Integrating a Pan-European HVDC Grid into the North African AC Transmission System

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Abstract

Establishing an overlay grid in Europe and expanding it to the Middle East and North Africa (MENA) has high potentials to support the pan-European and MENA energy exchange. Scenario-based modeling has proven that a meshed HVDC grid is able to transmit large volumes of renewable energy generated offshore or in deserts and arid regions over long distances to the industrial zones and load centers. Based on scenarios for energy generation and exchange in MENA this paper gives an outlook on the integration of the pan-European HVDC grid with MENA to support both local energy supply and export to Europe.

1 Introduction

The idea of generating renewable energies (RE) in deserts and arid regions is not new [1], [2] but has high potentials for the growing energy demand and reduction of usage of fossil fuels. Own research shows that it is possible to produce much more energy generated by sun and wind in the Middle East and North African (MENA) region than it is required for the local demand. The excess energy can be used to support Europe’s energy demand, as also proposed in [1], [2], [3]. Besides the potential of delivering clean energy to Europe’s industrial zones and load centers there are also challenges to overcome. One big question is; how to transfer the energy from MENA to Europe?
This paper describes the volumes of energy that could possibly be transferred from MENA to Europe and evaluates the technical feasibility of a supporting grid in form of an HVDC overlay grid and its integration into the MENA AC transmission system [4].

2 Scenarios for Energy Exchange

Before modeling or designing a transmission grid for delivering energy from MENA to Europe the expected volumes of energy for local demand and export have to be determined.

2.1 Modeling the Energy System

A model-based, energy-economic optimization of the EU-MENA electricity system has been carried out (analogue methodology has been applied in [3]). Major inputs for the modeling comprise an in-depth analysis of the available RE-potentials using a geographic information system (GIS) and an assessment of the electricity demand in MENA until 2050. The model derives the most cost-efficient expansion strategy for RE generation and storage technologies in MENA under different scenario assumptions. Goal of the analysis was, on the one hand, a detailed modeling of possible electricity generation portfolios with high RE shares in MENA and, on the other hand, an evaluation of the potential exchange of electricity among MENA countries (and regions therein) and between MENA and the EU. The time horizon of the modeling extends until 2050.

2.2 Scenario Definition

The above described modeling was carried out against the background of a set of scenarios. The scenarios were defined based on the following parameters:

- ambition level of CO_2 reduction goals,
- restrictions and availability of interconnectivity between MENA and Europe and
- development of the local energy demand.

Two of the scenarios describe a possible development without exchange of electricity between EU and MENA and two scenarios represent an interconnected electricity system in which electricity exchange between the regions is possible.

2.3 Scenarios for Energy Exchange

As a result of the modeling the potential energy exchange as well as statements on cost-optimized interconnections between MENA and Europe could be derived.

2.3.1 Interconnections between MENA and EU

In [5] four interconnections between MENA and Europe were proposed. In [6] and own research it was found that there are eight to nine interconnections required between MENA and Europe. Eight of them spread nearly evenly over the Mediterranean Sea. A ninth interconnection could be established between Egypt and Greece especially in case of integrating additional Middle East countries.

2.3.2 MENA Collector Grid

Primary goal is to cover the local energy demand within MENA, namely energy flows between MENA countries due to the variance in generation of RE and local demand. Therefore, interconnections have to be established between MENA countries. These interconnections cover the entire MENA region and are connected to the overlay grid in a later step of modeling the HVDC grid. These interconnections represent a collector grid and it will be evaluated if they can be integrated into the existing AC transmission grid or HVDC grid.

2.3.3 Energy and Power Flows

For the target year 2050 and the scenario with the highest energy exchange it is found that most of the interconnections must transfer approximately 10 GW of power. A total net energy flow of 117 TWh among MENA countries and 347 TWh between MENA and Europe was found. The simulation results show that there is approx. three times the energy available for export than it is required locally. This export of energy could cover 7-8% of Europe's energy demand in 2050 which is proposed in [7].

3 AC Transmission Grid

In order to evaluate the ability of the existing AC transmission grid to handle the expected power flows, the AC transmission grids in Europe and MENA were analyzed and modeled. The AC transmission grids of 220 kV and above were modeled based on [8], [9] including their synchronous zones [10].

Existing and currently planned interconnections [11], [12] were modeled for both, interconnections between MENA and Europe and interconnections between countries and synchronous zones. It was found that some of the interconnections could handle the power flows expected by 2030. For the target year 2050, however, interconnections need to be built newly or extended by at least ten times their current capacity if already existing at all.

Also it was determined that the existing AC transmission grid in MENA is not able to handle the expected power flows without massive and expensive grid expansions. Additional lines have to be installed, voltage levels need to be raised and additional compensation of reactive power is required. In order to avoid these massive AC grid expansions it is useful to set up an overlaying grid.

4 Overlaying HVDC Grid

The HVDC grid is the most promising grid for wide-area energy transmission of large volumes of energy [13], [5] and for interconnecting far away located generation plants (e.g. offshore) and load centers or industrial zones. The present HVDC grid was modeled based on [5] and extended by the results of aforementioned scenario results.

As the existing AC transmission grid is unable to handle the predicted energy exchange, one solution is to extend the pan-European HVDC grid to MENA and form a multi-terminal HVDC collector grid there. Such an HVDC overlay grid contains at least one converter station in each of the MENA countries and HVDC lines along the industrial zones and areas for RE generation, mainly along the coastline of the Mediterranean Sea and Atlantic Ocean.

5 Conclusion

Scenario-based modeling of the EU-MENA electricity system showed, that energy transfer between MENA and Europe cannot be handled by the existing AC transmission grids or interconnections for both, the MENA and European side. It is essential to establish an overlay grid in form of a multi-terminal HVDC grid if a wide-area energy transmission and pan-European-MENA interconnection shall be realized. Also, based on the results, a meshed HVDC grid in the form of a collector grid has to be established in the MENA region to enable local energy transfer among MENA countries. In ongoing work additional aspects required by such a multi-terminal HVDC grid are evaluated and solutions are developed. Such aspects are, but not limited to, grid operation, grid protection, interaction between DC and AC grid, grid stability and technical limitations.

6 References

[1] "DESERTEC Foundation," [Online]. Available: www.desertec.org.

[2] „Sahara Wind," [Online]. Available: www.saharawind.com.

[3] F. Zickfeld et al., „Desert Power 2050 - Perspectives on a sustainable power system for EUMENA," Dii GmbH, Munich, 2012.

[4] W. Platzer, „Supergrid: Efficient generation, storage and distribution of electricity," 2011.

[5] CIGRÉ WG B4-52, „HVDC Grid Feasibility Study," CIGRÉ, 2012.

[6] F. Trieb, „DESERTEC - EUMENA: Solarstrom aus der Wüste," Deutsches Zentrum für Luft- und Raumfahrt e.V., 2013.

[7] E. Tröster, R. Kuwahata und T. Ackermann, „European Grid Study 2030/2050," energynautics GmbH, Langen, Germany, 2011.

[8] Q. Zhou und J. W. Bialek, „Approximate Model of European Interconnected System as a Benchmark System to Study Effects of Cross-Border Trades," *IEEE Transactions on Power Systems*, Bd. No. 2, Nr. Vol. 20, pp. 782 - 789, May 2005.

[9] Arab Union of Producers, Transporters & Distributors of Electricity, „Electrical Network Arab Countries," 2007. [Online]. Available: http://www.medemip.eu/Calc/FM/MED-EMIP/AUPTDE/Electicity_Interconnection_Maps/Arab_World.pdf.

[10] ENTSO-E, „Annual Report 2010," Belgien, 2010.

[11] OME, „Electricity Interconnections in the Mediterranean Countries," Tripoli, 2003.

[12] F. Trieb, „Trans-Mediterranean Interconnection for Concentrating Solar Power," Stuttgart, June 2006.

[13] G. P. CCorimanya, „Operation of HVDC Grids in Parallel with AC Grids," Göteborg, 2010.