ERCIM "ALAIN BENSOUSSAN"
FELLOWSHIP PROGRAMME

ERCIM
European Research Consortium
for Informatics and Mathematics

Scientific Report

First name / Family name	Jing Lyu
Nationality	China
Name of the *Host Organisation*	NTNU
First Name / family name of the *Scientific Coordinator*	Marta Molinas
Period of the fellowship	01/12/2016 to 30/11/2017

I – SCIENTIFIC ACTIVITY DURING YOUR FELLOWSHIP

During the fellowship, my scientific activity includes three main research contents:

1. SSO mechanism analysis of MMC-based HVDC connected wind farms

A subsynchronous oscillation (SSO) phenomenon in modular multilevel converter (MMC)-based HVDC connected wind farms is a unique SSO phenomenon that appears different from those in DFIG-based wind farm with series-compensation line or wind farm integration through two-level VSC-HVDC transmission system, because the internal dynamics of the MMC may have significant impact on the SSO. Therefore, in order to accurately capture the terminal behaviour of the MMC, it is essential to include the internal harmonic dynamics in the MMC modelling. The impedance-based analytical approach is applied in this work. The small-signal impedance model of the MMC has been developed based on the harmonic state space modelling method, which is able to include all the internal harmonic effects. The SSO mechanism in the MMC-HVDC connected wind farm has been revealed from an impedance point of view. Furthermore, the influence factors, such as main circuit parameters, control strategies, controller parameters, and power level, on the stability of the interconnected system have also been examined by the impedance-based Nyquist plots.

The relevant results have been published in an international scientific journal [1] and a journal paper [5] that is under review.

2. **Stabilization control methods for suppressing the SSO in MMC-HVDC connected wind farms**

Based on the SSO mechanism analysis, several stabilization control methods have been proposed to suppress the SSO in the MMC-HVDC connected wind farms. First of all, an optimal design method for controller parameters has been proposed from a system point of view, where the small-signal stability of the interconnected system can be guaranteed by simply modifying the controller parameters of wind farm side MMC and/or wind power inverter. In addition, several additional stabilizing controllers have also been proposed in both the wind farm side MMC and wind power inverter, where the control objective is to reshape the impedances of the wind farm side MMC and/or wind farm so as to meet the impedance-based stability criterion.

The relevant results have been published in an international scientific journal [2], an international conference paper [3], and a journal paper [4] that is under review.

3. **Harmonic state space modelling and harmonic interaction analysis of a three-phase modular multilevel converter**

MMC is a power converter with a typical multi-frequency response due to its significant steady-state harmonics in the arm currents, capacitor voltages, and control signals. These internal harmonic dynamics can have a great influence on the terminal behaviour of the MMC. Therefore, different with the analysis method of the conventional VSCs, e.g. two-level VSCs, it is essential to consider the MMC internal dynamics when concerning the steady-state harmonic interaction and/or small-signal stability issues. In order to accurately model the MMC and to readily extend to higher harmonics for harmonic interaction studies, the harmonic state space (HSS) method is first introduced to model the three-phase MMC in this work. The steady-state and small-signal dynamic HSS models of a three-phase MMC are developed, respectively. The validity of the developed HSS model of the three-phase MMC has been verified by the results from both the nonlinear time domain simulation model in MATLAB/Simulink and experimental setup.

The relevant results have been published in a paper [6] that has been uploaded in arXiv and will be prepared to be submitted to a journal soon.

In addition, a part of the harmonic interaction analysis of the MMC has been carried out during the fellowship, which will be further extended and published in the future work.

II – PUBLICATION(S) DURING YOUR FELLOWSHIP

During the fellowship, I have written several papers, in which two journal papers [1]-[2] and one conference paper [3] have been accepted and published, and another two journal papers [4]-[5] are under review. In addition, one paper [6] has been uploaded in arXiv, which will be prepared to be submitted to a journal later. These papers are listed as follows:

[1] "**Subsynchronous oscillation mechanism and its suppression in MMC-based HVDC connected wind farms**," Jing Lyu, Xu Cai, Mohammad Amin, and Marta Molinas, IET Generation, Transmission & Distribution, 2017, accepted.

[2] "**Optimal design of controller parameters for improving the stability of MMC-HVDC for wind farm integration**," Jing Lyu, Xu Cai, and Marta Molinas, IEEE Journal of Emerging and Selected Topics in Power Electronics, 2017, accepted.

[3] "**Stabilization control methods for enhancing the stability of wind farm integration via an MMC-based HVDC system**," Jing Lyu, Marta Molinas, and Xu Cai, 2017 11th IEEE International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG), Cadiz, Spain, pp. 324-329.

[4] "**Stabilization control for suppressing subsynchronous oscillations in wind farm with MMC-HVDC system**," Jing Lyu, Marta Molinas, and Xu Cai, IEEE Transactions on Sustainable Energy, 2017, under review.

[5] "**Small-signal impedance modelling of modular multilevel converters by using harmonic state-space modelling method**," Jing Lyu, Qiang Chen, Xu Cai, and Marta Molinas, IEEE Transactions on Power Electronics, 2017, under review.

[6] "**Harmonic state space modelling of a three-phase modular multilevel converter**," Jing Lyu, Marta Molinas, and Xu Cai, arXiv:1706.09925 [cs.SY], 2017.

III – ATTENDED SEMINARS, WORKSHOPS, CONFERENCES

During the fellowship, I have attended one conference and two workshops, which are listed as follows:

1. **11th IEEE International Conference on Compatibility, Power Electronics and Power Engineering** (CPE-POWERENG), 4-6 April 2017, Cadiz, Spain.
2. **Workshop on "HVDC links in offshore windfarms"**, 11 May 2017, Trondheim, Norway, organized by the EU-funded BEST PATHS project and SINTEF Energi.
3. **2nd IEEE Workshop on Electronic Power Transmission and Distribution** (IEEE eT&D), 7-9 November 2017, Aalborg, Denmark.

IV – RESEARCH EXCHANGE PROGRAMME (REP)

Technical University of Catalonia (UPC), Barcelona, Spain
Prof. Pedro Rodriguez, May 14-20, 2017

I have done the Research Exchange Programme (REP) at Technical University of Catalonia (UPC), Barcelona, Spain, on May 14-20, 2017, where I was working in the research team of Prof. Pedro Rodriguez, i.e. Research Center on Renewable Electrical Energy Systems. During my stay at UPC, I have visited Prof. Pedro Rodriguez's lab and gained a better understanding of his research work. In addition, I have presented my work to them about modelling and analysis for stability of power electronic systems, and also discussed about the future opportunities for collaborative research.