

## Detection and location of HVDC commutation faults from PMU data

In order to achieve EU environmental targets, the use of renewable energies emerge as one of the cleaners, and currently cost-effective, measures that would lead to shift towards a sustainable future. Thus, the developing of Smart Grids, given that helps to increase renewables' penetration and increases energy efficiency, is a key point in the EC agenda.

Due to the variability inherent in renewable energy sources, as solar and wind energy, transmission grids will suffer bigger challenges as the share of RES increases. Highly controllable networks are needed in order to sustain stability. To upgrade the current network integrating power electronics and communications is crucial for being able to tackle future problems caused by generation-load unbalance in an energy system with high penetration of renewables.

The evolution of power electronics as HVDC connections, FACTS controllers, Phasor measurement units (PMU) and the decrease in Renewable energy sources (RES) prices are creating the perfect landscape for countries in order to renew their power networks. Wide-area measurement systems (WAMS) based on PMU's, whose reporting time is much faster than the usual SCADA system, allows the grid operators to see detailed dynamics of the system in real-time. Also, as the measurements are synchronized, grid operators can analyze the stability problem much better thanks to more accurate angle difference measurements.

High-Voltage Direct-Current (HVDC) transmission can be more advantageous than traditional AC transmission in many situations. These systems are a suitable and more efficient option for subsea connections, connection of asynchronous systems and long-distance bulk power transmission, among others. Due to a higher control capability, the network stability is enhanced by its use.

Therefore, both PMUs and HVDC will play a role in the managing of integrate renewable energy sources. The interaction of both systems with the rest of the transmission system under unbalanced situations still not deeply explored in some fields.

After an event in the Nordic system, it was recently realised that HVDC converter commutation failures are not visible to TSO control room. This is unfortunate as the faults may excite power system dynamics. While the SCADA system is generally too slow for detecting commutation faults, using phasor measurement units (PMUs), due to its faster reporting rate, dynamics events of the system can be detected. That's why a deeper understanding about how PMU's and HVDC-links interact, specifically how HVDC commutation failures are monitored by Phasor Measurement Units (PMUs).

Commutation Failures in LCC HVDC converters is a topic that is normally addressed from the component perspective, looking at converters' internal signals. How these commutation failures affect the outer AC network is not deeply understood yet. This thesis will provide proof of how commutation failures causes abnormal behavior in the AC network, and how PMU data can be used in order to distinguish commutation failure from AC faults. In order to do so, simulations have been carried out in PSCAD, DigSilent-PowerFactory and MATLAB-Simulink.

In the present days, algorithms for detect and locate AC faults based on Phasor Measurement Units (PMU) have been developed already. On the contrary, location of commutation faults in HVDC converters using sparse PMU measurements has not been treated in literature.

The main aim of the thesis was, firstly, to develop an algorithm for detecting and locating commutation failures using PMU data, but after the first simulations in MATLAB-Simulink, an unrecognizable behaviour in the AC current was found, which no one could explain at the first glance. To understand that behaviour became the main focus of the thesis. Simulations were carried out in PSCAD in order to address the validity of the previous simulations, finding the same unknown behaviour. For that reason, the aim of the thesis changed, being the algorithm less interesting and prioritizing the understanding about the reasons why the system reacts in that way when commutation failures happen and how can PMU data be used for characterizing that behaviour.

After some time and discussions, it was found that the reason of that behaviour is the configuration of the transformers in the HVDC-link. Therefore, new simulations were carried out in order to prove what was a hypothesis so far. Once the interaction between the HVDC and the AC system while commutation failures was understood, an HVDC was simulated in a complex network in order to understand how these faults spread, but without focusing on the development of an algorithm but only qualitatively, due to time limitations.

To sum up, the thesis broads the understanding of how PMUs and HVDC converters interact with the whole AC system, and seeks to use PMU data for fault, specifically commutation faults generated in the HVDC converters, detection and location purposes.