New methods for Frequency Signal Modelling and Impact Evaluation of New Resources

Thesis Summary

Power systems are increasingly gaining importance. Progressive electrification is happening all over the world in order to enhance energy efficiency and integration of Renewables Energy Sources (RESs). Electricity consumption is growing more than the other energy vectors.

This thesis work deals with the stable operations of electricity systems. Specifically, the starting research question is: what is and how can we measure the impact of Battery Energy Storage Systems (BESSs) performing fast frequency control? This question is inserted in the wide area of problems related to the decrease of rotating inertia in the electric grid. Since RESs presence continue to increase, Synchronous Generators (SGs) are being replaced by converters which will change the fundamental dynamics of the power system. Regulating energy from conventional fossil fuels sources will continue to decrease and BESS can provide the fast control needed by power system to remain stable. In chapter 3, the literature about BESS performing frequency control is ordered by proposing a novel categorization of the scientific works. In chapter 4 simulations are performed to quantify the impact of BESSs during a contingency by modelling the power system with a low order model. BESSs fast answer was divided in two services: fast Primary Frequency Control (PFC) and RoCof (Rate of Change of frequency) control which mimics the behaviour of physical inertia. A correct dimensioning of the two services has been assured imitating the behaviour of synchronous generators through the use of an Equivalent Saturation Logic (ESL). Both components of the control are fundamental to stop the frequency decay.

Another part of the Thesis is focused on the impact of BESSs during normal operations of the grid, when frequency is bounded in a strict operating range. In order to address this problem, a closed loop model must be used. In such a model frequency can vary realistically for a long period of time and BESSs can influence the frequency signal. In chapters 5 and 6 are developed two different methodologies to simulate a closed loop system: the first one based on the explicit computation of the load mismatch which creates the frequency deviation, the second one based on the use of the Fourier Transform Theorem (FTT) in order to reproduce the main power disturbances harmonics which are present in the grid. In such a way It has been possible to quantify the impact of BESSs making use of specific defined indexes. Besides an additional analysis with the low order model is performed in the frequency domain.

Due to the slow nature of the frequency signal in normal operations, RoCof control cannot improve frequency deviations. Even PFC produced by BESSs is not particularly more efficient with respect to Conventional Generation (CG). Secondary frequency control has apparently the most impact on the frequency signal. Moreover, an investigation is conducted on the main effects of PFC on BESS State of Charge (SoC) dynamics: the main result is that the impact of BESS inefficiency is negligible with respect to the effects caused by intra-day and average frequency dynamics. Also, a Variable Droop Strategy (VDS) for PFC is implemented to

find out its consequences on the system: the strategy improves the SoC profile without causing frequency unbalances.

Finally, in chapter 7 from utility scale BESS, the focus is moved to the evaluation of the impact of Electric Vehicles (EVs). Due to their expansion, EVs could represent the most part of batteries systems operating in the electric grid, therefore there is a great interest to study their potential for fast frequency control. However, EVs present additional modelling challenges with respect to BESSs for their correct characterization: they are not always attached to the electrical grid and need to recharge after a travel, besides they are connected to the distribution system which is more easily subject to congestion with respect to the transmission system where BESSs are usually installed. A complete framework to study the mentioned problems is detailed in this chapter and first steps are quantitatively developed.