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Simulation of modeling of multi-megawatt photolvoltaic plants with high voltage direct current grid integration

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ABSTRACT

This paper develops an integrated model of multi megawatt PV plant with HVDC (High Voltage Direct Current) or HVAC (High Voltage Alternating Current) network, using the specific software of power electronics PSIM. This model has been developed by functional blocks, including the photovoltaic field itself, the pertinent conversion units for the integration of each network as well as the network type for production. The models allow to obtain transmissions loss for any combination of the three variables on which they depend; network length (km), temperature (°C) and irradiance (W/m^2). To verify the validity of the model and demonstrate the distribution advantages of HVDC -even for relatively low-photovoltaic power plants in comparison to the common applications currently used in HVDC networks-, a case study has been used which has led to the conclusion that the use of HVDC networks may be convenient for this type of power generation plants.

1. Introduction

This research re-sparks the well-known *War of Currents* of the 19th century that had Edison, a proponent of DC and Tesla as the standard bearer of the AC (Francescutti, 2017). From the current perspective, it is a challenge to discern a single winner; it is a long-established fact that such technological disagreement will result in a technical tie between both forms of electric transport and distribution, given the current technological momentum experienced by HVDC (*High Voltage Direct Current*) technology.

Such momentum arises from its advantages, highly contrasted and derived from the absence of the capacitive and inductive phenomena in AC networks. Such capabilities can be summarized as follows (Bahrman and Johnson, 2007):

- Great transport efficiency. DC can carry large amounts of electrical power over long distances.
- Flexibility as it permits asynchronous interconnections.
- Suitable for submarine links.

These great benefits have propelled the proliferation of HVDC networks and consequently gaining ground to alternating current by transporting and distributing more megawatts year after year. Proof of this is the number of complete HVDC projects, in progress or about to be completed. A few of these projects are emblematic. Two of these examples include the HVDC link DC voltage to ± 500 kV of 2004 in *Three Gorges (Guangdong, China)*, capable of transmitting 3000 MW over 940 km (Moglestue, 2014) or, the HVDC interconnection link between France and Spain of October 2015, which transmits ± 320 kV and 1400 MW of transport capacity (Red Eléctrica de España, 2017).

Much like its advantages, there is a plethora of literature devoted to its disadvantages, the following are worth noting (Bahrman and Johnson, 2007):

- Higher cost of DC converters.
- Higher harmonic generation
- The intricate control employed in multi-terminal operations. The majority of the links are point-to-point.

Abbreviations: MMWPV, Multi-megawatt Photovoltaic; HVAC, High Voltage Alternating Current; HVDC, High Voltage Direct Current; HVDCGR, High Voltage Direct Current Ground Return; HVDCMR, High Voltage Direct Current Metallic Return; NOTC, Nominal Operating Cell Temperature; STC, Standard Test Conditions

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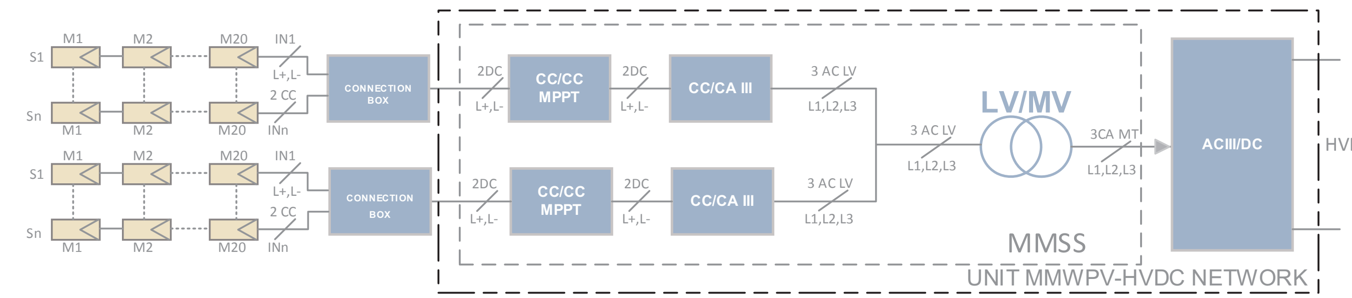

Fig. 1. Functional block diagram of the proposed MMWPV-HVDC station [Self-developed].

But perhaps the main technical hurdle that has had to overcome HVDC technology has been the lack of a suitable switch (Moglestue, 2014); when an AC switch is opened, an arc continues driving the current between the contacts to the next zero crossing. Since the DC current does not have this useful pass through the zero value of the current, a different approach is needed, and this has for a long time prevented the development of more complex HVDC network topologies (Moglestue, 2014).

However, these drawbacks are being addressed and or minimized by new switches capable of opening circuits with high alternating current, such as the hybrid switch developed by ABB. This switch combines semiconductor technology for the rapid interruption of DC with a fast mechanical switch (Ohlsson et al., 2013). In addition, the costs of the converter stations are decreasing, thanks to the increase of production in the sale of units and their greater integration in the market.

A direct consequence of HVDC's growing demand is the high expectations set forth by the sector in renewable energy generation based on its high efficiency in transportation and long distance transmission capabilities while incurring minimum transmission loss, giving Renewable Energies a fresh and hopeful boost. This is the case, for example, of the *TuNur project* (Llamas, 2017), consisting of a large solar thermal plant that is intended to be built in the Sahara of Tunisia to supply electricity to Europe through an submarine cable of more than 600 km connected to the grid European in the Italian part.

In this instance, it makes sense to use photovoltaic power plants in direct current since PV modules already produce direct current electricity from sunlight. Additional factors encourage a paradigm shift in the distribution of energy generated in these plants. These factors are as follows;

– The increased proliferation of DC powered equipment, such as the electric car, or LED lighting has prompted the review of low-voltage electrical distribution, and in some cases is being considered to generating power straight into DC, developing networks with a greater efficiency and cost reduction (Ministerio de Economia y competitividad, 2012).
– The birth of a new type of solar PV power stations, of floating type, on areas of water reservoir, such as the one in *Nishihira Pond* of 1.7 MW or 1.2 MW *Higashihara's pond*, both in the city of *Kato, Japan*, in operation since March 2015 (Ruiz, 2017). This revolutionary design has increased production thanks to its cooling effect, solving the lack of space while reducing the evaporation of water reserves (XVI Congreso Internacional de Ingenieria de Proyectos, 2014).
– Although the development of these floating photovoltaic fields is focused on reservoirs or the cited ponds, it opens the door for its use in maritime zones, emulating offshore wind farms. In fact, there are already PV modules on the high seas, prototypes and testing techniques for future use (Serrano, 2017).
– In both cases, submarine type links would be required, and under these conditions, AC transport is limited to short distance, given the high capacitance of isolated conductors, as already indicated.

Unlike the typical applications of HVDC networks such as large and long-distance energy transports, connections between asynchronous systems and submarine links, this research has a different focus. This paper explores its use in similar networks such as the large photovoltaic power plants in the range of several megawatts, but with inferior power typically handled by HVDC links.

Therefore, the fundamental objective of this study is the development of a simulation model for a grid connected multi-megawatt photovoltaic plant and its different technologies HVAC and HVDC. Such model can precisely detect energy losses incurred during distribution based on two of three variables that affect transmission, with the fixed network length; temperature and irradiance.

In this way, it will be possible to have a very useful tool in obtaining the critical distance of the links, in other words, the distance from which is most profitable to distribute in DC instead of AC, and that as a general rule is approximately between 800 and 900 km for aerial networks and 60 and 70 km for underground (Frau and Gutiérrez, 2005).

Another key aspect is verifying the suitability of small-scale HVDC links to distribute the production of multi-megawatt photovoltaic plants and determine if these plants can benefit from said advantages, which would undoubtedly lead to a greater integration and presence of Solar photovoltaic energy worldwide.

In Section 2, the various stages of work -that have been covered to achieve the objectives set out in the first section- are discussed along with a technical analysis of the conditions and functional requisites for the integration of the MMWPV plants into HVDC networks. This analysis culminates in a proposal of unit converter plant MMWPV - Network HVDC that will lay the foundation for the rest of the study. Subsequently, two working models of MMWPV plant are developed, including both HVDC and HVAC networks, Figs. 2 and 3 .

In Section 3, the models generated are applied to a specific case of MWPV plant, using real technical data of the integrating components and gathered from commercial catalogs. These elements have been previously modeled in a generic way (as already indicated) to obtain through the subsequent simulation the losses resulting from energy transportation according to the variables which define them including temperature (°C) and irradiance (W/m^2), and considering a specific length. This section concludes with a summary of results, Table 4.

Finally, Section 4 presents the most relevant conclusions based on the results including, the validity of the models, the technical and economic viability of the integration of MWPV into HVDC and the possible applications in both developed and developing countries.

2. Materials and methods

The simulation models were built upon a well differentiated four phase process:

(1) The phase of research and analysis of the PV plant elements including - distribution networks, with emphasis on the current situation and future trends or lines of development, taking as references, besides those indicated, the technical documentation of the leading manufacturers in the transport sector in HVDC, *ABB*, and *Siemens*.