A Design Approach for Overhead Lines Considering Configurations and Simulations

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Abstract. Nowadays, the contribution of the CAD modeling is not yet well exploited into the design of overhead lines. Even if some commercial tools are available, they are very similar to configuration tools with design rules related to reference normative. Sometimes, if 2D/3D CAD tools are employed, they are viewers or customized versions with specific features for the design of overhead lines. This situation limits the interoperability between the design of overhead lines and traditional software employed in the design of civil structures and infrastructures. Moreover, an information modeling approach is still lacking in current tools for the management of additional data about maintenance, cost, etc. In the context of overhead lines, the paper aims at showing an information modeling approach with a platform software which includes a configuration tool, a CAD module, an analytical-based solver, a costing tool, and a Finite Element Method solver. The CAD module is employed to define a 3D model including, as tag-objects, a set of information regarding the lifecycle design of overhead lines. Finally, a Finite Element Model solver enhances a second level of validation and enables advanced simulations.

Keywords: Configurations; Computer-aided design; Information Modeling; Finite Element Model; Overhead lines.
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1 INTRODUCTION

The employment of CAD tools is essential in several sectors from mechanics [4, 5] to Architecture Engineering Constructions (AEC) [2]. These sectors have been using an integrated information approach into 3D-CAD models to reduce time and optimize cost during the design phases. Moreover, interoperability is considered as a strategic characteristic for the design tools used in these engineering contexts [10]. For example, the Industry Foundation Classes specification, also known as IFC, is an open data file standard, based on the STEP structure, for representing and sharing information in the modeling of buildings and infrastructures [19]. This approach increases the interoperability giving important results in the context of AEC.

The highlighted interoperability between different design tools has not yet well analyzed in the context of overhead lines such as the power distribution (Figure 1). 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 for the design of overhead lines are configuration software which can have or not a 2D/3D modeling tool to support the geometrical definition of supports and conductors (which are also called as hanging cables [11]). However, the lack of interoperability limits the development of advanced simulations and the integration with other tools for simulations, costing, management, and so on.

Figure 1: Examples of overhead lines with a) poles and b) lattice towers.

Power overhead lines represent a recurring topic in literature. Since a 50-years return period is a common design practice for power transmission lines [3], there is a continuous demand of best design practice to improve the overall performance reducing time and cost related to the engineering design. The early studies were developed in literature in the ’60 and also in the ’80 [12]. Today, the research is mainly based on the optimization analysis 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 its service life, the risks of its use increase [8]. Therefore, analysis about the comparison between the substitution of structural supports (lattice towers, poles, etc.), or the reinforcement of the existing one, is already present in literature. Generally, even if the literature shows a relevant simulation activity about the geometrical optimization of poles [18] and lattice towers [15], these works are parameters-based without showing a CAD-based modeling approach. Some papers have also been paying attention to the cost optimization of such transmission lines [9, 17]. 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. Finally, the design of overhead lines is still based on a 2D-CAD representation and the use of 3D tools only concerns customized software not still open to interoperability and life cycle management.

The lack of interoperability reduces the possibility to add advanced calculation analysis to the traditional design workflow. For example, the cost evaluation could be integrated using a specific tool for costing. Moreover, the 3D simulations of an overhead line could be integrated into a more complex simulations where the wind action interacts with close buildings, infrastructures, etc. Enhancing the integration of general purposes software, into the design of such specific structures, could provide the instruments for analyzing new loading conditions not yet considered by current normative.

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.

2 STATE OF THE ART

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 [11]. Therefore, the reliability is an important quality factor in power distribution. Smart cities, and also smart homes, depend on the continuous distribution of electricity [7]. Typical outage sources are related to the weather conditions such as ice, snow, wind, and storms [6]. 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 [7]. 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 [12]. 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 [11]. An early CAD modeling of a transmission line was analyzed by Peyrot et al. in 1993 [13], but this approach was not extended in other research projects. They exploit the use of a GIS-type representation of the terrain as a modeling 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 [14]. 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 [15]. 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 [17]. A change of a single parameter, such as the conductor diameter, effects the loading conditions on the structural supports and their foundations [9]. 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 [17].

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 [6]. 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 [16]. 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.

Few commercial software tools have been developed in the last years to support the design of overhead power lines because in the developed countries the electrification of the territory has been carried out years ago and thus there are few new design projects. In this context, the main activity of engineers is to maintain the existing structures. On the other hand, electrification of the territory is still a primary necessity in developing countries, where new lines are being constructed every day. Furthermore, international and national standards are constantly changing and improving, and this implies that also old lines must be checked in order to verify the compliance with the new standards. The aim of the authors is to propose a specific computer-aided design process to support the new design and also the re-design of overhead lines, including some information related to the life cycle such as maintenance, cost, loading conditions, etc.

In this paper, the authors want to consider a platform tool based on a configurations tool and a 3D-CAD system to be used as an information repository for interacting with a FEM and a cost analysis. The introduction of a FEM simulation allows the project of an overhead line to be double checked using an early analytical analysis and a further numerical one. Even if the gap between these two methods is below 5%, a FEM simulation can be used to add different boundary conditions to the system analysis. For example, the interaction between wind and buildings and terrain can change the resultant conditions to the overhead system. Therefore, a FEM analysis can overcome the limits of standard simulations introducing additional and different scenarios to be simulated.

3 APPROACH

The main idea of the paper is to support the design of overhead lines by using a platform tool which includes configuration, design automation with a CAD module, and a double level of analysis using an analytical and a FEM tool. Figure 2 describes the proposed approach. In particular, even if the approach is generic for any overhead lines, the paper is focused on low-tension lines which use poles as sustains.

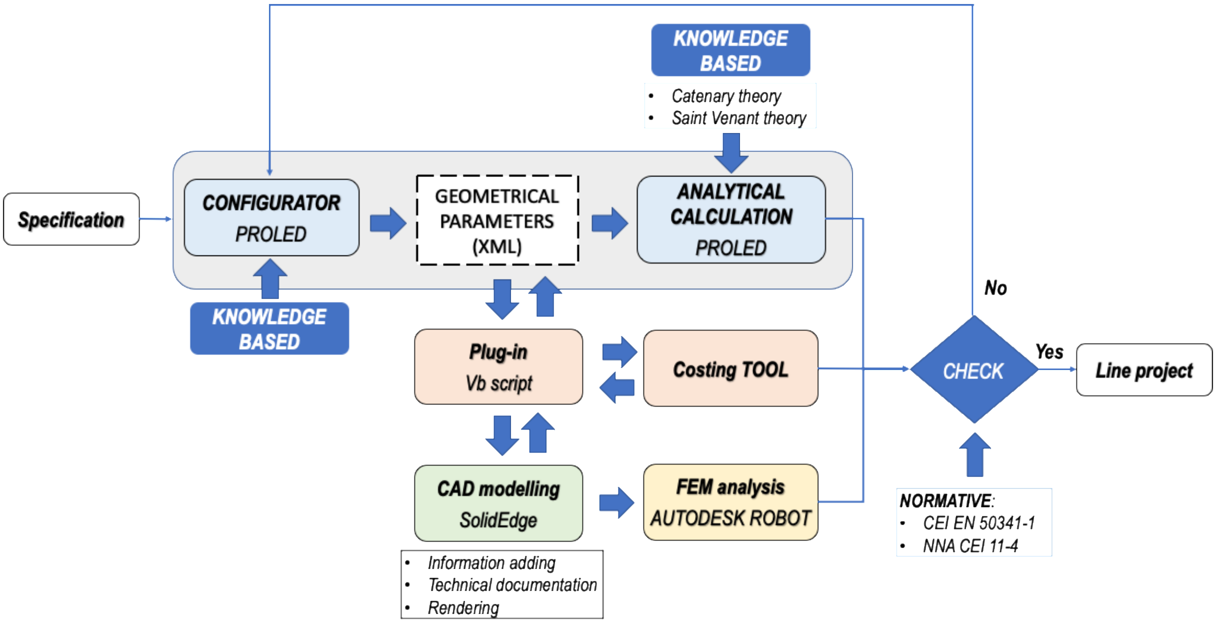


Figure 2: Scheme of the design process.

While the configuration tool implements rules related to know-how and reference normative, the CAD software is employed to define a 3D model including as tag-objects a set of information regarding the life cycle design of overhead lines. The analytical calculation gives early evaluation about the structural behavior of poles and conductors under loading conditions. Afterwards, a Finite

Element Model solver enhances a second level of validation and enables advanced simulations which can include additional boundary conditions not still provided by reference normative. Simultaneously, a tool evaluates the cost of the analyzed lines.

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 a 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.

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 Table 1.

Loading conditions	*Condition description*	*Temperature*	*Wind*	*Ice/Snow*
a)	Minimum temperature	Zone A -> -7°C Zone B -> -20°C	$\sqrt{C_e}V_b$ $0.76\sqrt{C_e}V_b$	/
b)	Maximum wind	-7°C	$\sqrt{C_e}V_b$	/
c)	Combined wind-ice/snow	-2°C	$0.6V_b$	S_k
d)	Maximum Temperature	Zone A -> 55°C Zone B -> 48°C	/	/

Table 1: Main loading conditions, 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 sustains (poles, lattice structures, etc.);
- Structural resistance of conductors;
- Minimum allowance from ground.

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. In this paper, the configurations data are used to automatically generate a CAD model of the line, using a developed script. The CAD model is useful because it can be used for aesthetics rendering, producing technical documentation, and importing the system geometry into a FEM software, such as Autodesk Robot® for the structural analysis. The results obtained from the FEM analysis are thus compared with the analytical computation, in order to have a double-check analysis. If the design satisfies the normative in both analyses, then the process is concluded; otherwise, the line needs to be reconfigured and the analysis starts again. The integration of the FEM simulation is not fully automatized. However, parametric templates for the loading conditions have been previously defined and stored into the FEM tool to reduce the setting time.

3.1 Configurations

ProLED is a software for geometrical and mechanical calculation of Power Lines developed by NeXT Srl (www.mynext.it). This software has been employed 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 (Figure 3).

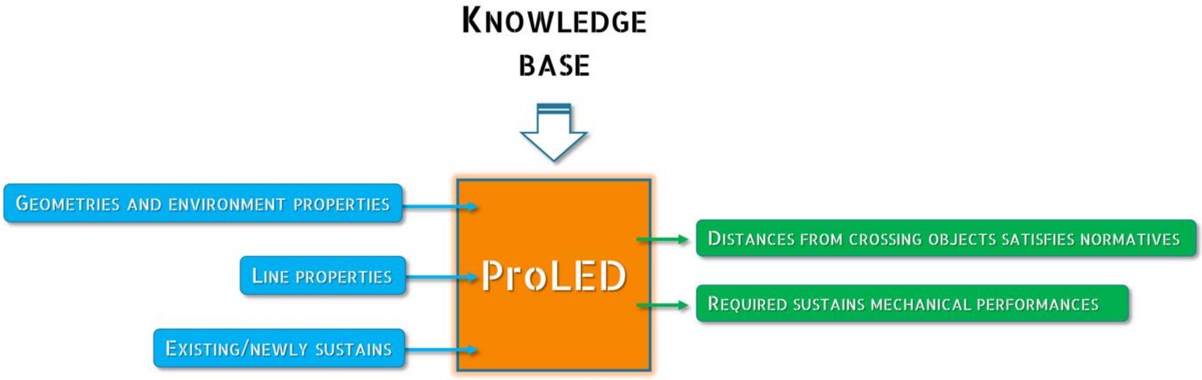


Figure 3: The configurations workflow elaborated by ProLED.

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.

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 (Figure 4).

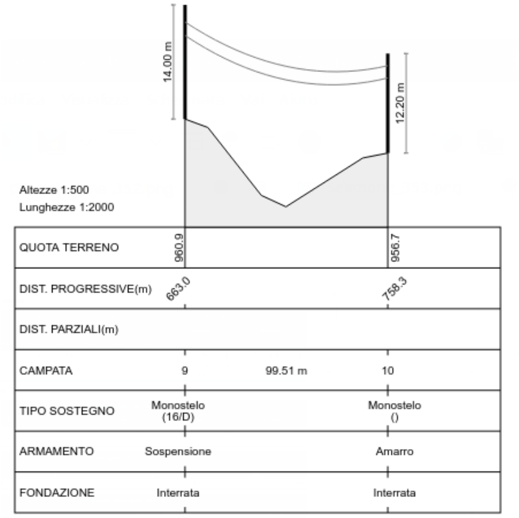
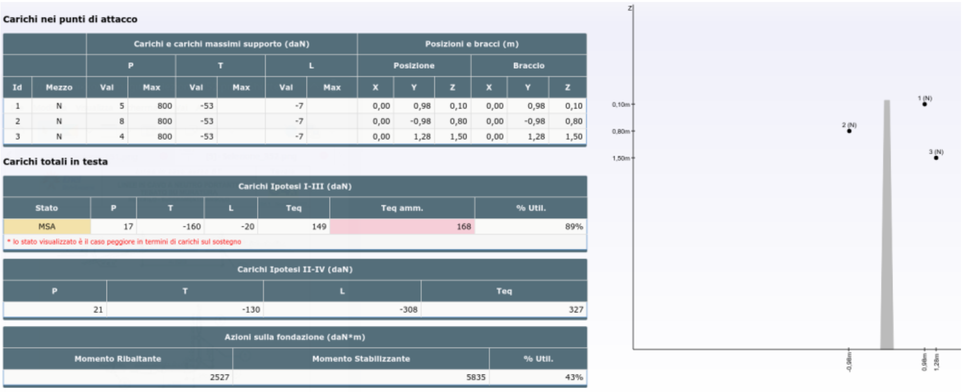


Figure 4: Report of the configuration related to a line span.


Carichi nei punti di attacco

		Carichi e carichi massimi supporto (daN)						Posizioni e bracci (m)					
		P		T		L		Posizione			Braccio		
Id	Mezzo	Val	Max	Val	Max	Val	Max	X	Y	Z	X	Y	Z
1	N	5	800	-53		-7		0,00	0,98	0,10	0,00	0,98	0,10
2	N	8	800	-53		-7		0,00	-0,98	0,80	0,00	-0,98	0,80
3	N	4	800	-53		-7		0,00	1,28	1,50	0,00	1,28	1,50

Carichi totali in testa

Carichi Ipotesi I-III (daN)						
Stato	P	T	L	Teq	Teq amm.	% Util.
MSA	17	-160	-20	149	168	89%

* lo stato visualizzato è il caso peggiore in termini di carichi sul sostegno

Carichi Ipotesi II-IV (daN)			
P	T	L	Teq
21	-130	-308	327

Azioni sulla fondazione (daN*m)		
Momento Ribaltante	Momento Stabilizzante	% Util.
2527	5835	43%

Figure 5: Report of the structural analysis related to a sustain pole.

After this calculation step, ProLED computes mechanical models to evaluate the strength of each sustain, considering the appropriate loading conditions (Figure 5). 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 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.

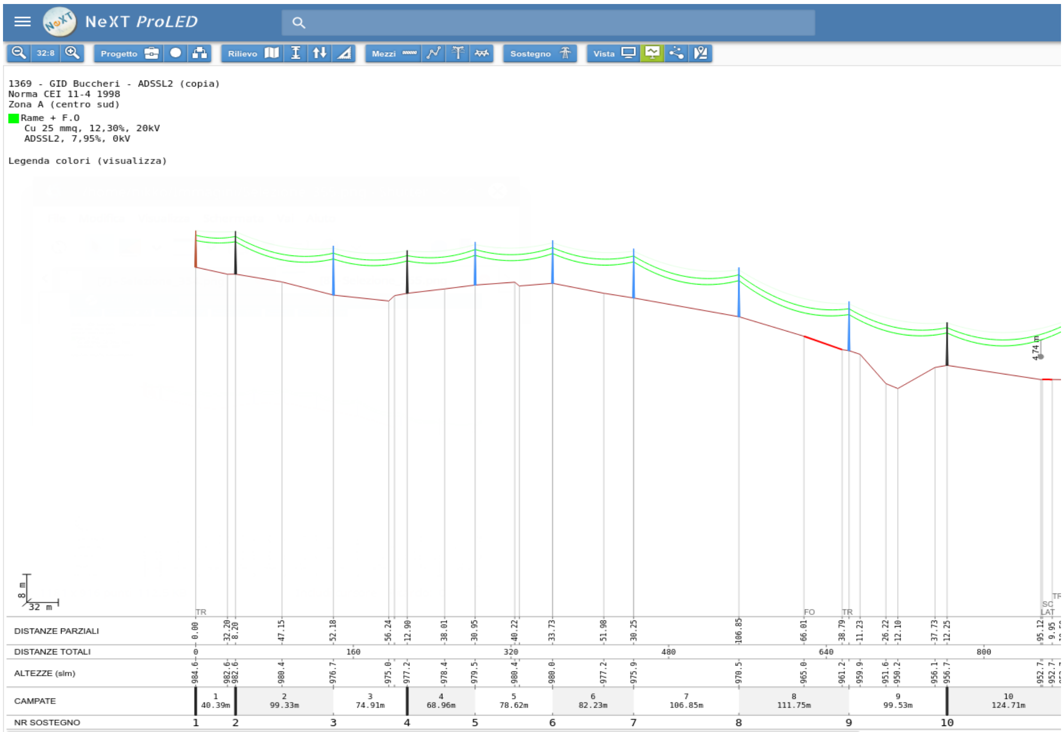


Figure 6: Section view of an example of overhead line (Elevation profile).

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: a sheet with a section view related to the entire overhead line (Figure 6). This view reports each pole. Moreover, it highlights altitude and distance between each sustain;
- Plan view: this is a planimetric view where it's possible to perceive the distribution of sustains into a terrain surface (Figure 7). This view is based on Google Maps view.

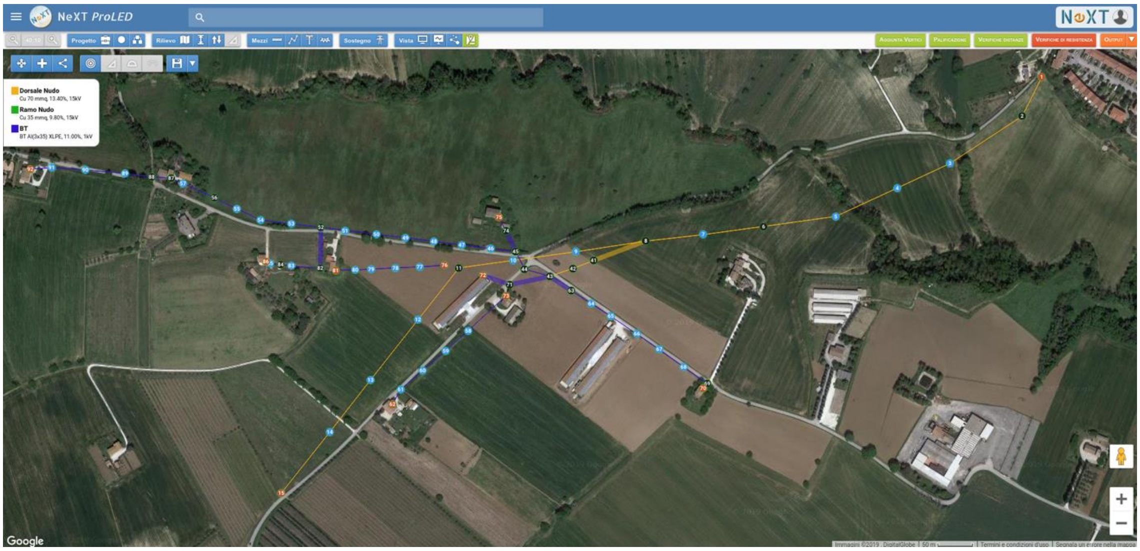


Figure 7: Example of a Plan view based on Google Maps.

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.

3.2 Information Modeling

This subsection deals with the information applied to the 3D CAD model of an overhead powerline. In particular, Figure 8 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 of poles and the loading conditions to be analyzed increase the complexity of such system. Each pole includes a number of isolators and brackets. Moreover, each pole can be different, and the length of each line can be variant form 100-200 m to 2.000 m. While the early pole's geometry is defined using ProLED, the final configuration is taken after the FEM analysis which can confirm or change the early technical configuration of such lines. The proposed information modeling is related to the design automation of the overhead line to be configured. Using a developed tool, a set of data has been applied to the CAD model in order to define a digital mock-up. Figure 8 also describes information data related to each item of the analyzed system such as poles and conductors (cables).

The information concerns: geometry, parameters, loading conditions, payback period, maintenance data, and cost.

The information modelling has been added to the CAD model using a developed plug-in which writes data into the tag-object of each component and shows this data using the annotation label provided by the PMI interface of the CAD system (Production Manufacturing Interface). Figure 9 shows an example of pole with the information added. Even if the system is still a prototype tool, the approach aims at enhancing the information modelling and sharing over a 3D geometrical modelling.

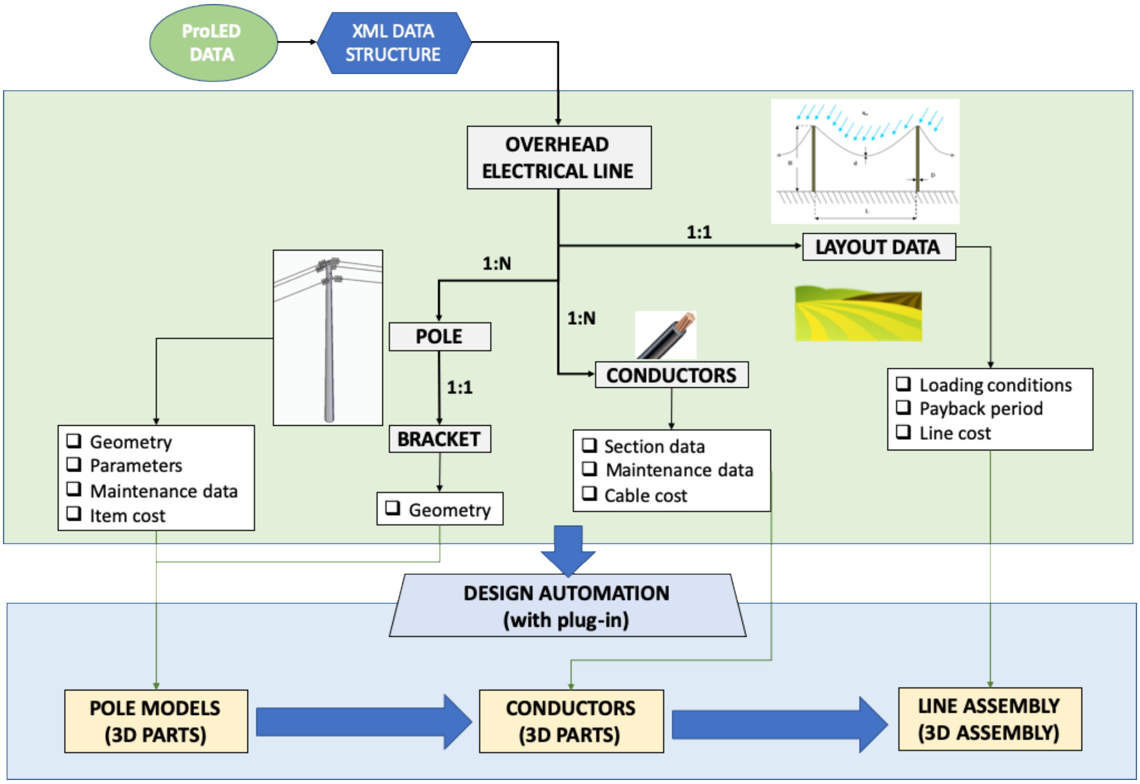


Figure 8: The structure of an overhead power line.

Using the API tools, this additional information has been stored in each tag-object related to the Objected-Oriented structure of the CAD model. However, geometrical parameters are also fixed into the variables table of parts and assemblies.

Figure 8 also describes how information is exported from ProLED to a data structure, represented by an xml file. The developed Plug-in (Figure 2) uses this structured information to build a 3D CAD model by a Design Automation approach. The API libraries of the CAD system have been used to automate the modelling phase. A routine has been implemented to read information related to each item and generate the relative 3D representation. In particular, the process starts with the generation of 3D models for each pole. Parametric templates have been used for a fast reconfiguration and generation of such models. Each template also includes a set of tag-objects which are used as repository of data related to the discussed information modelling. The complete power line is generated into a 3D assembly which uses the information related to the layout data for the parts mating. A second routine reads data from each tag-object and applies labels to the model for describing the additional information data related to maintenance, cost, etc.

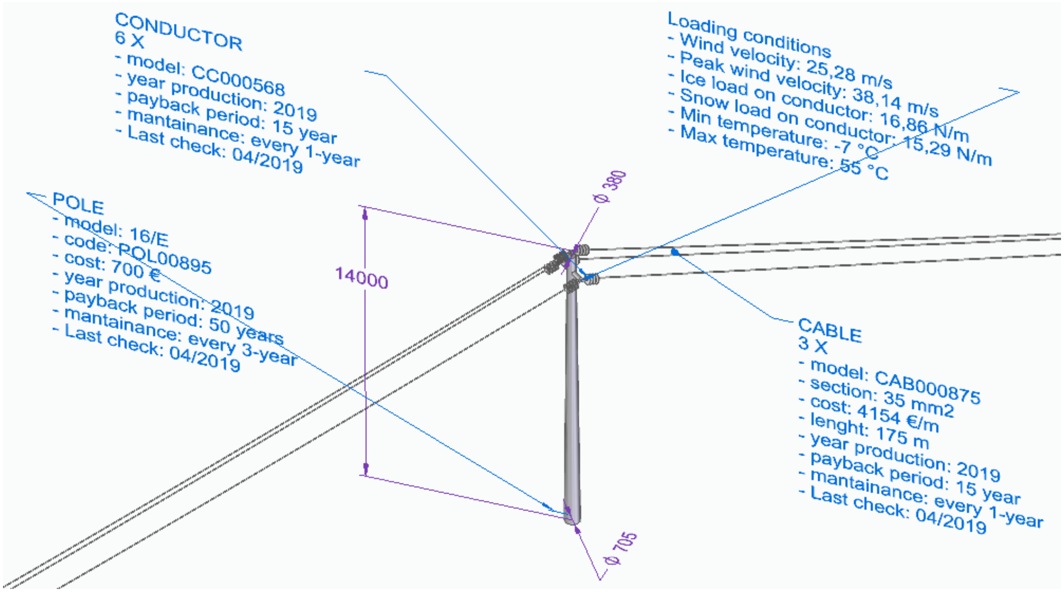


Figure 9: An example of information modelling for an overhead line.

3.3 Costing Tool

The cost for construction and erection of electrical overhead lines depends on several factors. Focusing on overhead powerlines up to 150 kV, the list of each cost item is following reported:

- Cost for the acquisition of ROWs (Right-Of-Way) and land cost;
- Cost of the equipment purchase from manufacturers; this cost item includes poles, cables, insulators, safety equipment, foundations, etc.;
- Cost for material transportation;
- Cost for line erection, which also includes the onsite engineering works and cables arrangement;
- Cost for engineering design and project-management.

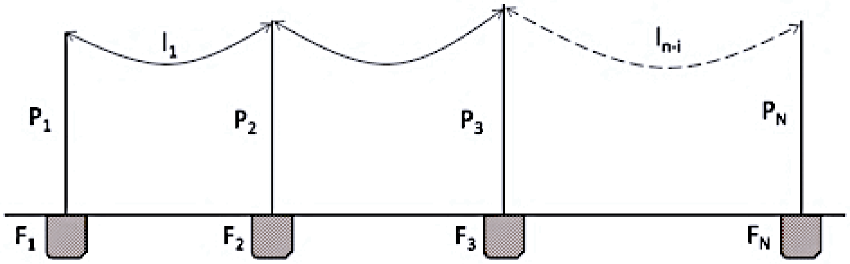


Figure 10: The line components for the cost analysis.

Some these factors, such as the Right of Way, land cost, and material transportation are highly related to the geographic region where the line is erected; therefore, these items are not dependent on the geometrical parametrization of the overhead line. For this reason, a simplified cost model has been implemented in this paper. The model takes into account the cost items related to equipment purchase. Figure 10 describes the main components related to the proposed costing analysis. The analyzed cost for an electrical overhead line is described in (3.1)

$$C_T = \sum_{i=1}^{N}(C_{P_i} + C_{F_i}) + \sum_{i=1}^{N-1}(3 \cdot l_i \cdot C_C) \quad (3.1)$$

where the term C_T represents the total cost of a line, *N* is the number of poles, C_P is the cost of each pole, C_F is the cost of each pole's foundation and installation, *l* is the length of each cable path, and finally C_C is the cost of a single cable. In particular, the term C_P is related to the geometry and class of the pole, which are described by top diameter, bottom diameter, height, and section thickness. On the other hand, the cost of each foundation is related to the specific pole. Every pole has its own foundation. The total cost related to each cable path is multiplied by 3 because this paper analyzed the lines with 3 cables. The installation and erection phases are not considered in this paper because little changes in the geometry of poles, cables, and foundations do not show a great variation in terms of installation and erection cost. While some cost data related to poles is shown in Table 1, an example of conductors list with the unitary cost per km is reported in Table 2.

	16D	*16E*	*16F*	*16G*	*16H*	*16J*
Top diameter [m]	0.41	0.38	0.35	0.33	0.30	0.27
Ground diameter [m]	0.78	0.71	0.63	0.56	0.48	0.41
Height [m]	14.50	14.50	14.50	14.50	14.50	14.50
Total height	16	16	16	16	16	16
Max Pull Force [N] (allowed)	6930	10650	13230	22300	3811	49980
Cost C_P [€]	800	700	600	550	500	450
Cost C_F [€]	450	450	450	400	400	400

Table 1: Design parameters for 16-m steel poles related to six classes: D, E, F, G, H, and J.

Cross Sectional Area [mm²]	*Average Diameter [mm]*	*Breaking Load [kN]*	*Weight [kg/km]*	*Unitary Cost [€/m]*
10	4.1	4.02	90	1206
16	5.1	6.37	143	1916
25	6.3	9.72	218	2921
35	7.5	13.77	310	4154
50	9	19.84	446	5976

Table 2: Datasheet of bare hard drown copper conductors.

4 TEST CASE AND SIMULATION RESULTS

The test case regards the modeling and simulation of a three-poles system installed in Piemonte, in the north-west of Italy. The line is installed in an area with low vegetation such as grass and isolated obstacles (trees, buildings), separated by at least 20 times the heights of the obstacles. The average height of the line from the ground is 10 m. The line is 300 km from the sea at an altitude of 800 m. Poles used in the line are welded sheet metal unified single-pole. In particular, 16G poles are used for the first and third support, and a 16H one is used for the central support. The span between each support is 80 m. The chosen conductor is a hard-drawn copper, with a cross sectional area of 35 mm^2. By inserting this information into ProLED, the software is able to define the loading conditions related to the specific boundary conditions.

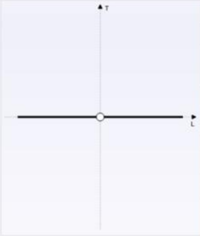
In this test case the current European and Italian standards, such as CEI EN 50341-1 and NNA CEI 11-4, have been considered. In particular, using ProLED, for each configuration the loads related to temperature, wind, and ice/snow are analyzed (Figure 12). Considering the proposed configuration:

- **Temperature**: the analyzed test case is located in Zone B, Italy; this implies lower temperatures respect to the national average values (see Table 1);
- **Wind**: ProLED follows the Italian normative in order to determine both the wind reference velocity (V_b), which represents a statistically average wind velocity for the line location, and the correction factor C_e, which is used to calculate the peak wind velocity from V_b; these parameters are influenced by factors like the distance from the sea, the height of obstacles and trees;
- **Ice/snow**: ProLED follows the European standards in order to determine S_k, which represents the thickness of a cylindrical sleeve generated by ice or snow around the conductors during cold seasons. The sleeve has a double effect on the line, since it causes vertical forces on the conductors, as well as it increases wind lateral forces.

Once the loads have been determined, the approach proposes the analytical calculation of the resultant stress condition of poles and conductors. The parabolic behavior of each conductor has been approximated using a Parabolic Equation and the State Equation [1]. This approximation allows tension and conductor's sag to be estimated for each loading condition.

Figure 11 reports the stress values caused by each conductor on the pole. They refer to the main loading conditions, as provided by European standard. This report concerns the two spans of the proposed three-poles system.

Campata di Sinistra 80.00m					
Cu 35 mmq, Leq. 80.00m					
Stato (zona B)	T.Posa (°C)	Tiri (daN)			
		Derivato	Base	Assiale	Ass.Ammiss.
Massima freccia B	15	149	189		
Massimo parametro B	15	268	189		
G & N costanti tipo 1	15	746	189	751	1119
G & N costanti tipo 2	15	721	189	726	1119
Vento a T minima	15	300	189	300	1119
Azione del vento	15	313	189	314	1119
G & N asimm.fless.⊥ tipo 1	15	590	189	593	1119
G & N asimm.fless.⊥ tipo 2	15	572	189	575	1119
G & N asimm.fless.|| tipo 1	15	550	189	552	1119
G & N asimm.fless.|| tipo 2	15	533	189	536	1119
G & N asimm.fless.tors. tipo 1	15	550	189	552	1119
G & N asimm.fless.tors. tipo 2	15	533	189	536	1119
Carichi sismici -20°C	15	268	189	268	1119
Carichi sismici G&N tipo 1	15	351	189	352	1119
Carichi sismici G&N tipo 2	15	333	189	334	1119



Campata di Destra 80.00m					
Cu 35 mmq, Leq. 80.00m					
Stato (zona B)	T.Posa (°C)	Tiri (daN)			
		Derivato	Base	Assiale	Ass.Ammiss.
Massima freccia B	15	149	189		
Massimo parametro B	15	268	189		
G & N costanti tipo 1	15	746	189	751	1119
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G & N asimm.fless.⊥ tipo 2	15	572	189	575	1119
G & N asimm.fless.|| tipo 1	15	334	189	335	1119
G & N asimm.fless.|| tipo 2	15	328	189	328	1119
G & N asimm.fless.tors. tipo 1	15	442	189	443	1119
G & N asimm.fless.tors. tipo 2	15	431	189	432	1119
Carichi sismici -20°C	15	268	189	268	1119
Carichi sismici G&N tipo 1	15	351	189	352	1119
Carichi sismici G&N tipo 2	15	333	189	334	1119

Figure 11: Report of the calculated conductor's stress for each line span under different loading conditions.

Using the proposed Plug-in (VB script), the geometrical information of the line (which is exported by ProLED tool) is imported in Solid Edge for the parametrical design automation of the relative overhead line. Figure 12 shows a parametric 3D model generated. The relative geometry has been simplified in order to improve the simulation performance in terms of time computing.

Finally, the CAD model has been imported in Autodesk Robot in order to perform the FEM Analysis. This has been done by exporting the Solid Edge parametric model into a sharing file format. As a future development, this phase should be automated.

Figure 13 and Figure 14 shows some report of the FEM analysis for different loading conditions. These reports refer to the FEM simulation of the CAD model. In particular, Figure 13 regards the loading condition of Maximum Wind. Figure 14 reports a combination of Wind and Ice/Snow loads. In fact, 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.

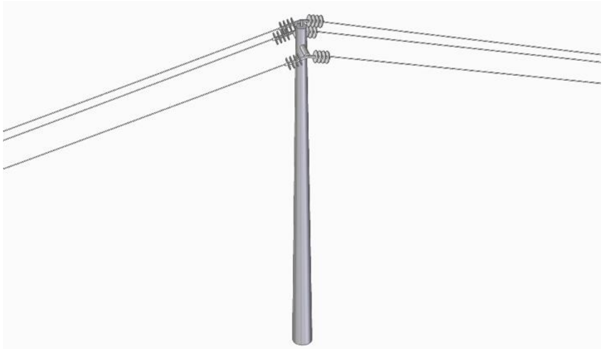

Figure 12: The simplified representation of a 16/E pole.

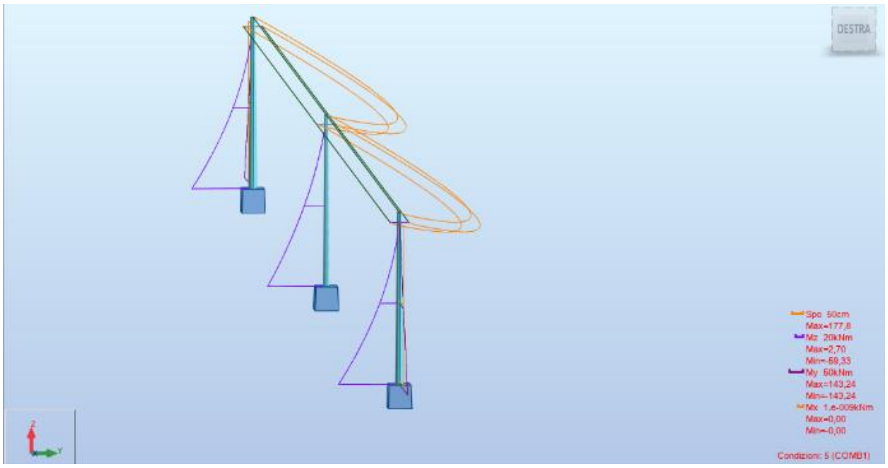

Figure 13: Simulation report related to Max Wind Loading.

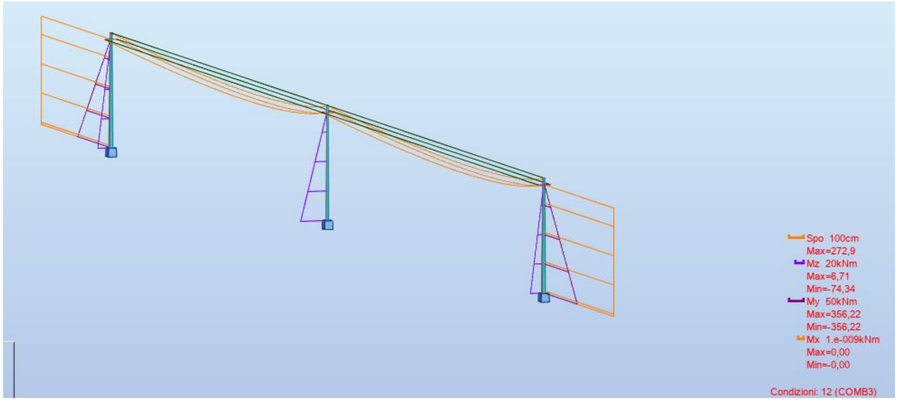

Figure 14: Simulation result related to a combination of Wind and Ice/Snow Condition.

Once the FEM simulation has been completed, it is possible to apply a double calculation check of the analyzed overhead line. Considering the compliance to the already mentioned standards (which limit maximum sags, structural strength of both poles and conductors), is it possible to compare the results from FEM simulations and analytical analysis. Table 3 deals with this comparison in terms of resultant stress on each conductor line. As reported, the percentage difference between FEM and analytical analysis is below 5%. Even if the Catenary Equation, which reproduce the behavior of cables and conductors, has been approximated by a Parabolic Equation, the results show a close difference with FEM simulations. Finally, the cost of the proposed overhead line system is about € 4800. This value has been automatically calculated using the approach described in Section 3.

Loading conditions	*Ultimate strength [kN]*	*Analytical - stress [kN]*	*FEM – stress [kN]*	*Difference [%]*
a) Minimum temperature	13.99	3	3.08	2.6
b) Maximum wind	13.99	3.13	3.26	4.0
c) Combined wind-ice/snow	13.99	5.50	5.71	3.7
d) Maximum Temperature	13.99	1.49	1.52	2.0

Table 3: Comparison between FEM and analytical results in terms of conductor's stress.

5 CONCLUSIONS

This paper proposes an approach based on computer-aided design for modeling overhead lines. The information modeling has been included into the CAD model. A tool has been implemented to perform the connection between ProLED, used for the configurations of overhead lines, and a CAD tool. The approach also introduces the use of a FEM software to complete the design check and validate the final configuration.

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. A cost method has been proposed to perform the rapid evaluation of an overhead line.

As test case, a three-pole line has been described. The comparison between analytical and FEM analysis has been reported. A gap of less than 5% has been analyzed. The proposed double checks confirm the configuration of the overhead line. Moreover, different simulations can be performed for more detailed analysis in the context of the FEM solver. Generally, normative loads are based on statistical and probabilistic data. Therefore, a more detailed analysis can consider different loading scenarios. While traditional commercial software for the configuration of overhead lines includes the loading set provided by normative, the introduction of CAD and FEM tools gives greater degrees of freedom to consider a detailed analysis in the design project. The interoperability between configurations, CAD and FEM tools can support the designer to develop the engineering detailed phase. A 3D simulation can include external details which can improve the estimation of the real loading conditions.

As a future development, an optimization algorithm can be included in the design workflow in order to reduce cost related to installation and materials.

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