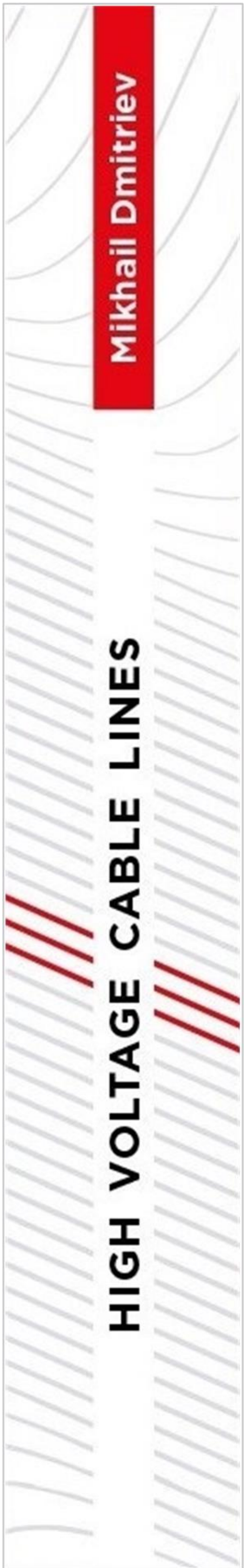
Mikhail Dmitriev

High Voltage Cable Lines



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St. Petersburg, 2021
Porto, 2024

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This book explores the design, construction and operation of alternating current cable lines rated from 6 to 500 kV, consisting of single-core or three-core cables with XLPE insulation.
It is intended for employees of design organizations and power grid companies, as well as university students.

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PREFACE

It is impossible to design modern, reliable and efficient XLPE-insulated cable lines based on outdated standards for paper-oil-insulated cables.

Unfortunately, the development and approval of the necessary standards that take into account all the peculiarities of the new generation of cables are 5-10 years behind. Since then, dozens of facilities have been commissioned based on suboptimal and sometimes even dangerous technical solutions, resulting in significant economic loss for power grid companies and the threat to human life and health.

Speeding up the standardization process is really important for the industry. However, new standards will not solve all the problems since the development of standards typically involves a narrow group of experts whose opinion is far from being the only correct one all the time. Also, due to their brevity, standards cannot accommodate all the calculation methods designers need and do not explain the reasons for specific requirements/restrictions/rules.

The above circumstances led the author to write a book on cross-linked polyethylene-insulated high-voltage cable lines. The book is based on the author's own research over the past 20 years and therefore does not include a "traditional" bibliography. Also, this book does not include references to standards since they do not address many questions entirely, and if they do, they do not give proper explanations. For the reasons mentioned above, the references list at the end of the book is somewhat unusual – the standards indicated there were published after most of the research that formed the basis of this book. Therefore, the standards are given not because the author needed them, but in order to advise the reader on documents on high-voltage cables.

The material in this book is intended for a broad audience. It is presented in the simplest language and includes only mathematical expressions with nothing more complicated than a square root and a natural logarithm. After reading the book:

– university students will learn about topical issues relating to cable lines;
– employees of design organisations will find simple and easy-to-understand calculation methods that enable to choose the best technical solutions and support specific sections of design documentation with sound arguments (the design is not convincing if it relies only on the use of computer software, even licensed and/or expensive);
– employees of power grid companies will be able to clarify or update their technical policy and find a rationale for introducing new solutions and equipment in cable networks.

For any questions arising when reading this book, please contact the author using the contact details from the website https://voltplace.com/

FROM THE AUTHOR

I was born and raised in the USSR, and English is not my native language. I admit, I have never read a single international standard in my life because I didn't have money to buy them. Instead, I sat down and developed my own cable line calculation system, simple and quite precise. Using it, I made many of important conclusions, which are set out in this book and were used in the creation of cable standards in the countries of the former USSR.

I suppose, my system of designations may differ from the international one because it has developed independently of the international one. My thoughts and conclusions may contradict what is accepted in the global cable industry. I believe this is more an advantage of my book than a disadvantage, as it makes the reader look differently on that he was sure of.

The important thing in the book is that I show where the formulae come from. I get them from scratch in front of the reader. It is very important in engineering to be able to write formulae. However, many of engineers began to forget this, blindly trusting numerous software which often lies, and it can be proved only if we have understandable formulae or field experiments.

The book contains the results of my professional work started in 2003. It is based on my own publications, the full list of which can be found on the website https://voltplace.com/ in the "About" section. You are most likely unfamiliar with them because they were published only in Cyrillic, as well as two my previous books on cable lines dated 2010 and 2021. I never thought of myself outside my homeland and did not want to write in English. However, never say never.

Mikhail Dmitriev
Porto, Portugal, 2024

Note: *if you want to support the author, then you can do it using https://voltplace.com/donate/*

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INTRODUCTION

Transmission lines (TL) serve a crucial purpose in the electric power industry, allowing electricity to be brought from where it is generated to places where it is consumed. Transmission lines are also designed to connect neighbouring power systems to allow their parallel operation, thereby improving the reliability of the entire power network due to the mutual reservation of its individual parts.

Transmission lines come in the following basic types:

- overhead line (OHL);
- cable line (CL);
- gas-insulated line (GIL).

The power transmitted by transmission lines is proportional to the voltage on current-carrying parts relative to the ground and the current in those parts. Current-carrying parts must be reliably insulated in order to raise the voltage on them. The type of insulation of current-carrying parts is the fundamental difference between the three types of transmission lines:

- for OHL, it is air at atmospheric pressure;
- for CL, it is solid insulation (polyethylene, rubber, oil-impregnated paper);
- for GIL, it is high-pressure gas (SF_6 gas or its mixture with nitrogen).

The three types of transmission lines (OHL, CL, GIL) also differ in such properties as:

- design and size;
- impact on the appearance of cities and the landscape of the area;
- susceptibility to climatic factors (wind, precipitation, ice, etc.);
- breakdown susceptibility (number of outages per year and their average duration);
- environmental friendliness (level of electric and magnetic fields, consequences of accidents);
- cost and duration of construction, maintenance and repair.

Today, GILs are rarely used (due to their high cost) when building transmission lines, and in the vast majority of cases, the choice is between OHL and CL. Compared with OHL, CL is 10 times more expensive to build than OHL of the same voltage class. However, there are instances when CL is necessary. CLs are typically used in the following cases:

- cities, resorts, and nature reserves, where the cost of land is so high that, despite the high cost of cables, overall, a CL is cheaper to build than an OHL and its buffer zone;
- large cities where OHLs are not permitted for aesthetic reasons, as well as for the electrical safety of the public;
- when OHL is connected to the indoor switchgear (SG) of a station or substation, when OHL cannot enter a building through its walls; in that case, a short CL is used, just a few hundred metres long, connected at the end of the OHL (that is SG cable entry for the OHL);

- when OHL passes through water or other obstacles using CL (cable section inserted in OHL);
- when transmitting power from hydroelectric power plants from the dam to the shore using CL (connecting step-up unit transformers, installed directly on the dam, with high-voltage SG on the shore);
- power supply to power plant auxiliaries (circulation pumps, feed pumps, etc.) using CL;
- setting up internal power supply networks for large manufacturing or processing plants in various industries using CL.

Clearly, the list of cases when cable lines are used is quite long. As a result, cable lines are vital and sought-after, and challenges related to their design require an in-depth study. Since the early 21st century, single-core or three-core cables with cross-linked polyethylene insulation (XLPE) have been primarily used when building new cable lines and repairing old ones. The book particularly explores that.

Usually, all transmission lines are classified according to nominal voltage:

- low voltage (less than 1 kV);
- high voltage (from 1 to 750 kV, in some countries up to 1000 kV).

The classification fully applies to cable lines, except that 750-1000 kV cables are not used because they are very difficult to manufacture, install and maintain. Therefore, it is no surprise that this book only deals with high-voltage cable lines rated up to 500 kV AC (as for DC cable lines, they are a special case and are not covered in this book.).

The book touches upon the design, construction and operation of high-voltage cable lines rated up to 500 kV AC, consisting of single-core or three-core XLPE-insulated cables. Despite the simplicity of calculation methods proposed in the book, they have an error of no more than 5-10% only, which was verified through:

- computer simulation (using popular software like EMTP etc.);
- full-scale experiments (where possible).

PART 1.
OVERVIEW OF CABLE LINES

Chapter 1.1. Basic Terms and Definitions

1.1.1. Cable and Wire

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High Voltage
Cable Lines

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