Thermal performance optimization of the underground power cable system by using a modified Jaya algorithm

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Abstract
This paper presents a modified Jaya algorithm for optimizing the material costs and electric-thermal performance of an Underground Power Cable System (UPCS). A High Voltage (HV) underground cable line with three 400 kV AC cables arranged in flat formation in an exemplary case study is considered. When buried underground, three XLPE high voltage cables are situated in thermal backfill layer for ensuring the optimal thermal performance of the cable system. The study discusses the effect of thermal conductivities of soil and cable backfill material on the UPCS total investment costs. The soil thermal conductivity is assumed constant and equal to 0.8 W/(m K). The cable backfills considered in the study are as follows: sand and cement mix, Fluidized Thermal Backfill™ (FTB) and Powercrete™ a product of Heidelberg Cement Group. Constant thermal conductivities of the backfills in the dry state are assumed, respectively, 1.0 W/(m K), 1.54 W/(m K) and 3.0 W/(m K). The cable backfill dimensions and cable conductor area are selected as design variables in the optimization problem. The modified Jaya algorithm is applied to minimize material costs of UPCS under the constraint that the cable conductor temperature shall not exceed its optimum value of 65 ºC. The cable temperature is determined from the two-dimensional steady state heat conduction equation discretized using the Finite Element Method (FEM). The performance of the modified jaya algorithm was compared with classical Jaya and PSO algorithms. The modified Jaya algorithm, for the presented case study, allows one to obtain lower values of the cost function.

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1. Introduction
The sustained growth of the global economy and increasing population, particularly in the developing countries, determine the increasing demand for electric energy supply. Electrical power worldwide is mainly transmitted with High Voltage (HV) Alternating Current (AC) overhead line technology. For instance, 96% of the onshore transmission network in Europe is build overhead, and only 4% is installed underground. Underground cables are mainly used over short distances, in areas where overhead lines are inexpedient or impossible to use, as well as for specific technical applications. Underground cabling is becoming increasingly attractive for use mainly for environmental and aesthetic reasons. Also, Underground Transmission Lines (UTL) are resistant to weather conditions and are installed when the use of overhead lines may result in an adverse impact on the environment, concerns over potential health issues, impact on property prices, or the condition of national parks or areas of natural beauty. UTL is also more reliable than overhead transmission lines when it comes to the cable line failure likelihood. Thus, UTL is recommended during design and installation in:

- densely populated urban areas (ease of network expansion, lower risk of electric shock, aesthetic reasons),
- electrical power outputs from power plants (i.e. conventional or renewable energy sources) and large energy consumers (i.e.}

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Undergrounding is not a new trend, as underground cables have been used for low and medium voltage lines in urban areas for a long time. Several countries use underground low voltage (LV) distribution lines in almost their entire network, with a target of 100%, such as the Netherlands, Singapore, and Denmark. For instance, Denmark is planning to underground 75% of its electricity grid shortly. It should be noted that almost 10% of the underground power projected lines are 400 kV transmission lines [4].

Nevertheless, use of underground cables in HV applications is still limited owing to their high installation and maintenance costs, as well as expensive repairs in case of an outage. It was estimated in Ref. [2] that underground lines could take from 48 to 480 h to be repaired during an outage, as compared to 8–48 h for overhead lines. The underground cables themselves also have a higher unit price due to their construction complexity and greater production costs [3].

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