Arial power line 3D cadaster

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Key words: Cadaster, 3D Geotechnologies, 3D Power Lines.

SUMMARY

Maps and plans (2D) are still the main resource to represent and consequently manage a city, a state and a complete country in Latin America. However, new trends in design and construction, together with accelerated geotechnical advances are changing the paradigms of the public policy. Currently, technology allows to manage complex objects in space (3D), changing the way that the territory, the property rights and their restrictions are described. Infrastructure and transport networks move through space in different ways, some are invisible by nature, such as cell phone microwaves, and others are invisible because they are underground, such as tunnels and pipes. Other networks are visible because they are built on the surface, such as roads and electrical service cables. The spatial relationships between networks and public and private properties, informal occupations, environmental reserves, mineral deposits and bodies of water have not been dealt with efficiently through 2D representations, so they require strategies to move to the 3D world. Structuring territorial cadastres and service networks in 3D is taking time along the region. It is in this context that the present work describes the processes used in Mexico to survey and represent everything related to power lines and proposes a gradual construction strategy for a cadastre 3D.

RESUMEN

Los planos y mapas (2D) aún constituyen el principal recurso para representar y consecuentemente administrar una ciudad, un estado y un país completo, no obstante, las nuevas tendencias de diseño y construcción, sumadas a los acelerados avances geotecnológicos están cambiando los paradigmas de la política de públicas. La tecnología ya permite gestionar objetos complejos en el espacio (3D), lo cual impacta no sólo la forma en que se ve el territorio sino la manera en que se describen los derechos de propiedad y sus restricciones. Las redes de infraestructura y transporte se mueven a lo largo espacio de diferentes maneras, algunas son invisibles por naturaleza, tales como las microondas de teléfonos celulares, y otras son invisibles porque son subterráneas, tales como los túneles y cañerías. Otras redes son visibles dado que están construidas sobre la superficie, tales como los caminos y los cables de servicios eléctricos. Las relaciones espaciales entre redes y propiedades públicas y privadas, ocupaciones informales, reservas ambientales, depósitos minerales y los cuerpos de agua no se han tratado eficientemente a través de las representaciones en 2D, por lo que requieren estrategias que les permitan pasar al mundo 3D. La estructuración de catastros territoriales y de redes de servicios en 3D está tomando tiempo. Falta asimilar conceptos, conocer más de aplicativos, cambiar normativa. Es en este contexto que el presente trabajo describe los modernos procesos usados en México para relevar y representar todo lo relativo a redes eléctricas y propone una estrategia de construcción paulatina de catastro 3D

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1. INTRODUCTION

A 3D cadastre must register land objects accurately in space and time, identifying and placing them geometrically as volumes at a given moment. A 3D cadastre allows you to relate land objects, or parts of them, reposition them retrospectively, project modifications and analyze the influence of new objects even before they exist, through the construction of prospective scenarios.
In the 3D cadastre, every land object must be recorded under the three coordinates of a sufficient number of points that allow it to be spatially located as a block in the reference frame and at the measurement date. The number of georeferencing points will depend on the case and will be defined by the surveyor according to the experience, to guarantee the precision parameters established by the cadastral standards.
The planimetric positioning of the land objects does not present major difficulty once the geodetic reference system is established, however, the definition of the most suitable surface reference to determine the heights, is still under discussion, particularly for the power lines.
The supply of electrical energy is important and necessary for development as well as for daily life. Electricity is an indispensable component of human activities since people are immersed in the use of electrical devices at work and at home. Electricity is as basic as proper nutrition, health, decent housing and education.
In this context of high demand, the Federal Electricity Commission - CFE together with the Single Union of Electricity Workers of the Mexican Republic, permanently take care the electrical system, which is in optimal conditions, carrying out preventive activities and constant maintenance. These processes are highly challenging in a country where the damage in the transmission and/or distribution of electrical energy can be generated by several factors such as weather events (hurricanes, tornadoes, frost, strong winds and torrential rains), sabotage actions, corrosion and/or earthquakes.
The possible reconstruction of power line transmission and/or distribution requires having the description of the relief along the lines and the complete registry of the network, counting on the precise location of each of the elements, as well as its detailed description.
Surveying, systematizing and representing all the elements of a power line is the first step to build a cadastre in which the Electric Substations and the Electric Power Transmission Lines are positioned in the space through a correct georeferencing. In this sense, the integration of geotechnologies plays a leading role, determine the most appropriate methods and systematize this knowledge in operation manuals, becoming a challenge.
This article describes the methods of surveying and recording the elements of a physical electrical systems managed by the CFE of Mexico (Figure 1), from the sources of electric power generation (wind, photovoltaic, geothermal, thermoelectric, etc.), through the transmission lines composed of support structures (towers and poles), cables, transformers, even distribution lines for end users.

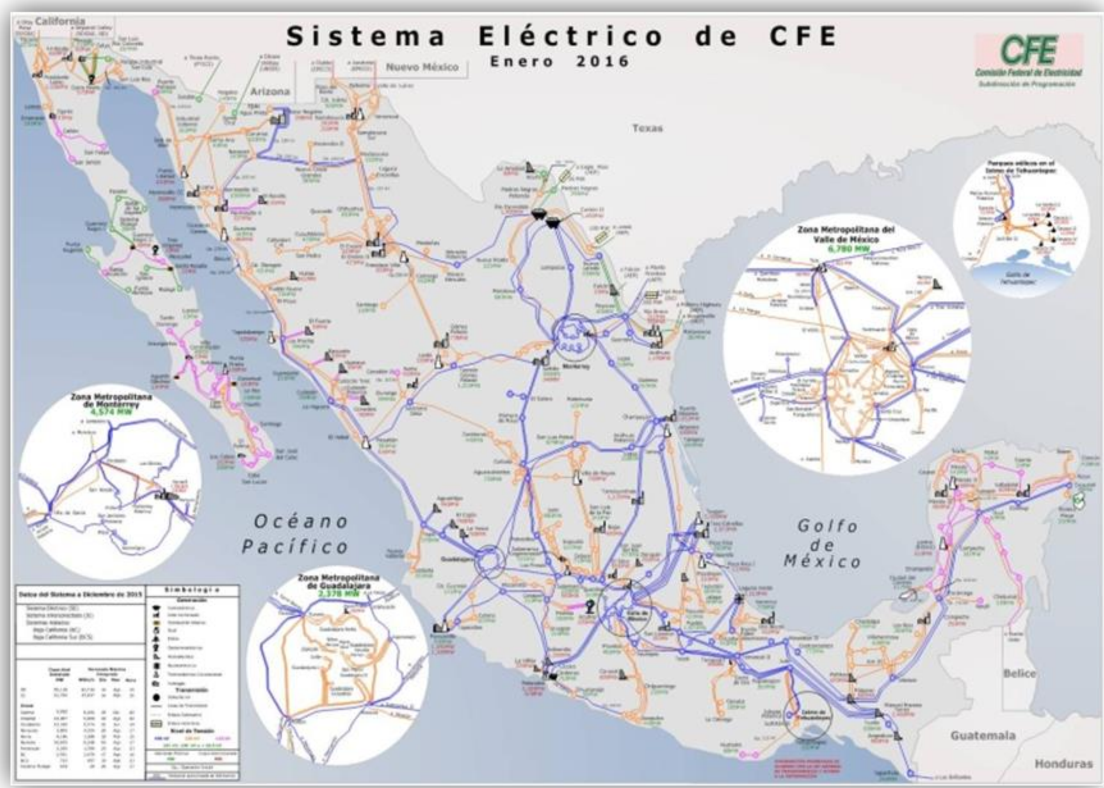

Figure 1. National Electric System of Mexico. Source: CFE

Most of the surveys of the network elements are developed using total stations and GPS / GNSS receivers of 2 bands linked to the National Active Geodetic Network - RGNA that is part of the Geocentric Reference System for the Americas - SIRGAS. Small-format aerial photographs obtained with drones, satellite images, terrestrial laser scans and airborne LiDAR (Light Detection and Ranging) systems are also used. LiDAR technology is also used for eventual invasion analysis, line recalibration and repositioning of structures.

2. STRUCTURE OF AN ELECTRICAL NETWORK

An electrical network can be defined as a set of electrical appliances and buildings necessary to generate, transform and distribute electrical energy, making the link between two or more circuits.

The generation of electricity is carried out in the power stations from fossil fuels, such as coal, gas, biomass; or from renewable energy sources such as wind, solar, nuclear, hydraulic, tidal, geothermal, among others.

The transmission of energy, which can be produced at long distances, starts at the power stations and reaches the substations in which the transformation is carried out, so that it can reach the different users at the required service voltage.

The most important concepts related to the transmission and transformation electrical installations are those related to the power stations and the transmission Lines (Figure 2).

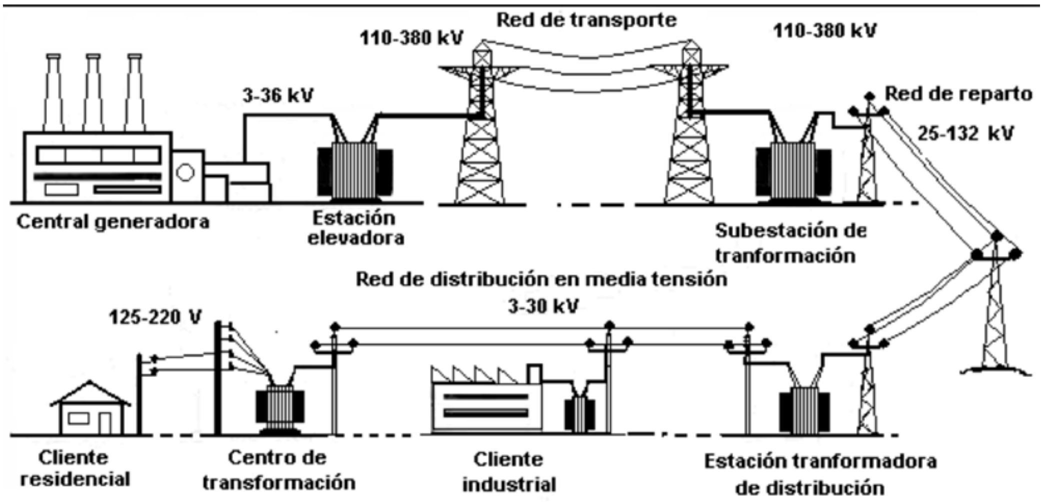

Figure 2. Power substations and Transmission Lines

2.1 Power substations

A power substations is a facility dependent on another principal one. It is intended to serve a specific area, it is composed of a set of electrical appliances located in a building structure, elements that are necessary for the conversion or transformation of electrical energy and for the connection between two or more circuits. There are several types of substations:

- Elevation substations (elevators). Associated with the power substations, it direct the power flow directly to the electrical system, raising the generation voltages (13.2 to 24kV) to transmission voltages (115 to 800kV).
- Substations of transformation (reducing). It reduces the transmission voltages to sub transmission or distribution voltages.
- Switching substations (switching). It only performs connection and disconnection operations (maneuvers), it does not have power transformers since it is required to modify the voltage level of the power supplies.
- Radial substations. It only has one power point and do not interconnect with others.

Substations can be classified according to different characteristics, Table 1 represents the classification related to the of it exposure/armor.

Table 1. Electrical Substations

Conventional Substations. There are also known as "isolated in air", since the energized parts and their equipment are exposed to weather conditions.	
Isolated in gas (exterior or interior). They are known as "gas insulated or armored", since their conductive parts and equipment are contained in a surrounding metal enclosure of the main equipment that allows to maintain the specified isolation levels safely.	
Hybrid substations. This type of substations combines elements of conventional substations and gas-insulated substations.	

2.2 Transmission Lines

An aerial transmission line is essentially a group of conductors arranged in parallel, mounted on supports that provide the required insulation between them and between ground conductors (Enríquez Harper, 2014). These lines are in the space and their location must be identified through coordinates. Its locations can be recorded through two-dimensional representation; however, it should be through three-dimensional drawings related to its physical characteristics.

In a transmission line the conductors that compose it are naked and form circuits that are isolated in air by means of glass, porcelain and synthetic accessories, suspended and/or finished in support structures, located along a trajectory. The purpose of the lines is to transport the electrical energy from the generation points to the transformation points and finally to the consumption centers. Due to their location in the space they can be:

- Arial, these are the most common due to the benefits it offers such as: lower cost, easy operation, rapid detection of faults, ease of maintenance, among others.
- Subterranean, there are used mainly in urban areas to avoid visual impact.
- Submarines, there are constructed in this way in cases of extreme need, being designed to withstand pressures under water.

The most common line support structures are represented in Figure 3.

The level of complexity of each structure can vary considerably as shown by the Figure 4. Knowing each detail of the tower or the pole is essential, particularly when the 3D system of the electrical system is being formed. Based on this knowledge the representation method: vector, voxels (volumetric pixels), point cloud, among others, is defined.

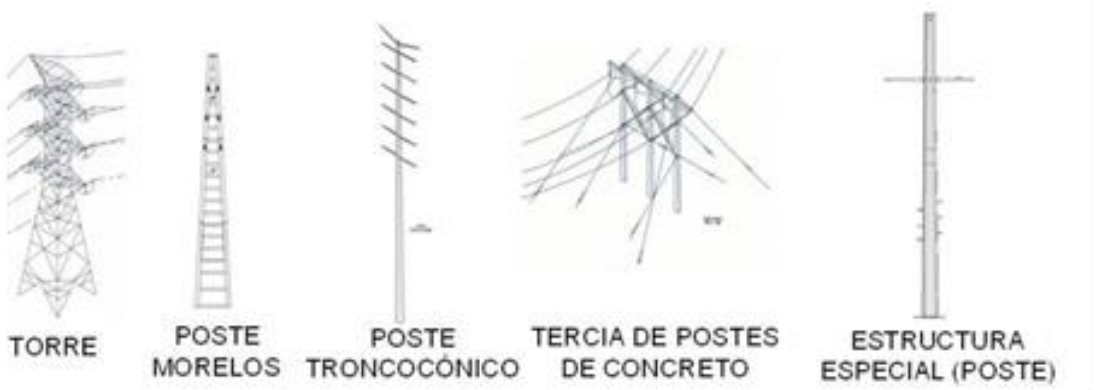

Figure 3. Typical support structures for transmission lines in Mexico
Source: "Electromechanical Design Manual of overhead power transmission lines, Federal Electricity Commission, Mexico."

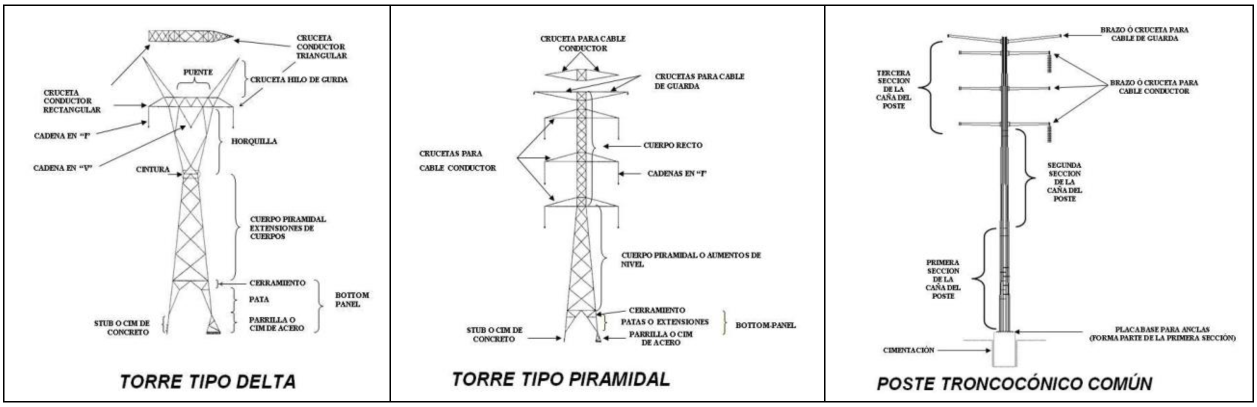

Figure 4. Different types of Towers and Poles

3. SURVEYING AND LOCATING POWER LINES

New electromechanical projects or of existing power lines have to have the georeferenced location of the power substations and the electric power transmission lines elements.

3.1 Substations surveying

Feasibility studies on the location and construction of a power substations include the development of environmental, social and legal analyses, as well as the compilation of data or the execution of geophysical, geotechnical, hydrographic, and hydrological surveys. The spatial reference of all these data is constructed from surveys and representations that must follow the rules and regulations in force.

The planimetric survey in the field identifies the boundaries and vertices that will make up the polygonal of the parcel, natural runoffs and storm drains inside and outside the premises destined to the substation, as well as the points of departure and arrival of transmission lines

(Figure 5). In addition, the use of land, crops, vegetation and the trajectory of the access roads to the property are surveyed. It is a multi-thematic survey that allows the creation of a multi-purpose cadastre.

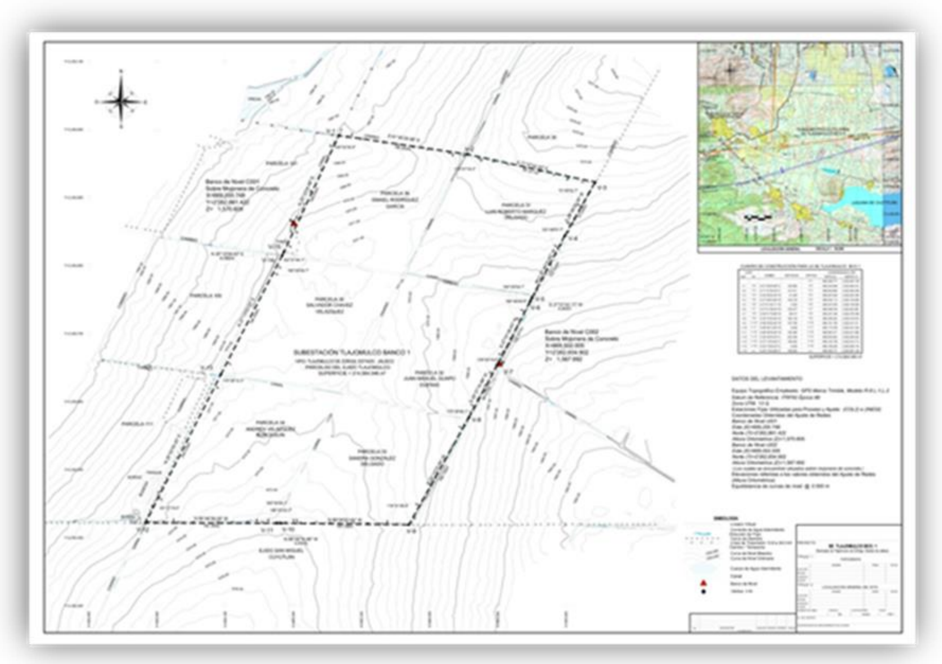

Figure 5. General location map of the site for a new substation

Once the previous studies have been completed, the project begins and is developed jointly by the teams of civil engineers, surveyors, mechanics and electricians. The professionals use different specialized software and obtain the graphic result of the project to be built which is used for the execution of the work. The detail map of new substations is essential (Figure 6).

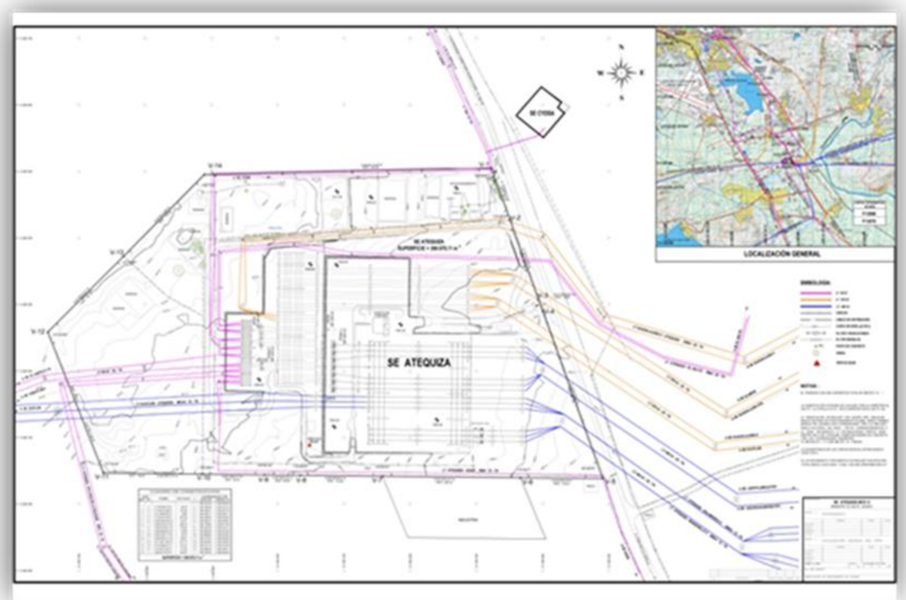

Figure 6. Detail plan of location of an existing substation

Existing stations are surveyed in different ways, through Total Station and terrestrial scanner (Figure 7), or by LiDAR (Figure 8).

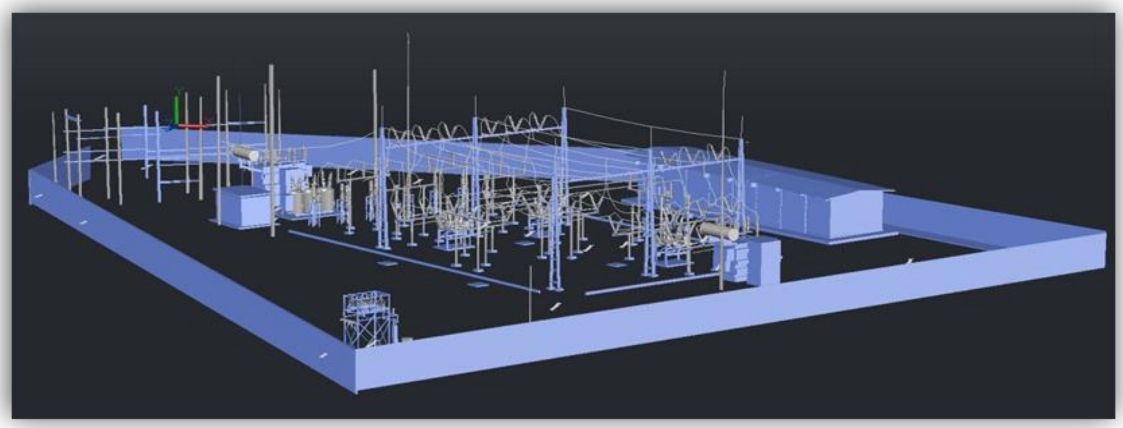

Figure 7. Representation of the site of a substation surveyed with Total Station and terrestrial scanner

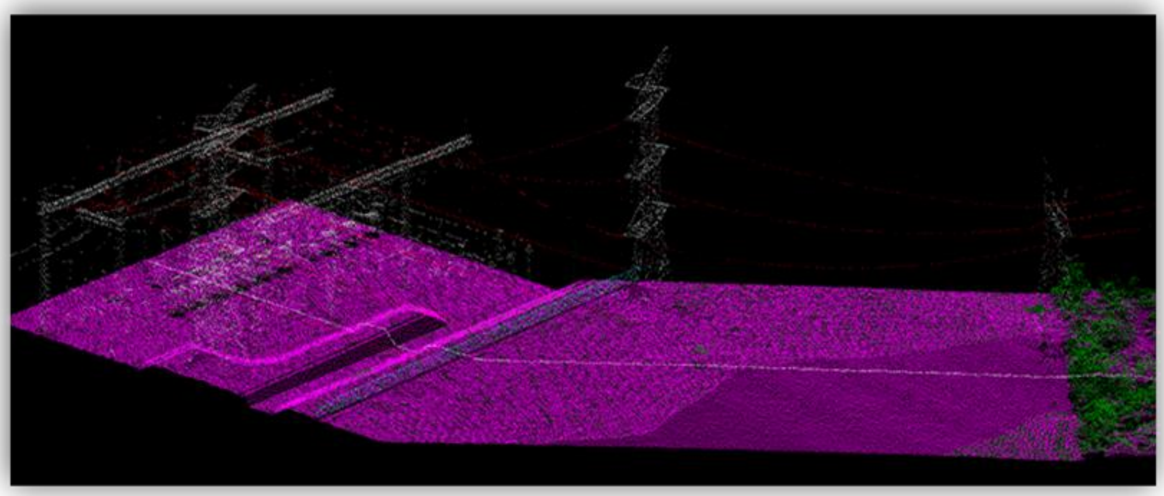

Figure 8. Representation of the site of an existing substation, surveyed with LiDAR

3.2 Surveying Transmission Lines

Once the topographic survey of the site and/or the substations is complete and the station location projected is defined, the trajectory of the lines is studied, analyzed and defined as a geometric axis through the exit points, of intermediate and arrival inflection.

During the development of the project, and in order to select the most viable trajectory, analyzes must be carried out to evaluate all the elements and segments involved, similar to how it is executed in the location of sites for the substations.

Thus, terrestrial surveys must be carried out, crosses with communication routes or liaison infrastructure, the different types of vegetation and sources of contamination should also be identified. All the elements of the area where the project has been considered and prospect for growth should be considered. All this information must be projected in the General Trajectory Location Maps.

The axis of the trajectory must be located, traced, georeferenced and marked in the field according to what is indicated for vector data standards. Inflexion points should be located in places sensibly flat or reasonably high, never in low areas or tops of hills, or very steep slopes, subject to the project's request. In addition, when there is parallelism between axes of transmission lines, the separation distances between them must be analyzed by the electromechanical specialists, so as not to expose the network to future problems or risks.

Once the definitive trajectory is known, it must be represented on a plane of general trajectory location, represented under the most convenient cartographic base for the project, such as topographic maps (Figure 9), aerial photographs, orthophotos, satellite images, urban plans, etc.

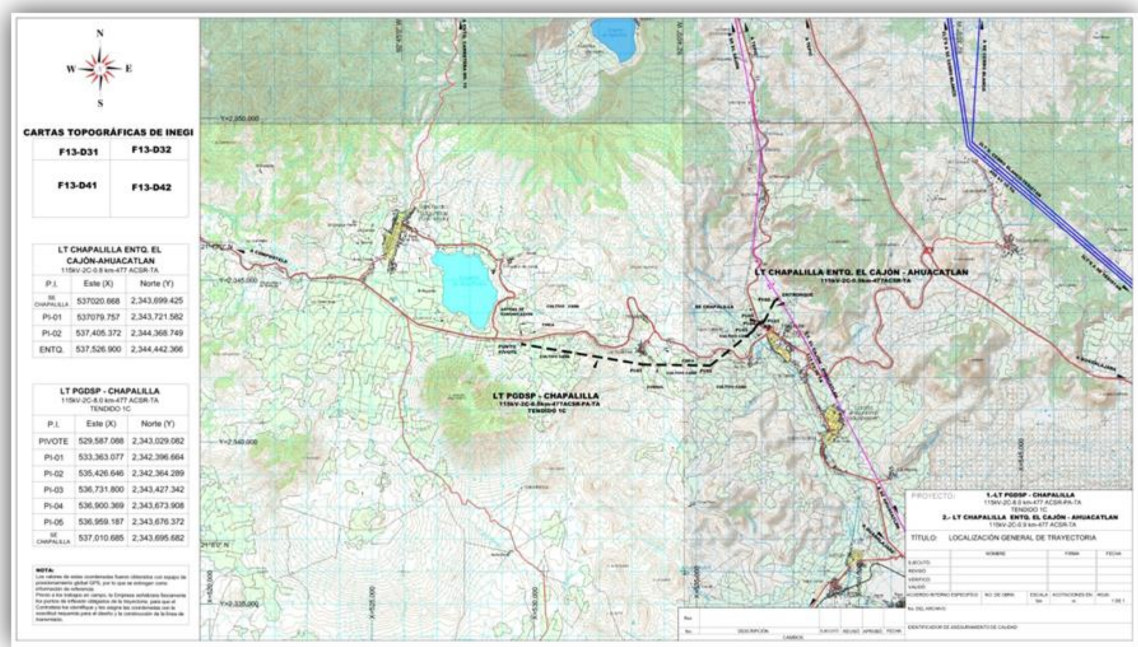

Figure 9. Map of general location of trajectory

The path defined by the electromechanical project must be materialized on the ground, so, a detailed topographic survey must be developed within a strip of at least 50m on each side of the line axis, using any of the different techniques and equipment already mentioned.

The data collected in the field should allow to identify the properties intersected by the transmission line passage in order to carry out the legal procedures before to start the construction and operation.

Since the survey is planimetric and altimetric, the maps and the profiles of the axis of the line must be drawn up. Once the surveys and representations have been completed, a map and project profile is generated using specialized computer applications to represent all the elements of the power line (Figure 10).

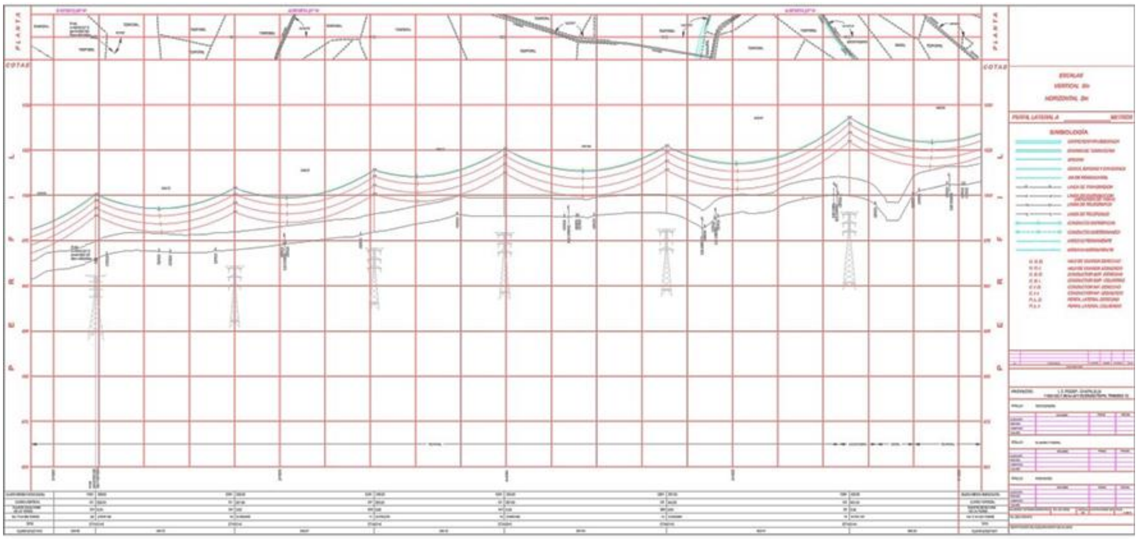

Figure 10. Integration of the relief with the electric grid project

The data must be systematized according to the current specifications. The results of the geodetic positioning are registered in the so-called "Geodetic File", which integrates all the fundamental data of the geo-positioning and control points. Since in Mexico there is a great tectonic activity, this document is crucial because allows to control the displacements and make network adjustments. All the elements are referenced to the DATUM ITRF 2008 Time 2010.0 referred to Geoide GRS80.

In addition, the so-called Register of Survey Points is generated (Table 2). This important document shows all the points obtained during a survey as a numerical result of the conjunction of vectors X, Y, Z.

Table 2. Register of Survey Points

No.	East (X)	North (Y)	Orthometric Height (Z)	Code	Description
Point number	Value of the X coordinate referred to the ITRF 08 season 2010.0	Value of the Y coordinate referred to the ITRF 08 season 2010.0	Value of the height referred to the GGM10	Code according to the catalog of topographic points	Description according to the catalog of topographic points

LiDAR technology is also used by electric power companies for topographic surveys. The results, in addition to being precise, are more abundant and are obtained in shorter times than in traditional topographic surveys, providing greater quantity and safety. The point cloud obtained through LiDAR allows generating the terrain profiles and integrating them to the elements of the power line (Figure 11).

Figure 11. Profile of the terrain generated from LiDAR data integrated with the electrical project

LiDAR technology has other applications. In cases where overhead electrical networks are already operating and their elements located on the surface, the clear visibility of the cables leads also to repower and recalibrate the lines, analyze invasions, position structures in their projected location, among other actions (Figure 12).

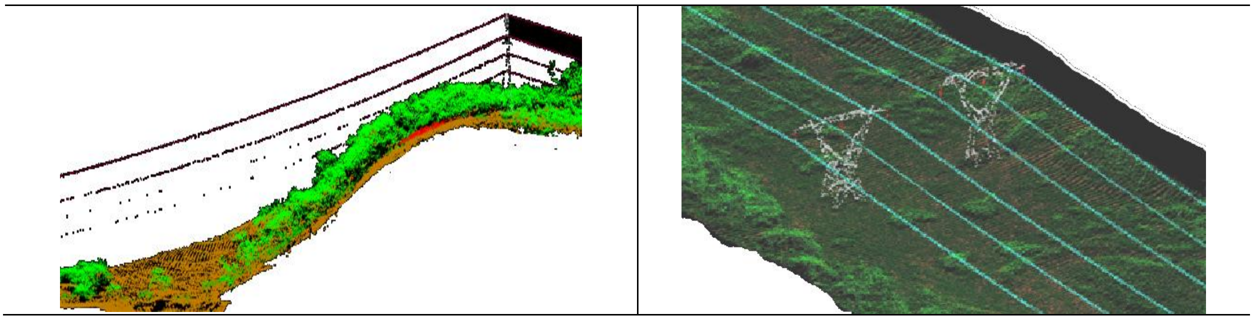

Figure 12. Representation of the transmission lines from LiDAR data

Drones are also used for surveys of potential sites for substations, belts under transmission lines and power lines already installed. This technology reduces execution times and costs. The sequence of operations is similar to that followed by traditional photogrammetry: verification of the guidelines of specific current legislation, design of the flight plan, placement of ground control points with GPS/GNSS, execution of the flight, processing of the obtained images and generation of the cartographic products like:

- Orthophotos or Ortomosaics, thematic and precision,
- Digital Elevation Models,
- Digital Terrain Model,
- Digital Surface Model,
- Vegetation Models,
- Contour and Profiles.
- Inputs for BIM formats

Geospatial analysis are carried out on this material, it makes possible the decision making process related to projects definition and monitoring of existing project through the following actions:

- Real-time video inspection,
- Printing of 3D models,
- Virtual Tours along the lines,
- Volumetric calculations.

The integration in GIS environment of all the data obtained through the different techniques presented up to this point, allows to generate spatial representations and reality simulation models in a prospective game about the final structure of the project (Figure 13).

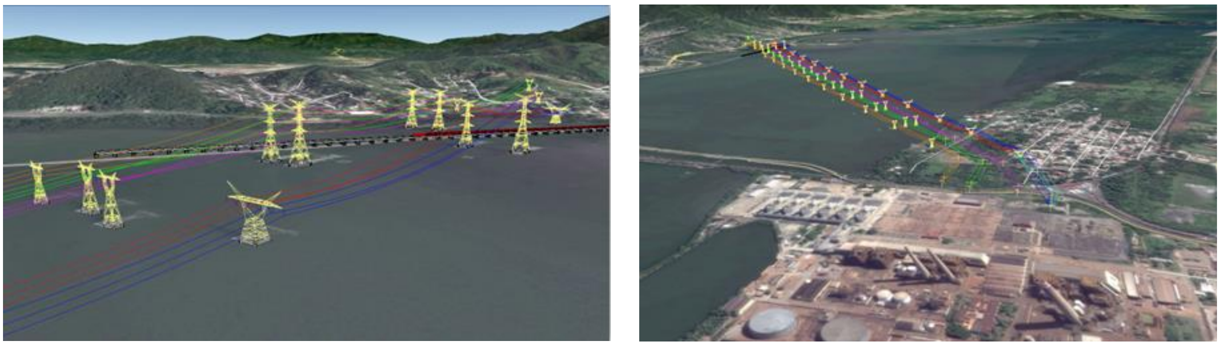

Figure 13. Preliminary electrical network with all the structuring elements

In the case of underground transmission lines, the survey is also carried out through topographic techniques. The specifications are similar to those corresponding to the aerial popwer lines. The survey allows to identify if the underground projected trajectory will not be hindered by some pipeline, electrical or communication power cables, tree roots, stratigraphic discontinuities, fractures, caverns or fillings.
Regardless of the type of line, aerial or underground, the surveys must contemplate several important details destined to structure databases and elaborate multi-thematic maps among which stand out:

- Land boundaries and land use (agricultural, forestry, urban, industrial, tourism, etc.)
- Rivers, streams, runoff, channels, drains.
- Lagoons, estuaries, dams, flood zones, swamps.
- Roads, roads, gaps, bridges, railways, pipelines, power lines, telephones, telegraphs.
- Type and height of buildings.
- Types of vegetation, crops, orchards, groves and their heights at the time and maximum growth.

Once the electrical project is completed, the topography intervenes in the location of structures where high voltage cables will be suspended and profiles obtained to determine the levels of each of the structures to be installed according to the project. Once all the information is available, construction begins, period during which the surveyor engineer responsible for the work makes the corresponding lines to the foundations, verifies the verticality and assembly of the structures, supervises the installation of insulators, check the tension of the conductor cables and terminate the work.

4. POWER LINE CADASTRE

The network cadastre is one of the essential thematic cadastres of the multipurpose model. The sites where the substations and the interference strips are located under the transmission lines not only have physical / geometric connotations of dimension and location, but also legal ones. The implementation of a power line implies possible expropriations, interference by easements in the airspace, on the surface and below it. It is a complexity of RRR that generates a complexity of geometries, bodies intersecting and touching in the space that can only be surveyed and represented under modern 3D technologies.

Each one of those spaces, in addition, must be correctly valued since each m^3 (no longer m^2) is part of the increasingly complex real estate market.
Most elements of the power line are still in a CAD environment. The Civil3D application is used to interpret the point clouds obtained with LiDAR while orthophoto processing is done mainly with Arcgis. This application is also used to manage the database of elements of the power line: electrical substations, elevation substations, switching substations and electric transmission line which, and although it is done in 2D, creates a fertile environment to structure a 3D cadastre in a 3D SIG environment.
The system that manages the database is called GESEN - Georeferencing of the National Electric System developed under the commercial platform Arcgis de Esri. It contains the Transmission Lines and the Electrical Substations totally georeferenced and allows to update and consult the information permanently.
The relational geodatabase is made up of numerous data tables for each element of the network. Figures 14 and Figure 15 show a couple of examples.

CAMPO	DESCRIPCIÓN	TIPO Y ANCHO
ORIGEN	Nombre de la SE de origen.	Texto (100)
DESTINO	Nombre de la SE de destino.	Texto (100)
NOMENCLA	Nomenclatura asignada por el Centro Nacional de Control de Energía.	Texto (5)
TENSION	Tensión diseñada en kV.	Texto (4)
LONG_KM	Longitud en km.	Doble
CALIBRE	Calibre del conductor.	Texto (15)
TIPOCON	Tipo de conductor.	Texto (15)
ZUTM	Zona UTM donde se asienta el proyecto.	Texto (2)
RESIDENCIA	Residencia responsable de la zona del proyecto.	Texto (2)
OBSERV	Cualquier observación si existe.	Texto (255)

Figure 14. Table of Underground Circuits of the GESEN Geodatabase

The GESEN cartographic database consists of four layers:

- Towers
- Transmission lines
- Circuits
- Electrical Substations.

The representations are in 2D, each element of the network has a specific symbol.

TORRES		
CAMPO	DESCRIPCIÓN	TIPO Y ANCHO
CIRC 1	Nombre del circuito en orden de mayor relevancia y voltaje.	Texto (100)
CIRC 2	Nombre del circuito 2 siguiente en orden de mayor relevancia y voltaje.	Texto (100)
CIRC 3	Nombre del circuito 3 siguiente en orden de mayor relevancia y voltaje.	Texto (100)
CIRC 4	Nombre del circuito 4 siguiente en orden de mayor relevancia y voltaje.	Texto (100)
CIRC 5	Nombre del circuito 5 siguiente en orden de mayor relevancia y voltaje.	Texto (100)
CIRC 6	Nombre del circuito 6 siguiente en orden de mayor relevancia y voltaje.	Texto (100)
NOMCLA1	Nomenclatura del circuito 1 asignada por el CENACE.	Texto (5)
NOMCLA 2	Nomenclatura del circuito 2 asignada por el CENACE.	Texto (5)
NOMCLA 3	Nomenclatura del circuito 3 asignada por el CENACE.	Texto (5)
NOMCLA 4	Nomenclatura del circuito 4 asignada por el CENACE.	Texto (5)
NOMCLA 5	Nomenclatura del circuito 5 asignada por el CENACE.	Texto (5)
NOMCLA 6	Nomenclatura del circuito 6 asignada por el CENACE.	Texto (5)
NEST1	No. de la estructura según CIRC1.	Texto (20)
NEST2	No. de la estructura según CIRC2.	Texto (20)
NEST3	No. de la estructura según CIRC3.	Texto (20)
NEST4	No. de la estructura según CIRC4.	Texto (20)
NEST5	No. de la estructura según CIRC5.	Texto (20)
NEST6	No. de la estructura según CIRC6.	Texto (20)
CODIGO	Código de la estructura según catálogo del Departamento de Diseño de Líneas.	Texto (14)
1 TIPO	Tipo de estructura.	Texto (4)
NCIRC	No. de circuitos de diseño de la estructura.	Entero corto
TENSION	Tensión de diseño de la estructura en kV.	Texto (4)
2 USO	Uso de la estructura.	Texto (14)
3 CIMENTA	Tipo de cimentación.	Texto (15)
PI	Punto de inflexión.	Texto (12)
X	Coordenada de Longitud de la Zona UTM que corresponda.	Doble
Y	Coordenada de Latitud de la Zona UTM que corresponda.	Doble
Z	Elevación sobre el nivel medio del mar.	Doble
RESIDENCIA	Residencia responsable de la zona del proyecto.	Texto (2)
OBSERV	Cualquier observación si hay.	Texto (255)

Figure 15. Table of Towers of the GESEN Geodatabase

5. PERSPECTIVE OF A 3D CADASTRO OF THE ELECTRICAL NETWORKS

The users of the power lines cadaster are currently dealing with 2D systems. Figure 14 is certainly the most representative of the spatial connotation of a power line, showing its 3D elements, positioned on the relief in 3D. It shows the concrete possibility to build a 3D cadastre with a spatial database representing all its elements in space and time for CFE.

Consolidating the use of a 3D cadastre of power lines also implies incorporating the most modern visualization techniques that allow to enhance and transparency the bodies represented in 3D, make generalizations in 3D, annotate in 3D, publish 3D data on the web, enhance the use of augmented reality, immersive virtual environments and interaction techniques and time. Having a 3D cadastre brings even more opportunities for clear visualization of modeled reality by facilitating the understanding of different spatial relationships such as 3D overlays, contact of parcels located above and below the surface, intersections of constraints in space (such as that are present under the transmission lines). The 3D environment also allows measurements in 3D, increasing the level of intervention of the designers and user interaction with the data of the network.

Among the applications with 3D visualization capability, useful for the structuring of 3D cadastres for networks are: computer-aided design (CAD), geographic information systems (GIS) and 3D viewers without editing options. An example of the latter is the well-known Adobe Acrobat format, which also proposes an option for handling PDF files in 3D and offers minimal options for modifying color, transparency and projection. Google also proposes a

three-dimensional globe (Google Earth) that includes the visualization of buildings in 3D for some cities of the world.
The third dimension in the cadastral system would generate new opportunities for technicians and even for new users of electrical data. Interacting with the 3D visualization of cadastral data is useful to identify and understand the three-dimensional geometrical limit of the parcels, measure inside and outside the 3D horizontal property units, find objects adjacent to a 3D legal object, both vertically and horizontally, identify the Rights, Responsibilities and Restrictions (RRR), as well as merger or subdivision volumes. The 3D cadastre will allow to track other networks and infrastructures of public services (tunnels and bridges), control their proximity with property boundaries and detect spatial intersections, verifying visually the spatial validity of new projects without overlapping neighboring volumes and without unwanted 3D gaps.
The CFE's alphanumeric database is ready to operate in the 3D GIS environment.
The planimetric positioning of the land objects does not present major difficulty for the power line in Mexico, once the reference system was established the ellipsoid ITRF08, time 2010.0. In parallel, the country adopted the Geoid Gravimetric 2010 GGM10. Thus, the country has the complete spatial reference system for the positioning of each element of the 3D power line.
The ellipsoidal height is adopted with efficiency to position urban plots since it does not present ambiguities and can be obtained with adequate precision to the cadastre at a certain moment. In this sense, since the tectonic movements have their known effects from the official measurements of displacements, it is perfectly possible to correlate the coordinates of the same object in space in two different epochs. However, given the magnitude of the geographic space covered by the CFE, the ellipsoidal height is not sufficient to meet their needs, with the use of orthometric height being mandatory to position the elements of the power line.
Mexican topographic engineering has experienced technicians and the most up-to-date survey instruments. The integration of data from multi-sources is in operation and the representations from 3D models are booming, however, the territory and objects are still represented through traditional maps and profiles. In this context, group of professionals that manages the geographic database started to represent the elements through bodies instead of figures, and that the positions in space instead of in a map projection.
The expectation is to integrate arial power line cadastre into the Land Administration Domain Model (LADM, ISO19152:2012) for Mexico, which does not officially exist yet.

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