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Abstract

Supply of Large Cities Using Modular Multilevel High Voltage Direct Current Converters

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THESIS CONTENTS

ABSTRACT

The scope of this thesis comes from an actual necessity, considering that present power systems are becoming more and more congested due to an increase in power demand, from both industrial, office and residential loads. In a research published by the U.S. Energy Information Administration in 2017 [1], several observations can be brought forward. The first underlines an estimated 28% increase in world energy use by 2040. The second conclusion from this study shows that renewable resources will hold a significant portion of the total energy mix, which will also pose new challenges. One possible answer to the congestion of AC networks is the implementation of new high voltage DC networks (HVDC), which allow massive energy flows in an economical and highly controllable manner.

Another point of inflection which further stimulates the development of HVDC networks is the increasing attention towards environmental conditions. More specifically, in the past 10 years, there have been numerous initiatives to reduce the number of fossil fuel power plants in favor of renewables such as photovoltaic power plants or wind-turbine farms. Some examples of such initiatives are [2] [3]: UN Conference on Sustainable Development (2012), UN Sustainable Development Summit (2015), the European Union Green Deal (2019) etc. The proliferation of renewable resources also brings several new problems. The first issue relates to the location of such plants, which is most often in remote areas, far away from consumption zones. The second issue comes from the intermittent nature of such resources, due to weather conditions (clouds, storms, drought, disruptive extreme weather etc.). In such instances, HVDC can provide efficient power transfer from generation to load zones, in strictly controlled operational parameters, in either a voltage source (VSC) or current source (CSC) converter configuration.

In the European Union zone, the biggest environmental change trigger is the Green Deal, which provides a roadmap with actions regarding efficient use of resources and pollution reduction [4]. Moreover, it provides a frame for significant financing of all actions which can ensure that the EU will be climate neutral by 2050. With this respect, a high portion of available funds is directed towards the energy sector in general, and the revamp of electrical grids in particular. Therefore, the Green Deal ensures proper financing for special projects such as HVDC links or HVDC grids, which are especially expensive and have a long investment return time (more than 10 years). Therefore, the biggest barrier for implementing HVDC grids, which is the high investment cost, can now be easily overcome with the use of Green Deal grants.

VSC-HVDC transmission is one of the most dynamic fields of research due to significant advancements in materials needed for the construction of various components, improvements in control systems (e.g. faster and more efficient SCADA systems, sensors with bigger accuracy etc.) as well as better experience regarding operation of HVDC links/grids. All these aspects favor the expansion of this technology, considering that there are now more than 80 HVDC projects, which are planned to be finalized in the next 15 years. Great interest is presently shown for the modular multilevel converter topology (MMC), which is an evolution of the classical VSC-HVDC.

Main objectives

The focal point of this thesis is a topic of high interest, which stems from the need to supply large cities, which are most often located far from generation zones, with significant power from renewable resources, through long distance overhead and underground power lines. This can be achieved through costly HVAC grid, but there are significant limitations regarding voltage stability. Therefore, the most likely solution is the use of a HVDC transmission system (in either two or multiterminal configuration). Presently, there are few existing VSC-HVDC grids which supply large cities, and most are in China. Therefore, this thesis uses the opportunity to analyze such a scenario for the European region, with a strong focus on a solution for supplying the capital of Romania using VSC-HVDC technology. The principal objectives of the thesis are:

- To perform a thorough analysis regarding state-of-the-art for MMC-HVDC technology;
- To perform a review of steady-state and dynamic simulation models;
- To identify the most facile techniques for MMC-HVDC control;
- To identify existing MMC-HVDC multiterminal grids which supply large cities;
- To discover current limitations of multiterminal HVDC grids and possible ways of overcoming them;
- To evaluate all steps regarding multiterminal MMC-HVDC development;
- To study all operational characteristics of multiterminal MMC-HVDC;
- To identify existing legislative drivers for MMC-HVDC development;
- To expand the concept of supplying large cities using multiterminal MMC-HVDC;
- To perform steady state and dynamic simulations on a benchmark system;
- To extend the dynamic simulations to a possible multiterminal MMC-HVDC system applicable for Romania.

Thesis Structure

This thesis is structured into 8 chapters and contains consistent information which is presented in approximately 170 pages.

The first chapter of this thesis provides an overview of VSC-HVDC. More specifically, it shows the advantages and disadvantages of this technology, in comparison with CSC-HVDC. Moreover, it presents the types of VSC as well as the structure and basic operating principles. Finally, it provides examples regarding existing projects.

The second chapter is focused on the modular-multilevel HVDC, which is a special type of VSC-HVDC with high potential. Furthermore, this technology is further detailed from a structure point of view, and its advantages and disadvantages are underlined. More specifically, each submodule type is thoroughly presented, taking into consideration all aspects related to output voltage, losses and fault capability. Furthermore, the same chapter shows a variety of existing MMC-HVDC projects with two or more terminals, with the objective of creating a complete picture regarding present maximum ratings (e.g. for voltage, power etc.). Moreover, some examples are given regarding future installations and forthcoming trends in the development of MMC-HVDC networks. In the end, some context is given to ongoing research regarding hybrid MMC-HVDC topologies.

In the third chapter, MMC-HVDC modelling is discussed, taking into consideration the fact that certain representations are only applicable in specific use-cases. As such, an extensive view is given over the detailed equivalent model and the average value model, which ensure a successful dynamic analysis over the behavior of MMC-HVDC converters. Moreover, all aspects related to steady-state models are shown in detail in order to further underline the flexibility and operational efficiency of the MMC-HVDC.

The fourth chapter provides information regarding MMC-HVDC control, with all the relevant aspects related to direct or vector control, to the levels of control, to the pulse width modulation, to capacitor balancing etc. This topic is very important because it influences the performance of any converter. In this chapter, an efficient PI parameter tuning technique is provided, and it is based on the modulus optimum criterion. As such, this technique is applied to the inner and outer converter control loops.

Multiterminal MMC-HVDC is discussed in the fifth chapter. This type of grid, which is presently crossing the barrier between concept to reality has a multitude of topics which need to be addressed. Firstly, a more comprehensive view is given to the state of the art as well as all aspect related to multiterminal HVDC grid development and operation. Secondly, attention is provided to techniques regarding grid protection: use of AC circuit breakers, use of DC circuit breakers and use of special converter topologies.

The focal theme of this thesis, which is the concept of supplying large cities using MMC-HVDC is conferred in chapter six. Additionally, all legislative drivers are discussed (especially the European Union Green Deal), and some examples are given regarding existing financial tools which can ensure a business case for multiterminal MMC-HVDC development projects. In order to underline all aspects, some examples of large city supply are given: the Zoushan project, KunLiuLong and EuroAsia interconnector. Nevertheless, some Romanian past proposals and concepts in the field of HVDC are identified and some views are given regarding possible implementations of MMC-HVDC grids in Romania.

Chapter seven contains the case study, in which several scenarios with applicability in Romania are approached. The first scenario discusses a two terminal HVDC link between Cernavodă (which is a large energy generation zone, consisting of a nuclear power plant as well as numerous renewable plants) and Bucharest (which consumes approximately 15% of the total energy production of Romania), that uses a combination of overhead and underground power lines. Next, the scenario is further extended into a new configuration with an additional terminal located near Tarnița, which is a proposed 1000 MW hydroelectric power-plant. All scenarios are approached using dynamic simulations, considering realistic conditions.

The final chapter is targeted towards establishing conclusions and perspectives, as well as underlying all original aspects of this thesis.

Summing up, the topic of this thesis, "Supply of Large Cities Using MMC-HVDC" is of high current interest because of the increasing awareness towards environmental protection in the context of already saturated HVAC grids. In this thesis, an original twist is given to this topic, by tackling all existing limitations and advantages and by applying all concepts in a hypothetical Romanian HVDC link/grid, using present day power-flow data. Moreover, the case-study underlines all theoretical aspects and becomes a launching platform for innovative scenarios that are adapted to potential examples in Romania. All unique elements are further promoted in various papers targeted for national and international conferences and journals: [41] [42] [43] [44] [45] [65] [84] [113] [114] [115].

KEYWORDS

Insulated Gate Bipolar Transistor, High Voltage Direct Current Transmission, Multiterminal Network, Vector Control, Modulus Optimum, Pulse Width Modulation, Controller Tuning, Park Transformation, Detailed Equivalent Model, Average Value Model.

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