of modular multi-level VSCs, power electronic devices are more and more installed in the HV and EHV grids. This creates challenges from operational co-ordination of grid-connected converters and small-signal stability perspective both in the sub-synchronous and super-synchronous (harmonic) frequency regions, mainly due to such systems being characterized by relatively low damping and hence the observation of resonance interactions.

These resonance interactions at super-synchronous frequencies will lead to high harmonics in the grid but should not be misinterpreted as high steady-state harmonics. The phenomenon is rather referred to as harmonic stability and the root cause is the interaction of a converter controller with a grid resonance. This is in contrast to steady-state harmonics normally being observed when a poorly damped resonance is excited by a harmonic source. Therefore, in the case of converter controller harmonic stability, different modelling, analysis techniques and mitigation methods are necessary.

Furthermore, the application of long HVAC cables and the presence of increased number of power electronic devices can lead to low frequency resonances and unwanted interactions within the sub-synchronous frequency range with classical AVR and AQR systems commonly present in the power system. This shows a need to extend classical power system stability analysis techniques (e.g. eigenvalue analysis) to include also various types of controllers utilized in grid-connected converters without going into classical stability analysis in conventional power systems.

No commonly agreed method is available for the analysis of potential sub-synchronous and super-synchronous (harmonic) stability problems. Hence, there is a need to provide a general overview of the topic highlighting sub-synchronous and harmonic stability issues of grid-connected power electronic devices supported with a state-of-the-art literature review as well as industrial experience. The working group's objective is to describe the phenomenon and explain available methods for analyses with their advantages and disadvantages as well as providing a common understanding on modelling, analysis, evaluation and mitigation techniques.

Scope:

1. Review of existing literature regarding subject related stability issues including state-of-the-art converter stability aspects.

2. Definition of stability phenomenon to be covered within the technical brochure.
    a. Stability effects above the fundamental frequency, i.e. harmonic stability.
    b. Small-signal stability below the fundamental frequency, i.e. sub-synchronous stability.
    c. Clarification of definitions to avoid misinterpretation with steady-state harmonics and classical harmonic propagation analysis.
    d. Symptoms and root causes of sub-synchronous and harmonic stability phenomenon.
    e. Examples of sub-synchronous and harmonic stability phenomena observed and their impact on wider power systems.

3. The impact of grid-connected converter controllers on sub-synchronous and harmonic stability phenomenon.
    a. Classification of typical controllers used in modern converters.
    b. Evaluation of various control loops and techniques and their impact on stability, e.g. voltage control, current control, phase-locked loop.
    c. Frequency range of interest and controller interactions/couplings.

4. Overview of linear modelling and analysis methods to perform small-signal stability studies, e.g.
    a. Classical control theory approach of linear time-invariant systems, i.e. compensator and plant interactions, and possible general extension to linear time varying systems including e.g. linear time-varying periodic systems.
    b. Impedance-based stability criterion.
    c. Advantages and disadvantages of single-input single-output and multiple-input, multiple-output representation.
    d. Relevant stability evaluation methods, e.g. eigenvalue analysis, Nyquist criterion.

5. Other analysis techniques.
    a. Time-domain numerical simulations of linear and non-linear systems.
    b. Frequency and sequence coupling investigation.
    c. Stability of non-linear dissipative dynamic systems including e.g. limit cycle and bifurcation theory investigation.

6. Description of mitigation methods to overcome sub-synchronous and harmonic stability issues, e. g.
    a. Clear evaluation criteria and minimal requirements regarding the stability indices, e. g. stability margins, damping.
    b. Recommendations to address plant resonance profile at early stage during the grid-connected converter controller design.
    c. Converter coordination guidelines in modern power systems to avoid potential instability, e. g. passivity requirements.
    d. Mitigation measures incorporated in the grid-connected converter control (e.g. active damping) or within the power system electrical infrastructure (e.g. passive damping), also at later stage of project development or during operation.

7. Guidelines on general approach to such studies and the availability as well as choice of tools. Identification of limitations with the available analysis tools and suggestion of

possible areas for development.

Deliverables:

☒ Technical Brochure and Executive summary in Electra

☒ Electra report

☒ Tutorial[5]

Time Schedule: start: June 2018 **Final Report**: June 2021

Approval by Technical Committee Chairman: M. Waldron

Date: 01/03/2018

Notes:[1] or Joint Working Group (JWG), [2] See attached Table 2, [3] See attached Table 1, [4] Delete as appropriate, [5] Presentation of the work done by the WG, [6] See attached table 3

Table 1: Technical Issues of the TC project "Network of the Future" (cf. Electra 256 June 2011)

1	Active Distribution Networks resulting in bidirectional flows
2	The application of advanced metering and resulting massive need for exchange of information.
3	The growth in the application of HVDC and power electronics at all voltage levels and its impact on power quality, system control, and system security, and standardisation.
4	The need for the development and massive installation of energy storage systems, and the impact this can have on the power system development and operation.
5	New concepts for system operation and control to take account of active customer interactions and different generation types.
6	New concepts for protection to respond to the developing grid and different characteristics of generation.
7	New concepts in planning to take into account increasing environmental constraints, and new technology solutions for active and reactive power flow control.
8	New tools for system technical performance assessment, because of new Customer, Generator and Network characteristics.
9	Increase of right of way capacity and use of overhead, underground and subsea infrastructure, and its consequence on the technical performance and reliability of the network.
10	An increasing need for keeping Stakeholders aware of the technical and commercial consequences and keeping them engaged during the development of the network of the future.

Table 2: Strategic directions of the TC (ref. Electra 249 April 2010)

1	The electrical power system of the future
2	Making the best use of the existing system
3	Focus on the environment and sustainability
4	Preparation of material readable for non-technical audience

Table 3: Potential benefit of work

1	Commercial, business or economic benefit for industry or the community can be identified as a direct result of this work
2	Existing or future high interest in the work from a wide range of stakeholders
3	Work is likely to contribute to new or revised industry standards or with other long term interest for the Electric Power Industry
4	State-of-the-art or innovative solutions or new technical direction
5	Guide or survey related to existing techniques. Or an update on past work or previous Technical Brochures
6	Work likely to have a safety or environmental benefit