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A detailed North African HVDC Grid for a pan-European-North African Electricity Exchange

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Abstract. Renewable energy (RE) has been chosen as an alternative to reduce fossil fuel and eliminate generation by nuclear power. The North African (NA) region has a vast potential for RE sources. The RE potential even exceeds the local demand, thus it has the potential to be exported to the Europe Union (EU). However, implementing such a pan-European-North African electricity exchange implies substantial challenges for the transmission grid infrastructure. An HVDC grid is chosen as the best alternative to transmit a huge amount of electricity over long distances. A detailed model is required to understand the HVDC grid behavior. Therefore, this paper presents the model of an HVDC grid for electricity exchange between NA and the EU. The paper defines the number of interconnectors, location of converter stations and transmission lines for the time horizon 2050.

Keywords: HVDC, DC transmission, Grid expansion, Renewable energy

1 Introduction

Reducing the usage of fossil fuels as energy source will decrease CO_2 emissions. Renewable energy (RE) is an alternative to fossil fuels and will eliminate the electricity generation by nuclear power. However, RE is a form of energy that is produced locally in a few areas with high RE potentials. These sites are usually located far away from load center and industrial zones. Therefore, grid expansion has been identified [1], [2], [3] as well as the High Voltage Direct Current (HVDC) transmission, as a valuable element for electricity transmission over long distances. A pan-European HVDC grid extended to North Africa (NA) has been discussed several times [2], [3], [4] which can export excess energy from RE sources to Europe [4], [5], [6]. That is due to the fact that the NA region has a vast potential for RE sources. This potential can cover local demand by far and has the potential for electricity export to neighboring regions, such as the European Union (EU). Realizing such nationwide electricity exchange is associated with a number of technical challenges related to the required grid infrastructure [2], [4] which are explained herein.

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2 Potential for Electricity Export in 2050

A study about the potential electricity generation and local demand of NA has been carried out [7]. Five NA countries (Morocco, Algeria, Tunisia, Libya and Egypt) are involved in the study for the time horizon 2050. The study revealed the RE potentials in NA using a model based on a geographic information system (GIS) for generation and a top-down model for the development of local electricity demand until 2050 based on population growth, gross domestic product and energy intensity. Four scenarios were proposed based on climate policy, energy efficiency and transmission grid development [7]. The highest net electricity exchange between NA and the EU reaches 347 TWh per year in 2050.

In another step the results were further detailed. This was done in an analysis on national level focusing on strategic location planning and short-term operation of individual power plants and an evaluation of optimal storage design for CSP plants in NA [8]. As a result of the analysis, the five NA countries could be further detailed into twenty-three regions and hourly time series for electricity generation and consumption for the year 2050. By calculating the electricity export of each region the potential electricity exchange to the EU and inter-country power flows can be calculated. Fig. 1 shows the electricity export and import as well as the annual average of electricity exchange for each region.

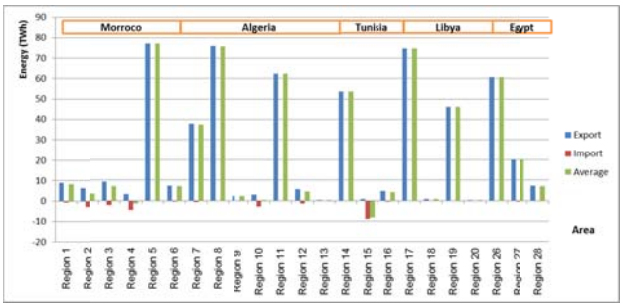

Fig. 1. Potential electricity exchange of each region for the year 2050

3 Transmission Grid

Based on the results of the study for electricity exchange requirements for the transmission grids were derived and a comparison between AC grid expansion and the construction of an HVDC grid was done.

3.1 AC Transmission Grid

In line with the study the AC transmission grids of Europe and NA were modeled and transfer capacities determined. The results about existing transmission capacities and until 2020 planned interconnectors between NA and the EU revealed that the electricity exchange until 2030 could be handled but not for the target year 2050.

Expanding the AC transmission grid in NA would require a 7 times higher transfer capacity of its actual capacity for the overall AC transmission grid. Considering the potential exchange and location of each region, it is favorable to expand the AC transmission between regions that have small potency for electricity exchange and proximate locations. All other electricity exchange should be transmitted through an overlaying transmission grid in form of an HVDC grid.

3.2 Overlaying HVDC Grid

Some studies have been conducted and identified a meshed HVDC grid as overlay grid for wide-area transmission, specifically for interconnecting NA and the EU [1],[2],[3]. In [2] four interconnectors between NA and the EU were identified for example. In line with this study eight cost-optimized interconnectors between NA and the EU has been identified as well as an meshed HVDC grid within NA.

Based on the electricity exchange potential for each region, as shown in Fig. 1, four NA countries are selected to have HVDC converter nodes installed which connect to the interconnectors to the EU. The HVDC converter stations should be located close to Toulal and Mellaoussa in Morocco, Benisaf, Musthapa and Ramdane Djamel in Algeria, Grombalia in Tunisia and Abu Kammash and Bengazi in Libya.

In addition to that, regions with a high electricity export that are far from the next interconnector are selected to be connected to the HVDC grid in order to avoid AC grid expansion due to reactive power problems. Including these additional regions into the HVDC grid will form a meshed HVDC grid in NA.

Based on these results a model has been created in the power system simulation tool DigSilent PowerFactory. Voltage Source Converters (VSC) are used for the HVDC model, since VSC has the ability to change the power direction without a change of the voltage polarity.

4 HVDC Grid Operations

Based on the modeled HVDC grid the operation method of such a grid will be implemented and evaluated. Generally there are several operation tasks to be considered. Basically the converter stations of an HVDC grid act like a power plant. Therefore, their throughput power needs to be scheduled like the generation of a power plant. Based on forecasts and power flow calculations each converter station will receive a set point for its power throughput on a frequent basis. This is done based on the hourly time series provided by the study.

As the frequency is the reference variable to control the equilibrium between generation and load in AC grids, it is the DC voltage in a DC grid. Basically there are two control methods for the DC voltage control - the voltage margin control and the voltage droop control. Both of them have advantages and disadvantages over each other but both consider specific operation modes only. For a more continues or smooth operation a DC voltage control method has been chosen that is described in [9]. A p-v characteristic is used to adapt the power flow based on the DC voltage at each converter node.

Also, main aspect of installing an HVDC grid is the relief of the AC grid. Hence, the HVDC grid shall participate in the AC grid's power flow. As this is not done naturally the HVDC grid has to be controlled for that. This can be done using the voltage angle gradient method [9] which will be implemented for further evaluation.

5 Conclusions

The present analysis points out that the NA countries have a huge potential for electricity generation by RE and excess energy to be exported to Europe. Implementing a pan-European-North African electricity exchange implies substantial challenges for the transmission grid infrastructure. An HVDC grid is chosen as the best alternative to transmit a huge number of electricity over long distances to Europe. A detail model in NA is developed and proposed based on the electricity export potency. Four countries in the NA region are selected as potential locations to install interconnectors to Europe. An HVDC transmission grid model is set up to study the grid behavior. Load flow calculations will be carried out to observe the HVDC grid behavior and to implement an HVDC grid operation strategy.

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