Application of Machine Learning Models for the Thermal Rating of a 400 kV Cable System and their Validation

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ABSTRACT

This paper summarizes the investigations of Wiener Netze on the use of artificial intelligence in the form of machine learning as an alternative to analytical and numerical methods for the dynamic rating calculation of a 400 kV cable system. The investigations show that with a suitable validation methodology, even simple algorithms such as decision trees can be used for good predictions of the cable temperature of the investigated cable arrangement. Furthermore, more sophisticated models such as recurrent neural networks for time series modelling can predict cable tempeartures for different time horizons between 1 and 24 hours with high accuracy.

KEYWORDS

High Voltage Cable System, Artificial Intelligence, Machine Learning, Thermal Rating, Modelling Validation

INTRODUCTION

Creating sufficient transmission capacity in the electrical grid is not only a technical requirement, but also an economic and social one. In order to achieve the energy and climate transition within the European Union (EU), it is crucial to increase the efficient use of new and existing grid infrastructure [1]. This is especially true for high voltage (HV) cables, which are essential, both as existing grid components and due to their dominant role in offshore wind or as interconnectors. One of the possibilities identified by the EU as crucial for achieving efficiency gains is the use of dynamic line respectively cable rating [2].

The established analytical method for the thermal rating of HV power cables for stationary and dynamic loads is given by the IEC standards [3-5]. However, due to the necessary assumptions that have to be made in the course of the calculation, it can be difficult to obtain consistent, comparable and thus trustworthy results. This circumstance prompted CIGRE WG B1.56 to produce Technical Brochure 880, which laid the foundation for the validation of analytical cable rating methods in 2022 [6]. In the course of its work, the working group also noted, among other things, the dependence of the result on the calculation engineer and presented it at Jicable 2019 [7].

The finite element method (FEM) has been a popular alternative in the thermal rating calculation of power cables for more than a decade and its application and potentials are the subject of numerous publications. Nevertheless, there is still no set of standards on the application of this method. This is mainly due to the fact that it is a rather difficult undertaking because of the large number of degrees of freedom that the calculation engineer has in the application of the FEM (multiple ways to implement physics, multiphysical couplings, large number of different software tools, etc.). With [8], a technical report has existed since 2003 that deals with FEM in the rating calculation of power cables. However, as CIGRE TF B1.84 concluded in 2021, the motivation for using FEM in [8] was mainly to cover situations with stratified soil conditions, transient thermal applications and the inclusion of convection at the soil-air interface, which was not accurately covered by the relevant IEC standards. As a result, today there is neither comprehensive guidance on the application nor on the validation of FEM models in the rating calculation of HV cables. It should be mentioned that this is also currently being worked on by CIGRE WG B1.87.

Due to the increase in sensors and the advancing transition towards a smarter grid, data-driven models based on machine learning (ML) are more frequently finding their way into the electrical grid. Among other things, these also represent a promising alternative for the dynamic thermal ratings of HV cables. It should be mentioned at this point that the use of artificial intelligence (AI) in energy technology is anything but new. As early as the 1990s, a number of application areas for AI were already identified in the T&D industry, e.g. [9]. However, with the increase in distributed temperature sensing (DTS) systems on HV cables as well as the increased use of data from various sources, such as weather data, for the grid operation, it is only recently that framework conditions have been created that enable the application of such data-driven modelling approaches.

As with any new technology, however, these methods need to be properly verified and validated before they can be used in power system operations. Therefore, an attempt was made by Wiener Netze GmbH to investigate possible AI applications for the thermal rating and monitoring of HV cables. For this purpose, a 400 kV cable test setup was used, on which a wide variety of stationary and dynamic loads were applied under real conditions. Over a period of more than three years various parameters such as cable and soil temperatures, soil moisture and weather data were measured and recorded. The data was used to create, verify and validate data-driven machine learning models for the dynamic thermal rating of the 400 kV cable system.

400 KV CABLE TEST SETUP

Information about the 400 kV cable test setup like:

- used HV power cable
- laying configuration
- installed sensors and their placement
- measurement equipment used
- applied load profiles
- etc.

can be found in [10] and in even greater detail in [11].

DATA

Data Acquisition

The applications of machine learning are based on data. Data is needed to build and train the models, to validate the models, to test the models, and even after all these steps