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Investigation of necessary modeling detail of a large scale EHV transmission network for slow front transients

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ABSTRACT

Traditionally, extra high voltage (EHV) transmission systems consist exclusively of overhead lines (OHL) but in the recent years the utilization of high voltage AC (HVAC) power cables is increasing due to environmental, political and operational aspects. To study the impact of HVAC power cables on temporary overvoltages and slow front transients, a simulation model of the large-scale network is required. Guidelines concerning the modeling detail for the surrounding network need to be established to ensure sufficient accurate results. Existing guidelines for purely OHL transmission networks may not be adequate since the integration of HVAC power cables shift the harmonic impedance of the network to lower frequencies and that can affect the extent of the needed simulation model. Much effort can be saved from obtaining detailed data for an extensive but proper model, but a less detailed model might not describe the network behavior with sufficient accuracy. In this study, simplification options are considered, for which the time to construct and analyze a simulation model can be reduced. The simplification options are compared with the reference model (full detail), and judged based on three indicators for the level of accuracy: frequency and amplitude of the main resonance, and maximum over-voltage. As a result, guidelines on the extent of the simulated network and in which detail the model has to be built are proposed. The inverse approach, i.e. increasing level of detail until simulation results hardly change leads to similar results, but requires equivalent short-circuit networks for the rest of the grid. The method is tested for the Dutch 380 kV grid where an underground cable connection of 10.8 km length is introduced in 2013 and a second connection is planned for 2017.

1. Introduction

In the past, OHLs were the dominant means for transmitting electrical energy at HV and EHV levels. However, some weather-related incidents, technical changes, strong competition in the cable sector, increased urbanization as well as other political and environmental aspects are leading to an increasing utilization of HVAC underground power cables [1]. Recently, a new 380 kV transmission route in the Dutch transmission system is installed including a 10.8 km double circuit underground cable connection with two cables per phase [2–4]. In Fig. 1 the Dutch 380 kV grid is shown.

Due to the limited experience in the Netherlands with underground power cables at 380 kV, the Dutch TSO (TenneT) decided to research switching operations in HVAC cables, in order to study possible undesired overvoltages and resonance phenomena [5,6]. In order to study these phenomena accurate simulation models should be built where the chosen modeling depth strongly influences the simulation results [7]. For transmission networks solely consisting of OHLs there are proposed guidelines concerning the modeling depth needed for accurate results when simulating energization and reenergization transients, which state that the detailed model of the system must comprehend the part of the network up to the second substations behind that of the operating circuit breaker [8]. However, these guidelines might not be adequate when HVAC power cables are integrated in the studied network due to their different electrical properties (higher capacitance) which shift the harmonic impedance of the network to lower frequencies.

To predict the impact of underground power cables on transient behavior, an extensive part of the network needs to be modeled as

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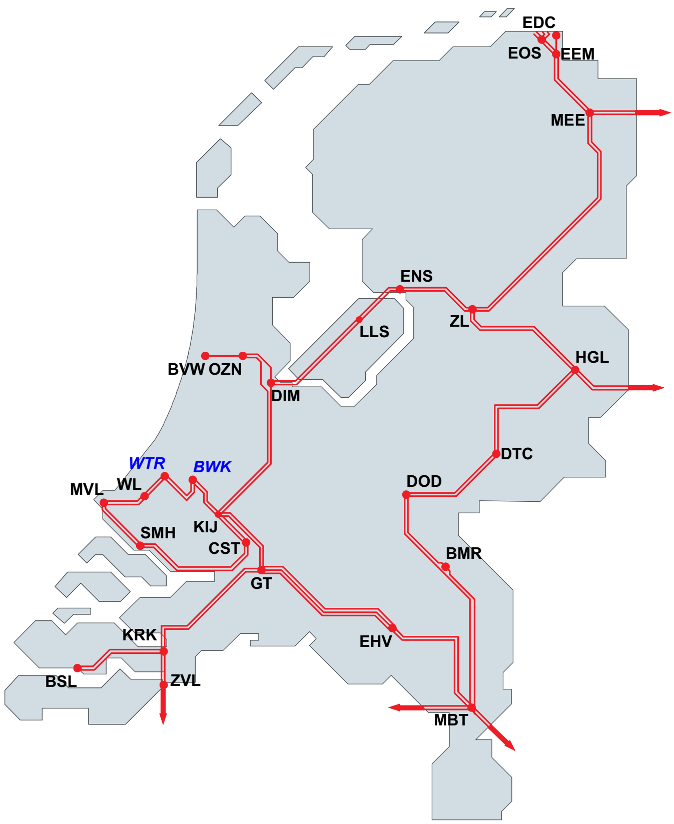

Fig. 1. Substations in Dutch 380 kV transmission system with a cable connection located between Wateringen (WTR) and Bleiswijk (BWK).

seen from the underground power cable. However, there is a lack of guidelines on the level of detail and depth of the network that needs to be modeled. Moreover, the extent of the model depends on the type of phenomena to be simulated. For lightning surges, it is usually sufficient to concentrate on the section where the lighting is expected to strike, since the level of over-voltage attenuates fast along the network. The affected section requires appropriate modeling for e.g. pylon impedance, cross-bonding method, busbars and substation equipment to adequately simulate fast transients. For power frequency related phenomena the whole grid has to be taken into account, but design details responsible for high frequency surge reflection and transmission may be ignored. The present study involves circuit response on switching transients, more specifically the reliability of predicting over-voltages depending on the detail level and extent of the network model. This involves resonance frequencies typically up to 10 kHz.

There are reasons to limit the extension of the simulated network. It can be time consuming to gather all the information, in particular when information is required on short term, e.g. changing the grid configuration upon a fault. Moreover, when systematically studying the effect of parameters on circuit response, the evaluation time can be significantly reduced. It should also be mentioned that focusing on the 380 kV Dutch grid is a simplification by itself since the connections to neighbouring countries and to lower voltage grids are not modeled in detail.

A common way to determine the extension of the network to be modeled is based on an iterative process in which the complexity is gradually increased until simulation results remain unaltered ("bottom-up" method). In this paper, the inverse approach is also investigated for which the reference model of the complete studied network is available and serves as a starting point while the complexity is gradually decreased ("top-down" method). The idea is to investigate to what extent both approach directions converge to

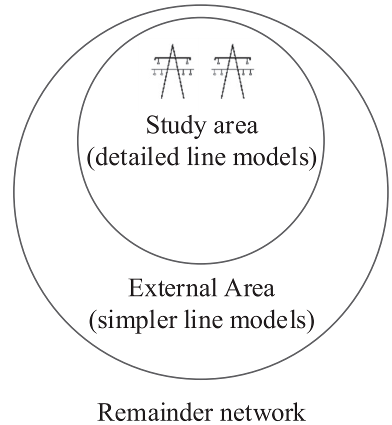

Fig. 2. A network subdivided in three areas: study area, external area, and remainder of the network.

similar requirements for the modeling detail. The results of the two methods are compared and used as a basis for establishing systematic rules to decide upon necessary model depth and details. This will lessen the effort to simulate the network behavior for studying transients.

In Section 2 both approaches used to reduce the model complexity and the criteria for comparison are presented. Section 3 describes the establishment of the reference network. The resulting simplified models of the Dutch 380 kV transmission network, for both methods are analyzed in Section 4. Section 5 gives the conclusion regarding the validity of the "bottom-up" method as well as preliminary guidelines on the necessary model extent and detail.

2. Approach

Refs. [9–12] propose a general concept dividing the whole network into three areas: the study area (with detailed line models), the external area (with simpler line models), and the remainder network (not important for the study of transients), see Fig. 2.

This approach is adopted in this paper. The Wateringen (WTR) to Bleiswijk (BWK) connection is focal point of the study area and maximum detail is employed for this section. Connections to other countries and to grids at lower voltage level (220 kV, 150 kV) are always considered as part of the remainder network and need proper equivalent circuits based on the corresponding short-circuit power or the powerflow. The boarders between these regions, comprising the external area in Fig. 2, are adapted as indicated in Section 2.1. The indicators for assessing simulation accuracy are discussed in Section 2.2.

The focus in this study is on frequencies of up to 10 kHz, caused by line switching transients, often referred to as slow front surges [8]. PSCAD/EMTDC simulation software is used to calculate the transients [13,14].

2.1. Model complexity

The best way to evaluate the effect of complexity reduction is a comparison with the real network. To this end a reference model is constructed in which high level of detail is incorporated. The reference model is described in Section 3. Next, simplifications are introduced and the resulting method is referred to as the "top-down" method. The whole 380 kV transmission network in the Netherlands, serves as the reference model and includes the following details:

- transmission routes with their length, phase order and transpositions.