LCE-04-2017

Innovation Action

An Integrated Platform for Increased FLEXIbility in smart TRANSmission grids with STORage Entities and large penetration of Renewable Energy Sources

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 774407

Executive Summary of D12.2 – Report on development and analysis of the physics-based and the measurement-based grid predictive modelling approaches

Report Identifier:	D12.2		
Work-package, Task:	WP12	**Status – Version:**	1.0
Distribution Security:	PU	**Deliverable Type:**	R
Editor:	LUA		
Contributors:	NESTER, LUA		
Reviewers:	STER, WING, CHALMERS, ICCS		

Quality Reviewer:	SCHN
Keywords:	Grey-box, Black-box, PSS, Low-frequency oscillation
Project website: www.FLEXITRANSTORE.eu	

Table of Contents

Executive Summary

1.1 Scope of deliverable

The scope of the deliverable aims at providing adaptive models for grid behaviour prediction, namely for the detection of low-frequency oscillation (LFO) modes in power systems. In this report, a grey-box model and a black-box model are developed to predict grid behaviour under large frequency excursions, the former based on physics and the later based on measurements from a Wide Area Monitoring System (WAMS). Furthermore, a methodology to integrate the black-box and grey-box models has been developed. These models will be then utilized to adapt the turbine and generator controls of a power plant to the varying grid conditions, which enables the units to ride through large transient events.

1.2 Concept and methodology

The main function of a power system is to convert energy from one of the naturally available forms to electricity and transport it through the electric grid to the different points of consumption. Thus, many equipment and controllers have been used to maintain the balance between what is being demanded and generated in a reliable manner with a high degree of quality.

Stability of the power system needs to be maintained even when subject to large low-probability disturbances so that the electricity can be supplied to consumers with high reliability. Certain system disturbances may cause loss of synchronism between a generator and the rest of the utility system, or between interconnected power systems of neighbouring utilities. Various control methods and controllers have been developed over time that have been used for this purpose.

In order to damp power system oscillations and increase system oscillation stability, the installation of Power System Stabilizer (PSS) is both economical and effective. PSSs have been used for many years to increase the damping of electromechanical oscillations. However, PSSs suffer a drawback of being liable to cause great variations in the voltage profile and they may even result in leading power factor operation and losing system stability under severe disturbances.

The power system can be characterized by widespread system interconnections composed of multiple machines connected by transmission grids. In the interconnected large electric power networks, there have been always unwanted unprompted system oscillations at very low frequencies in the order of 0.2-2 Hz. These low-frequency oscillations are major constraints for power transfer capabilities between regions in a power system, mainly between weakly interconnected areas during heavy load conditions.

In order to improve the performance of traditional PSS systems, this deliverable describes a solution that combines grey-box and black-box models for the adjustment of the parameters of an adaptive PSS.

1.3 Key activities

The key activities that have been performed within the scope of the present deliverable are the following ones:

- First, the development of an algorithm based on a grey-box model for the identification of LFO modes in power systems is presented and validated using IEEE 39 bus system. The simulation results are also discussed about its use in low-frequency oscillation detection. The grey-box model output is a database of the potential LFO modes for the specific power system, which results from several simulation cases established for a set of scenarios applied to such power system. These simulation cases include bus-bar fault, line fault, generator trip and load trip under various conditions. The LFOs are characterized in terms of rotor oscillation frequency and magnitude. Ultimately, the objective of this algorithm is to transfer this database information into a black-box model, which is receiving real-time measurements from the grid to update the settings of the dynamic PSSs that will adjust their response accordingly.

- With respect to the black-box model developments, they are trained by using a database comprised by the steady-state conditions of a power system to approximate the relationship with LFO modes. The steady-state conditions are described by the voltage and current phasors, as well as by the active and reactive power flows. The deliverable addresses both a flowchart describing the formulation of the database and a comparison of several machine learning techniques with respect to their accuracy on predicting LFOs damping and frequency.

- Finally, a description of the design for the integration of the grey-box and black-box models for the dynamic PSS control system is made, as the integration of the grey-box model data would allow to enhance the performance of black-box models during the transients.

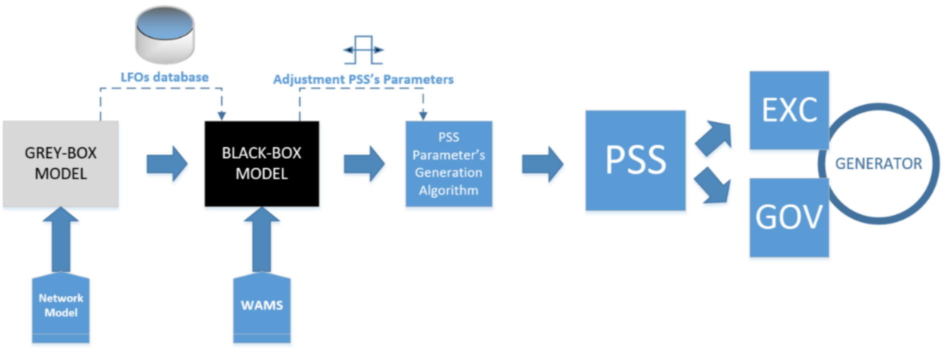
1.4 Key results/Main findings

The key results that have been obtained in the deliverable are described below:

- Grey-box models (physics-based): An algorithm has been developed to exploit the knowledge of the physical properties of the system, described by the mathematical models, to investigate its dynamic behaviour. Towards that end, several contingency scenarios have been designed to assess the stability properties of the given system using the real-time simulation platform OPAL-RT ePHASORSIM. The said algorithm is applied on the IEEE 39 Bus System but it can be easily used for any power system.

- Black-box models (measurement-based): An algorithm has been developed to utilize the system measurement data to, without any knowledge about the system inner workings, predict the characteristics of a LFO. Artificial Intelligence and machine learning techniques have been used to approximate the relationship between these inputs (i.e. system measurements) and outputs (i.e. LFO damping and frequency).

The design of the proposed adaptive PSS control system is depicted in the next figure.



The grey-box model, which takes into consideration the network model of the power system, analyses the system's dynamics for multiple scenarios in order to identify potential LFO modes that could be activated. This analysis generates a database of simulations that will be used by the black-box model to complement the training process of the data-driven algorithm.

Then, the trained black-box model will receive real-time information from the power system (e.g. through Remote Terminal Units or Phasor Measurement Units deployed on the field), and afterwards will identify the characteristics of the targeted LFO mode, i.e. damping and frequency. This information will be used to tune the PSS parameters in order to improve the attenuation of that mode, through the exciter and/or governor control of the generator.

1.5 Conclusions

Low-frequency oscillation exist naturally in power systems due to the electromechanical interactions between the generation units. The LFO phenomena was analysed to highlight the importance of monitoring and controlling critical oscillations within the frequency range of 0.2-2 Hz.

Overall, the obtained results indicate the potential of a real-time monitor and prediction algorithm that can be used by control devices such as the PSS to enhance the reliability of the system under the presence of LFOs. Considering the wider integration of renewables and vast interconnection of power systems, novel control techniques using AI and machine learning can increase the stability limits and capacity of transmission lines. This can contribute significantly to power systems becoming more flexible, efficient and sustainable.

The work carried out in this deliverable will be combined with the adaptive PSS research which is being carried out in parallel, to be implemented in a hybrid environment on a laboratory to demonstrate and validate the developed control functionalities. Once the required validations have been performed, the final goal will be to set up these advanced controls in a real demonstration scenario, specifically in the Cogen Zagore power plant in Bulgaria.