1. FUNDAMENTALS

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The Introduction to an article generally covers four or five main stages:

1.- Establishing the topic area: General statement(s) about a field to provide the setting.

2.- Describing previous research relevant to the topic – with references: Specific statements about the aspects of the problem already studied by other researchers

3. Establishing a niche: Preparing for present research by counter-claiming; indicating a gap; question-raising; continuing a tradition. Showing need for present research

4. Occupying the niche: Introducing present research by outlining purposes/ objectives of the writer’s study

5. Optional statements that give a value or justification for carrying out the study.

(\*) Depending on the journal, you may have to include an outline of the rest of the paper. This is common in a dissertation, but less so in a paper

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2. INTRODUCTION 1 (EXAMPLE) [Identify the movements described above]

EUROPE has plans for greatly expanding the share of renewable sources to supply its electric energy consumption. These include not only the deployment of distributed generators but also the integration of a large amount of offshore wind energy, mainly form the North Sea, and solar energy from neighboring countries across the Mediterranean. Furthermore, grid-expansion plans in Europe also include the interconnection to the currently asynchronous Baltic Energy Market [1]. This scenario calls for a reinforced transmission system with characteristics such as: power transmission over long distances, strong across-border interconnections, long cables (often submarine) and, all this, friendly combined with smart and decentralized (decentralised) distribution. Along these lines, High Voltage Direct Current (HVDC) transmission technology has long been proposed as the best candidate to overcome difficulties such as long cables or asynchronous connections and, accordingly, new point-to-point links are being built or considered. Moreover, there are serious plans for building a European multi-terminal HVDC grid (or “Supergrid”) [2].

Voltage Source Converter HVDC (VSC-HVDC) technology has clear advantages for multi-terminal systems in comparison with classic Line Commutated Converter (LCC) HVDC technology (see [2], for example). While there are still some obstacles for the European VSC-HVDC supergrid [2], technology is gradually maturing towards a sound and viable alternative [3].

In view of the possibility of heavily loaded electrical grids containing multi-terminal VSC-HVDC systems (MTDC, for short), Transmission System Operators (TSOs) want to assess to what extend this technology can improve the transmission system performance. HVDC technology will mainly be used to provide additional paths to transport or integrate large amount of power, above all when cables are required. However, the flexible control of active and reactive power in each one of the converter stations when using VSCs, raises the question whether VSC-HVDC could also improve the transmission system transient stability, which is defined as the ability of the power system to maintain synchronism of the generators against large disturbances [4]. Transient stability has been traditionally addressed, locally, by controlling the electromagnetic torque of synchronous generators [4] with fast automatic voltage regulators (AVR). More recently, [5] showed that the speed of the centre of inertia (COI) could be used with advantages when controlling the excitation of synchronous generators to improve transient stability. Control of the mechanical power would also be, theoretically, possible for this purpose but it is slow in traditional generation units except in steam turbines with fast valving [4].

Examples in the literature show that transient stability can be, indeed, enhanced by suitable control strategies for point-to-point VSC-HVDC links [6]–[9]. Furthermore, the work in [10] shows that supplementary Lyapunov-based controllers of the active or reactive power at each terminal of an MTDC system can damp power oscillations between two areas connected by the multi-terminal system, after a fault in one of the areas. These controllers use a linear combination of the speeds of all synchronous generators in both areas, to calculate the extra power to be injected by each VSC. However, in this study, the improvements are not quantified. A much more thorough study is presented in [11] where also a Lyapunov-based control strategy for an MTDC system is used to improve power system transient stability. The algorithm is evaluated computing the critical clearing times (CCT) for some faults. This time, however, a fixed amount of active power is injected or not into the AC grid by each VSC depending on the deviation of each generator speed with respect to the speed of the COI. An alternative local frequency-based control strategy is also studied but better results are obtained using the speed of the COI. Clearly, the proposals of [10] and [11] imply a Wide Area Measurement System (WAMS).

In this work, a new active power control strategy based on the frequency measurements in all the converter stations of the MTDC system is proposed to improve transient stability of the transmission system. In comparison to [10] and [11], the global data used here are much easier to obtain and have a much simpler implementation since the frequency at the AC side is always available for each converter (e.g., using a PLL), for synchronisation (synchronization) purposes, and it could be communicated to all the others in different ways.

First of all, this paper will present the fundamentals of MTDC system modelling. Secondly, a general framework to describe the proposed control strategy and another one using local measurements will be presented. The latter is based on the ideas for frequency control presented in [12] and [13]. These two strategies will be described and some theoretical aspects will be compared. For example, a Lyapunov-function based analysis of these two strategies will demonstrate that they can actually improve transient stability. Moreover, it will be shown that the proposed strategy is readily compatible with a distributed DC-voltage control in the HVDC grid. Thirdly, the strategy in [11] will be briefly described to also be used for comparison in a case study, although full description and analysis is referred to the original reference. Finally, simulation results of a case study will illustrate the performance of the proposed strategy and will show that it can greatly increase the CCTs with respect to those obtained without any strategy or using only local measurements. The CCTs obtained have also been compared, in some cases, with the ones obtained with the strategy in [11] showing a reasonably good performance.

Special attention has been given to the behavior of the DC-link voltage, which was not illustrated before and is strongly dependent on the active power flow. DC-voltage distributed control (droop) has been implemented in this work (for the proposed strategy and the one based on local measurements) and details of the parameters used are given in the paper. Simulation results show that the DC-voltage fluctuations are a key limiting factor when applying power control in MTDC systems for transient stability enhancement and these can be greatly reduced using the proposed multi-terminal control based on global frequency measurements. The scope of this paper has been restricted to the use of a proportional control with global measurements but MTDC systems are complex multi-variable control systems with many alternatives to explore. MIMO control techniques are used in [14] to determine the gains for the DC-voltage controller with the aim of improving angle stability when a VSC is lost. Meanwhile the work in [8] suggests that model predictive control could be used to modulate the active and reactive power injections in MTDC systems for transient stability enhancement.