Title:
A Design Approach for Overhead Lines Considering Configurations and Simulations

Authors:
Paolo Cicconi, p.cicconi@staff.univpm.it, Università Politecnica delle Marche, Italy
Steve Manieri, s.manieri@staff.univpm.it, Università Politecnica delle Marche, Italy
Nicola Bergantino, n.bergantino@mynext.it, NeXT Srl, Italy
Roberto Raffaeli, roberto.raffaeli@uniecampus.it, Università degli Studi eCampus, Italy
Michele Germani, m.germani@staff.univpm.it , Università Politecnica delle Marche, Italy

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Introduction:
Nowadays, the employment of CAD tools is essential in several sectors from mechanics [2, 3] to Architecture Engineering Constructions (AEC) [1]. These sectors have been using an integrated information approach into 3D-CAD models to reduce time and optimize cost during the design phases. The design of overhead lines is still limited to the use of customized and specific software which limits the interoperability with other tools used for general purposes. Most of these tools are configuration software which can have or not a 2D/3D modelling tool to support the geometrical definition of supports and conductors (also called as hanging cables [9]). However, the lack of interoperability limits the development of advanced simulations and the integration with other analyzes. Even if the literature shows a relevant simulation activity about the geometrical optimization of poles [16] and lattice towers [13], these works are parameters-based without showing a CAD-based modelling approach. Some papers have also been paying attention to the cost optimization of such transmission lines [8, 15]. These works mainly concerns a parameters optimization to reduce the life cycle cost of a distribution line. However, few researchers have considered both costing and structural analysis in their works, as described in the next section.

The study on overhead lines is a recurring theme in literature. Since a 50-years return period is a common design practice for power transmission lines [7], there is a continuous demand of best design practice to improve the overall performance reducing time and cost related to the engineering design. Today, the research is mainly based on the cost optimization to evaluate the design of new lines or the re-design of existing ones. In fact, when a transmission line is approaching the end of the service life, the risks of its use increase [6].

The present paper deals with an information modeling approach for the design of overhead lines. The method describes an interoperability design platform which considers the integration of geometry, boundary conditions, simulations, cost, and life cycle information. This approach considers the geometry of each supporting pole, the location area with obstacles, the analytical calculation of the loading conditions, and the interaction between 3D-CAD model and FEM simulations.

Research Background on Overhead Lines:
Actually, electricity is very important for the society because it is necessary for supporting various activity. Any disruption in the distribution lines may result in large economic loss [9]. Therefore, the reliability is an important quality factor in power distribution. Smart cities, and also smart homes, depend on the continuous distribution of electricity [5]. Typical outage sources are related to the

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weather conditions such as ice, snow, wind, and storms [4]. Additional damage conditions are related to earthquake and trees falling. Even if undergrounding lines avoid a lot of disadvantages related to the reliability of power transmission, overhead lines still remain the cheap solution [5]. Therefore, the design optimization of overhead lines is a current topic in literature due to the growing interest for a reliable electricity distribution.

Early studies on the design optimization of these overhead lines started in the '60 [10]. In the '80, Olbrycht studied an algorithm to optimize the cost of transmission lines considering a fix number of poles to be arranged on a defined route [9]. An early CAD modelling of a transmission line was analyzed by Peyrot et al. in 1993 [11], but this approach was not extended in other research projects. They exploit the use of a GIS-type representation of the terrain as a modelling input. However, this work was mainly limited by the technology related to the tools available in the early '90s. For example, any FEM solver and any integration between CAD and FEM are not analyzed. Additionally, the life cycle information was not considered. In the second part of the '90s, a Knowledge Based System was proposed by Picard et al. to support the tower configurations and the cost per kilometer of high-voltage transmission lines [12]. However, they did not consider any simulation activity during the described design phase. More recently, in 2012, Raghavedra proposed a design optimization based on FEM simulations [13]. He used STAAD PRO-04 and ANSYS as simulation solvers. However, his work was only based on the optimization of a single tower. Therefore, he did not analyze the design optimization extended to a complete transmission line. Additionally, the 3D-CAD model representation on the transmission line is not considered.

Generally, the design of a transmission line depends on the configuration of an appropriate set of parameters and data [15]. A change of a single parameter, such as the conductor diameter, effects the loading conditions on the structural supports and their foundations [8]. The influence of the change propagation is an important topic in this application context. Since the construction of such lines involves heavy investment, a careful analysis needs to be carried out at the planning stage when the decision is making. In this context, Teegala et al. proposed a genetic algorithm approach for the cost assessment and optimization of overhead power transmission lines [15].

Recently, much research has been focusing on the safety optimization and cost reduction since 2014. Virtual prototyping is often used to simulate extreme loading conditions related to wind, snowing, and their combination. While some loads conditions are well described by normative, other events are still under investigation. For example, the freezing radiation fog is a new weather event in the North of France. Therefore, Dulcloux and Nygaard published in 2018 a research work to estimate the real ice loads to be considered during the design activity [4]. In the same period, Stengle and Thiele analyzed a simulation approach to investigate the loads related to a downburst wind acting on an overhead transmission line in Northern Germany [14]. All these research works highlight an increasing interest in the design of overhead lines to reduce cost and increase safety and reliability. Virtual prototyping is applied in several papers; however, the recent developments have excluded the role of the CAD-model into the design workflow. In this study, the authors want to consider a platform tool based on the 3D-CAD system to be used as an information repository and as a tool for interacting with FEM analysis.

Approach:

The main idea of the paper is to automate the design of overhead lines and verification of existing lines by using a configuration tool in combination with a CAD modeler, and double checking the results obtained using a FEM tool and an analytical model. The entire process is shown in Fig.1.

The configuration tool used in this paper is ProLED 2.0, which is a commercial software developed by NeXT srl. This design tool enables the user to configure a new line by selecting different types of existing supports, considering the topological characteristics of the environment such as altitude and geographic position. A prototypical plug-in has been implemented to perform the data export and interoperability with the CAD system employed. This plug-in converts the configuration data, exported by ProLED 2.0 in an XML structure, into a Visual Basic script which automates the design of the 3D line using the Application Programming Interface toolkit provided by the CAD system. The related CAD model is parametric; therefore, each change can come back to ProLED 2.0 by the export of an updated XML file.

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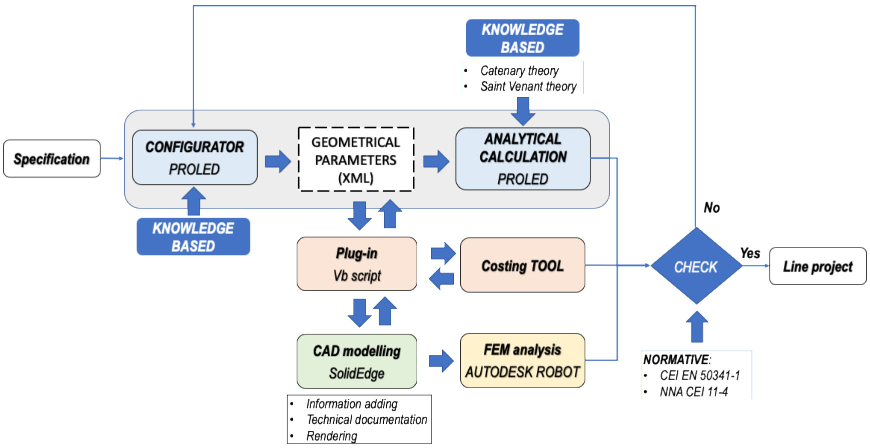

Fig. 1: Scheme of the design process.

The design of overhead lines is regulated by normative; in particular, in Italy the main normative references are CEI EN 50341-1 (European) and NNA CEI 11-4 (National). For each configuration, the normative provide a procedure to calculate the loading conditions to be used for the structural analysis, and the constraints to be satisfied. In particular, the main loads are resumed in Tab. 1.

Loading conditions	*Condition description*	*Temperature*	*Wind*	*Ice/Snow*
a)	Every Day Stress	15°C	/	/
b)	Minimum temperature	Zone A -> -7°C Zone B -> -20°C		/
c)	Maximum wind	-7°C		/
d)	Combined wind-ice/snow	-2°C	0.6 Vb	Sk
e)	Maximum Temperature	Zone A -> 55°C Zone B -> 48°C	/	/

Tab. 1: Main loading condition, as defined in the standards.

Once the loads have been applied, the line must satisfy many constraints. In the proposed paper, the constraints that have been considered are:

- Structural resistance of the sustains (poles, lattice structures, etc.);
- Structural resistance of the cable;
- Minimum allowance from ground.

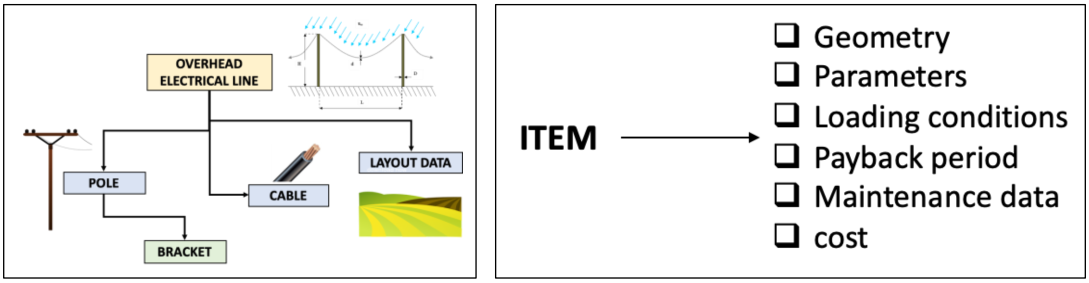

Fig. 2: a) structure of an overhead power line; b) scheme of the information data for each item.

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Firstly, the constraints satisfaction is verified analytically by calculating the stress state and the deformations of conductors with the Catenary theory. Secondly, the analyzed line is verified using a FEM tool such as Autodesk Robot® (structural analysis). The results obtained from the finite element analysis are thus compared with the analytical computation, in order to have a double-check analysis. If the design satisfies the normative, then the process in concluded; otherwise, the line needs to be reconfigured and the analysis starts again. Fig. 2a describes the simplified system-structure of a low-voltage power line. A typical low-voltage power line network consists of a set of poles which support the conductors (cables). The number poles and the calculation of loads provided by normative increase the complexity of such system. Each pole includes a number of isolators and brackets. Fig. 2b reports the information data related to each item of the analyzed system. The information concerns: geometry, parameters, loading conditions, payback period, maintenance data, and cost.

Regarding the line configurations, ProLED is the software employed for the geometrical and mechanical calculation of Power Lines. This tool is developed by NeXT Srl (www.mynext.it) to support the configurations of overhead lines. In particular, this system implements a Knowledge Base which elaborates geometrical data and specifications to configure conductors and a set of structural sustains such as poles or lattice structures. The engine of ProLED applies normative, analytical models, and constraints to define the configurations of a power line project. The input data required for solving the configurations is:

- Location data: altitude, georeferential position, list of obstacles such as roads, buildings, etc.;
- Conductor specifications: type of conductors, voltage, presence of one or more fiber optic cables, number of conductors per sustain;
- Poles/Towers specifications: type of sustains (poles or lattice towers), spatial distribution of each pole/tower, conductors (or other cables) between each couple of sustains.

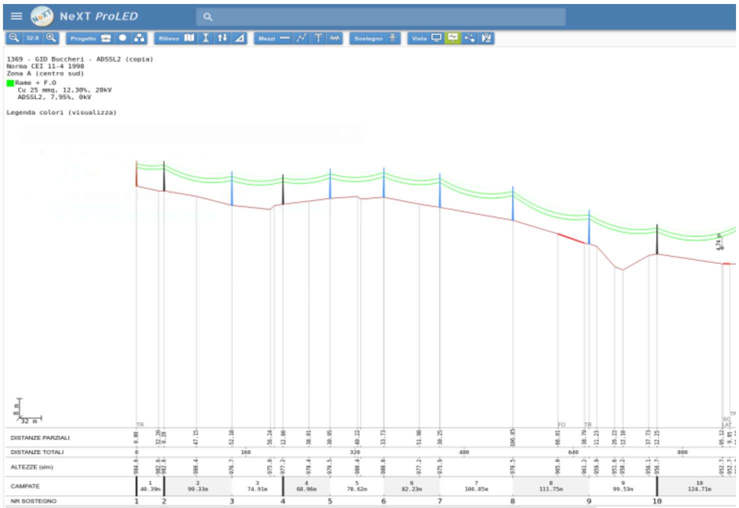

Fig. 3: Section view of an example of overhead line (Elevation profile).

First of all, ProLED solves the equations related to the overhead catenaries for each line span between two consecutive poles or lattice towers. ProLED also computes each span length and evaluates the distance between conductors and objects, as provided by normative. After this calculation step, ProLED computes mechanical models to evaluate the strength of each sustain, considering the appropriate loading conditions. These loading conditions refers to wind, ice, snow, earthquake, etc. In particular, a derivative state of tension has been calculated for each load condition in order to evaluate the effect on

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a catenary-object. In fact, a catenary-object changes its length and state in functions of temperature, pre-tension, and applied forces. Finally, ProLED selects the right configurations of poles and towers from a set of possibilities already stored into a database. The defined configurations are able to withstand the loads provided by normative.

As a configuration report, a 2D scheme is elaborated to support the further design activities. In particular, two types of views are provided in ProLED: Elevation profile (Fig. 3) and Plan view (Fig. 4).

The designer can also edit each line-object from both views (Elevation profile e Plan view). Regarding the definition of any possible obstacles, ProLED can directly acquire the position of each object (poles, lattice structures, obstacles, etc.) from Google Maps under a certain degree of accuracy. This feature avoids measurements in filed. In this paper, the configurations of overhead lines have been evaluated using ProLED 2.0. A third version of ProLED will released at the begin of 2020 and it will provide a 3D modelling too with the possibility to import data from .las files.

Fig. 4: Example of a Plan view based on Google Maps.

<u>Test Case:</u>
The test case regards the modelling and simulation of a three-poles system. The configuration data regards an installation in North Italy. Fig. 5 and Fig. 6 shows some report of the FEM analysis for different loading conditions. These reports refer to the FEM simulation of the CAD model. In particular, Fig. 5a regards the loading condition of Maximum Wind and Fig. 5b a combination of Wind and Ice/Snow. In particular, the geographical position of the line requires to consider Ice instead Snow in combination with Wind. Moreover, using a FEM tool, the 3D deformation of conductors is also evaluated and represented.

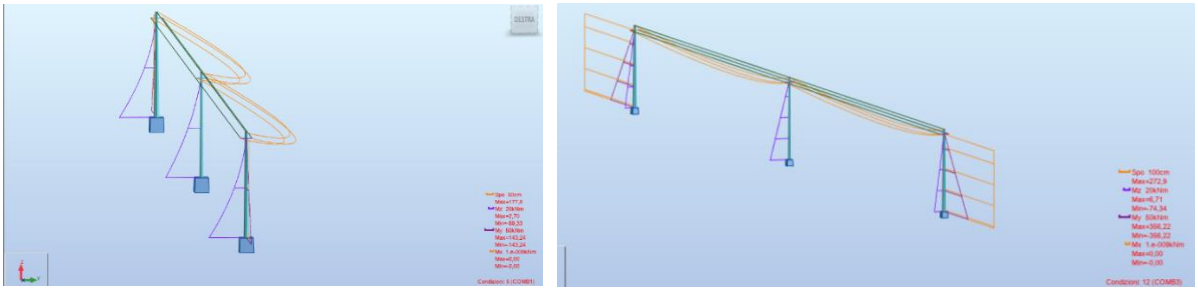

Fig. 5: A FEM simulation report related to: a) max wind loading; b) combination of wind and ice condition.

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Conclusions:
This paper proposes an approach based on computer-aided design for modelling overhead lines. The information modelling has been included into the CAD model. A tool has been implemented to perform the connection between CAD tool and FEM software. The approach aims at reducing the gap between configurations and simulations in the context of overhead powerlines, introducing the 3D-CAD representation as an information modeling to be used in embodiment design for cost calculation and details analysis.

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