Recommended voltages for HVDC grids

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Introduction

While High Voltage Direct Current (HVDC) solutions for bulk power transmission have been developed and implemented commercially since 1954, recent years have seen a strong increase in the number of HVDC projects. This trend is due to a number of factors:

- The need to transmit large amount of power from remote locations,
- The integration of renewables specially off shore wind generation,
- The interconnection of systems,
- The introduction of the UHVDC and the voltage source converter.

Although the majority of HVDC projects are point-to-point, some multiterminal HVDC projects have been implemented. Until very recently they were limited to the LCC technology. A number of VSC HVDC projects have been designed to be multi-terminal ready and to date at least two multiterminal VSC projects have been commissioned in China. In this context, there have been discussions within the last 5 years on many fronts regarding the feasibility of DC grids. It is clear that if DC grids are to evolve then some standardization or harmonization of the DC voltage levels will be necessary. To date the voltage levels of most HVDC projects are optimized on a project by project basis.

The Brochure tackles the issue of standardizing or harmonizing the dc voltage levels. There are a number of advantages if the dc voltages are standardized:

- Limiting the need of DC/DC conversion equipment and associated costs (CAPEX, losses);
- Rationalization of spare parts;
- Harmonization of maintenance procedures which can lead to reduction of maintenance time and improvement of reliability indices;
- Reduction of supplier qualification costs;
- Optimization of DC converter and line or cable design, with the subsequent reduction in capital and operating costs.

These benefits have to be considered during the system planning decision processes, taking into account that the DC voltage selection will no longer be selected as the only optimization variable for the specific needs of individual projects. Considering that these projects may later evolve into DC grids, one of the main goals of this Brochure is to provide guidance to system planners in making this analysis.

Outline of the brochure

After two introductory chapters, the Brochure approaches the issues of selecting the DC voltage from several perspectives.

Chapter 3 provides a short historical review of harmonization and subsequently standardization of voltages in AC networks. This background provides key insights for DC systems, which can be expected to follow a similar trajectory from isolated systems in which voltage levels are optimized individually to large-scale interconnected systems based on a few standardized voltages. The chapter also discusses voltage definitions in current standards for AC systems.

Chapter 4 reviews existing and future HVDC projects with respect to DC voltages. Until now, many voltage levels have been used in LCC and VSC (as shown in figure 1). Current projects have been point-to-point projects with very few exceptions and for the most port were not planned with a DC grid integration in mind. •••

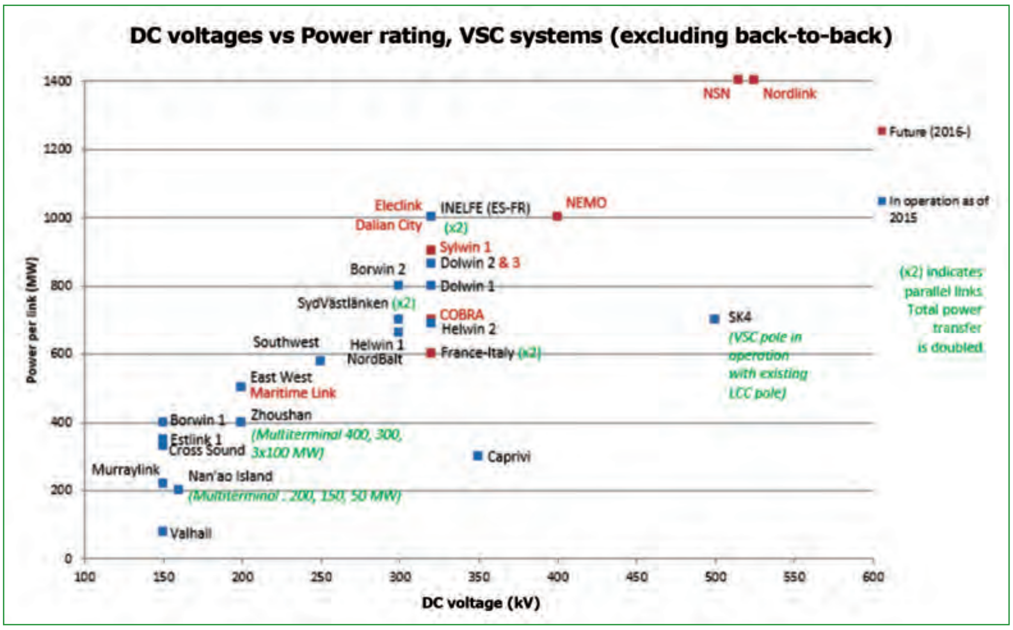

Figure 1 – DC voltage vs Power rating for existing and planned VSC systems

Chapter 5 is intended to provide guidance to the system planner for choosing DC voltages in individual projects, highlighting the pros and cons of choosing harmonized DC voltages depending on the outlook of HVDC grids in the area of interest.

Chapter 6 discusses technical aspects regarding the choice of DC voltages for given project parameters. Voltage limits for components are reviewed, taking into account modular design approaches. The chapter also discusses voltage definitions in DC systems, and a proposed definition for the DC voltage.

Chapter 7 reviews alternatives to an initial choice of harmonized voltages, i.e. later interconnection of DC systems with different voltages. Voltage upgrading and DC/DC conversion solutions are discussed based on available literature.

Chapter 8 builds upon the previous chapters to propose a list of recommended voltages for DC systems, and a toolbox to choose DC system voltages for specific projects. This toolbox takes the form of a flowchart, with a proposed software tool presented in the appendices.

Chapter 9 discusses other challenges to HVDC grids beyond the harmonization and standardization of voltages, while **chapter 10** summarizes the main conclusions and results of the Brochure. Key conclusions are briefly discussed below.

Key conclusions of the brochure

Recommended voltages for hvdc grids

Based on three main drivers for the choice of voltage in HVDC grids, the Brochure recommends a list of voltages•••

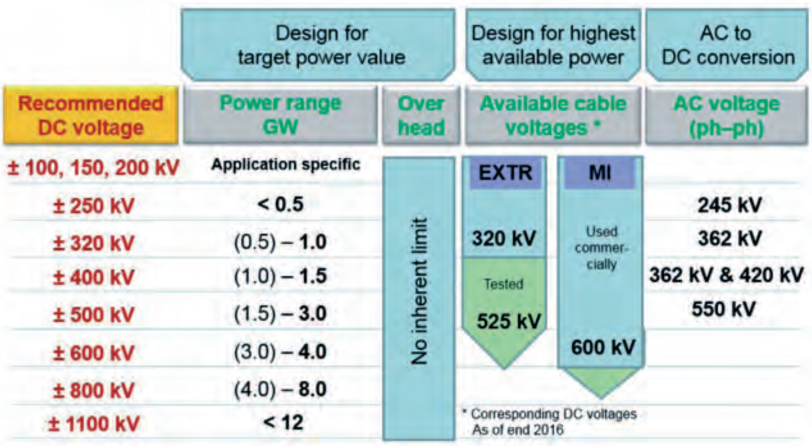

Figure 2 – Proposed recommended DC voltages

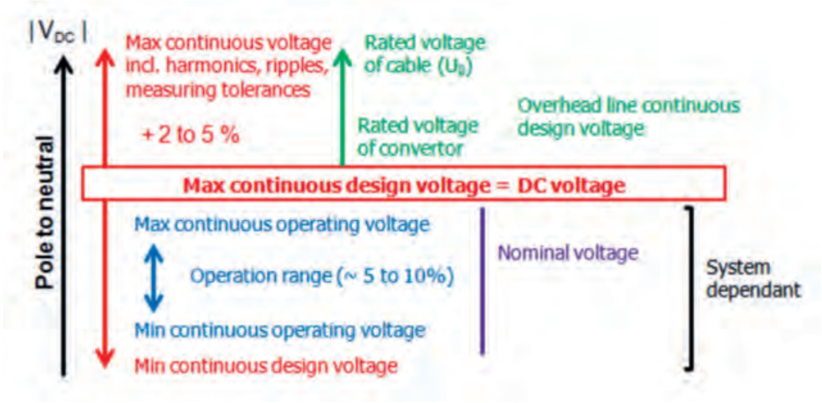

Figure 3 - Relevant continuous and rated voltage definitions in DC systems

to be used in future projects (figure 2). These values correspond to typical power ranges as expected in future projects, and will allow for transition from AC systems with standardized voltages to DC systems. We recognize that some projects will tend to use the latest available technology, based on power requirements or system optimization, even if the corresponding voltage may not be in line with the recommended values.

Definition of the voltage for HVDC grids

Apart from the actual recommended values, the use of clear and consistent voltage definitions in all new projects is a key requirement to enable the progression towards HVDC grids. At present, there are different practices in defining the voltage of a project. This can create strong ambiguity for the system planners and designers.

Based on current definitions in IEC standards and established practices in AC systems, the Brochure proposes a definition for the "DC voltage" of an HVDC grid, as "the highest mean or average operating voltage excluding harmonics and commutation overshoots". The relationship with other steady state voltage quantities is shown in figure 3.

This definition should be complemented with an overall review of insulation coordination in HVDC systems, which will provide additional terminology applicable to transients. IEC 60071-5 already provides information for LCC systems and a dedicated CIGRE WG (B4-71) will expand this material for VSC systems.

When to use recommended voltages

At present, most HVDC projects are still point-to-point systems, and the outlook for these systems to evolve into or become part of larger meshed HVDC grids is uncertain. The use of recommended voltages may not be deemed essential as the voltage can be used to optimize the cost of the project. However, we recommended the use of values in figure 2 in order to facilitate the later progression towards larger HVDC systems in the future.

Indeed, some multi-terminal projects have already been commissioned or are ongoing, and long-term system planning studies in several areas of the world are considering meshed HVDC grids. In this context, the use of harmonized voltages will increasingly become essential in order to optimize both capital and operational costs. Furthermore, the use of standardized voltages would provide additional operational benefits for system operators, such as lower maintenance time for HVDC equipment and therefore increased flexibility for the system. System planning should therefore include this outlook and can benefit from the recommendations in this Brochure. The historical review of AC voltages strongly supports this approach of anticipating long-term evolution, with recommended DC voltage values to be used wherever possible.

At the same time, since the VSC technology is still evolving, one may consider that it is too early to establish a standard for DC voltages. The benefit of the recommended values will be to limit the number of voltages used in future projects, as we expect a large share of projects will follow the proposed guidelines of this Brochure. This should facilitate standardization in the future and lower the overall cost of transitioning to DC grids. ■