# Specifics of geodetic engineering measurements for staking out high voltage lines

**Petre Iuliu Dragomir, Alexandru Moldoveanu, Tudorel Silviu Clinci, Daniela Cristiana Docan**

Received: April 2015 / Accepted: September 2015 / Published: December 2015


**Abstract**
In this article are presented the implications of geodetic engineering measurements in the design, verification and execution of high voltage power lines. Depending on the location on the globe can arise specific situation that involving special solutions work. In these conditions requires integration of interdisciplinary knowledge related to the field of terrestrial measurements such as mathematical cartography, geodesy and surveying engineering measurements. In the case study is presented a special situation due to the existence in the area of two different coordinate systems

**Keywords:**
high voltage lines, staking out, coordinate systems.

Prof.univ.dr.ing. – Technical University of Civil Engineering, petreiuliu.dragomir @gmail.com
Master ing. – moldoveanu..a@gmail.com
Asist.univ.dr.ing-- Technical University of Civil Engineering – tudorelsilviu@yahoo.com
Lecturer, eng., PhD- Technical University of Civil Engineering, daniela.docan@utcb.ro

## 1. Introduction

Regarding the development of high-voltage electricity transmission lines, appeared specific objects of study such as:
- Increasing the power flowing through a power stations and the necessity to establish interconnections by long-distance high-voltage and very high-voltage transmission lines (for example, problems with parallel operation of electric utilities that are interconnected and operate synchronously, their stability to the occurrence of short circuits and overvoltage, the calculation of short-circuit currents);
- Problems of interference between high-voltage and very high-voltage power lines and telecommunication lines (for example, setting the allowable space and distance, protective measures against disturbance or electrocution)

These kinds of objectives are the subject of the High Voltage Technology, which is a branch of the electrical engineering discipline with a great importance into the *power engineering* field (for example, electrical engineering, power engineering).
This discipline was resulted as a necessity as soon as the first high-voltage installations was put into operation, having as main objectives the designing, building, testing, using and insulation of electrical devices in accordance with nominal operating voltage (for a long-term regime) and possible overvoltage [2].
High voltage domain refers in generally to voltage exceeding 1000 volts (1kV), which is divided into the following classes of electrical insulation:
- Medium Voltage (MV, Class A): 1 kV <Nominal voltage <52 kV;
- High Voltage (HV, Class B): 52 kV ≤ Nominal voltage <300 kV;
- Extra high voltage (EHV Class C) ≤ Nominal voltage ≤ 750 kV 300 kV;

- Ultra High Voltage (UHV Class D): Nominal voltage ≥1000 kV.

However, increasing the nominal voltage amount raises issues such as:

- The stability of the interconnected power systems;
- The necessity of using the *fascicular conductors for power lines (*in particular, for nominal voltage greater than 220 kV, in order to avoid the spontaneous corona discharges).

The power flowing through a power station which is usually transmitted through overhead power lines (OPL), has increased to several thousand megawatts (1 MW=1,000,000 W), therefore, the operation of the electrical equipment must be under the design parameters and also, must be safety (high reliability) (Popovici, D.,Lolea, M., 2011, p. 7).

In Romania, with the fast development of the industry has grown also the electric power industry. Thus, in 1950 performed first 110 kV line with a length of 127 km. In only 15 years, from 1950 until 1965, the national electricity transmission system has been summed up 5260 km of 110 kV lines, 663 km of 220 kV lines and 576 km 400 kV lines. In 2012, the electric power transmission network in Romania, managed and operated by C.N. Transelectrica S.A., which is the National Company for Power Transmission, included substations and electric lines with a rated voltage higher than 110 kV distributed as follows [2]:

- 79 power transforming stations of which: a750 kV station; 36 stations of 400 kV; 42 stations of 220 kV;
- 8931.6 kilometers of overhead lines of which: 154.6 km of 750 kV Overhead Line (OHL), 4703.7 km 400 kV OHL; 4035.2 km of 220 kV OHL and 38 km 110 kV OHL (interconnected lines with neighboring countries) [4].

In the overhead high-voltage lines, the geodetic engineering measurements precede, accompany and follow construction process. The importance of the engineering measurements importance increase as far as automatic equipment and methods are used in the building process and also the measurement technology is improving.

## 2. Conditions for clearways, protection zones and safety zones for overhead lines

The engineering surveys performed for the planning and design OHL documentation, and stake out engineering works, must take into account the conditions for right-of-way width (ROW), protection and safety zones of the overhead lines. Essentially, the following elements should be considered [3]:

Right-of-way width (ROW) illustrated in figure 1, symmetrical by the centerline, is given by:

$$CT = LLEA + 2 \cdot (l_{iz} + fc_{max}) \cdot \sin\alpha_c + 2 \cdot ds \qquad (1)$$

where:

- $LLEA$ is the maximum width of footprint transmission towers (m);
- $l_{iz}$ is maximum length of leg members anchor or guy wires or tensile anchors;
- $fc_{max}$ is maximum conductor sag, under the high wind conditions, calculated for the biggest distance between two towers (span length *expressed in meters*);
- $\alpha_c$ is maximum conductors tilt under the wind pressure ($^o$);.
- $ds$ is horizontal safety clearance zone, from the live conductors to its maximum deviation (m).

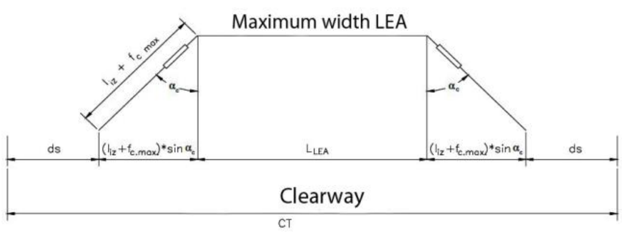



Fig. 1 Right-of-way width (ROW).

Size of sites for structures for tower foundations need to be permanently occupied during the existence of the overhead line and areas for construction and tower assembly, refurbishment work, maintenance equipment, ROW clearances, staging areas, and require access road. Those cleared areas are established according to: voltage level, tower design, footprint transmission towers, platforms for conductor pulling and platforms for OHL maintenance works.

## 3. Precision requirements

The accuracy of engineering surveying influences the resulted conductor gauges, span length, and conductor sag. This affects the forces applied on the structure of the overhead line (towers, conductors, insulation, and foundations).

The current regulations specify that positional accuracy of the details should be Δx, Δy, Δh ≤ +/- 15 cm.

Accuracy of longitudinal profiles for the final documentation should be Dx Δy Δh ≤ +/- 0.3 mm.

The accuracy of the horizontal angle between two alignments should be:

$$T_\alpha = 50^{cc} \cdot n \qquad (2)$$

where:

$T_\alpha$ is angle measurement tolerance (seconds);

$50^{cc}$ is standard deviation for one direction is $50^{cc}$;

n is the number of measured directions.

The measurement accuracy of the distances between poles is given by:

$$T_L = 15 + L \cdot 0{,}12 \quad (3)$$

where:

$T_L$ is the allowable tolerance for the observed distance between the centers of the two consecutive towers having a slope "p" up to $10^G$, and L is the horizontal distance in meters.

For the slope of line greater than $10^G$, tolerance T is increasing with:

• 29% for slopes between $10^G$ and $20^G$
• 58% for slopes between $20^G$ and $30^G$
• 87% for slopes between $30^G$ and $40^G$

The precision requirements for towers refer to:

- Linearity of the tower structures measured between two tower center …; the allowable tolerance should be:

$\Delta L \leq L / 100$

- Allowable vertical deviation is 0.2% of tower height.
- Crossarms deviation from the right angle; they must not exceed 0,5% of the horizontal length of the crossarms from tower center.
-Other specific requirements regarding the tower structure planning (relative positioning of conductors, insulators) and tower assembly.

## 4. Specific engineering Geodetic Measurements

The site surveying used for planning and designing the OHL and the stake out engineering works in accordance with the dimensioned plans are relay on the geodetic support network.

Before addressing the steps involved in achieving geodetic support network, especially for the cross-border overhead power systems (OHLs), is necessary to *carry out the following tasks:*

- Analysis of the existing geodetic points in the area of interest;
- The study of the correspondence between the Reference and Coordinates System of the geodetic points in the area and the designed centers of the OHL tower;
- The coordinate transformations, if is necessary.

There may be situations where there is not a single reference and coordinates system used, but there are two different reference and coordinates systems (an old one and a new one intended to be used).

In these situations, it is necessary to analyze the reference and coordinates systems and carrying out the necessary transformation.

The geodetic support network design should take into account the GNSS technology for geodetic point positioning and total stations for the site surveying and stake out the OHL structure.

The topographic documentation consists into a plan layout that represents the line in a large scale and the corresponding longitudinal profiles that respect the precision requirements mentioned previously.

Setting plan scale is based on the precision requirements, taking as a main criterion for determining the scale, the precision representation of planimetry [6], according to:

$$\frac{1}{n} = \frac{\sigma_{pl}}{\sigma_d} \quad (4)$$

where:

$\sigma_{pl}$ is standard deviation of the well-defined point position on a map;

$\sigma_d$ is standard deviation of the well-defined point position on the ground;

$n$ is scale map denominator.

## 5. Case study

The case study presents a project conducted in Amman city, the capital of Jordan. The project refers mainly to geodetic engineering measurements and stake-out works for a functional overhead power line of 132 kV.

Analysis of the geodetic network situation concluded there are two coordinate reference systems: System Cassini-Soldner and Jordan Transverse Mercator coordinates and was identified two geodetic points in Cassini-Soldner system. By contrast with Cassini projection, where the reference surface is a sphere, Cassini-Soldner reference surface is an ellipsoid. Cassini-Soldner projection is a cylindrical projection square cross, fairness corresponding projection cylinder tangent to the meridian to its environment in the region. This is not a projection that preserves angles unchanged, but is commonly used in the last century to represent areas that have large expanses along latitude. Scale after central meridian is $\mu m = 1$, scale on all verticals is $\mu 1 = 1$. Cassini-Soldner projection is more advantageous to regions located along the central meridian, this projection underpinning the geodetic coordinates Rectangular - Soldner (considered by the sphere) which are well known in geodesy. Cassini-Soldner coordinate system is used in Jordan in both the cadastre and the special engineering works. Cassini-Soldner projection is a cylindrical whwre the cylinder is tangent to the sphere of the central meridian. Small circle parallel to the central meridian forms the north-south extent. A cylinder is designed around the globe and is tangent along the central meridian. Due to its similarity with Transversal Mercator projection, is the tendency to replcenent Cassini-Soldner projection with Transversal Mercator projection, as happened in many countries in the Middle East. In Jordan, is intended to replace the Cassini-Soldner system with Jordan Transverse Mercator system for both cadastral and topographic works. The projection shows a central meridian, along which the scale remains unchanged, all other meridians and parallels are curved, scale distortion increases rapidly with increasing distance from the central meridian [1].

Coordinate transformation from one reference system to another can be achieved by following the steps shown schematically in the figure below:

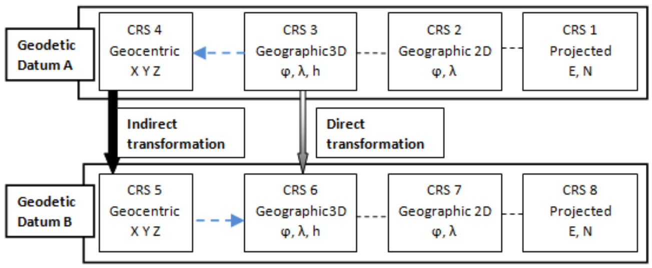



Fig. 2 Indirect and direct transformation of geographic coordinates [7]

Formulas for calculating latitude and longitude of the ellipsoid by plane coordinates north and east are [8]:

$$\varphi = \varphi_1 - \left(\frac{\nu_1 \cdot tan\varphi_1}{\rho_1}\right)\left[\frac{D^2}{2} - \frac{(1+3T_1)D^4}{24}\right] \quad (5)$$

$$\lambda = \lambda_0 + \frac{\left[D - \frac{T_1 \cdot D^3}{3} + \frac{(1+3T_1)T_1 D^5}{15}\right]}{cos\varphi_1} \quad (6)$$

where:

$$\nu_1 = \frac{a}{\sqrt{(1-e^2 sin^2\varphi_1)}} \quad (7)$$

$$\rho_1 = \frac{a\cdot(1-e^2)}{\sqrt{(1-e^2 sin^2\varphi_1)^3}} \quad (8)$$

$\varphi_1$ is point by the central meridian with the same coordinate point whose coordinates north must be determined and can be calculated from the relationship:

$$\varphi_1 = \mu_1 + \left(\frac{3e_1}{2} - \frac{27e_1^3}{32} + \cdots\right) sin2\mu_1 + \left(\frac{21e_1^2}{16} - \frac{55e_1^4}{32} + ..\right) sin4\mu_1 + \left(\frac{151e_1^3}{96} + \cdots\right) sin6\mu_1 + \left(\frac{1097e_1^4}{512} - \cdots\right) sin8\mu_1 + \cdots \quad (9)$$

where:

$$e_1 = \frac{\left[1-\sqrt{(1-e^2)}\right]}{\left[1+\sqrt{(1-e^2)}\right]} \quad (10)$$

$$\mu_1 = \frac{M_1}{\left[a\cdot\left(1-\frac{e^2}{4}-\frac{3e^4}{64}-\frac{5e^6}{256}-\cdots\right)\right]} \quad (11)$$

$$M_1 = M_0 + (N - E_N) \quad (12)$$

$$T_1 = tan^2\varphi_1 \quad (13)$$

$$D = \frac{(E-F_E)}{\nu_1} \quad (14)$$

Transition by geodetic coordinates and ellipsoidal height $(B,L,H^E)$ to Cartesian coordinates (X,Y,Z) can do the following steps.

Considering a point P located on the surface at a height above the ellipsoid $H^E$, the position of this point can be expressed through geodetic coordinates $(B,L,H^E)$ or by Cartesian coordinates (X,Y,Z).

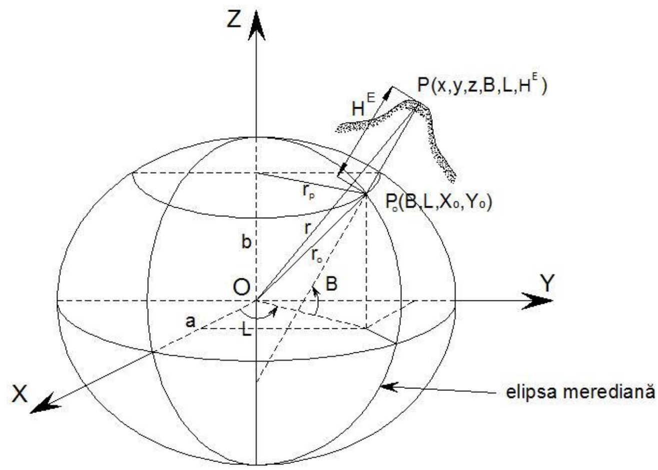



Fig. 3 Transition by geodetic coordinates and ellipsoidal height to Cartesian coordinates

$P_0$ is projection of point P on the reference ellipsoid;
$r_p$ is radius of the parallel passing through the point;
N is normal sea;
M is meridian radius of curvature;
W is a function of latitude;

$$N = \frac{a}{W} \quad (15)$$

$$M = \frac{a(1-e^2)}{W^3} \quad (16)$$

$$W = \sqrt{1-e^2\cdot\sin^2 B} \quad (17)$$

$$r_p = N\cdot\cos B \quad (18)$$

$$H^E = \frac{\sqrt{X^2+Y^2}}{\cos B} - N \quad (19)$$

The components of the position vector of a point $P_0$ located on the reference ellipsoid:

$$r_0 = N\cdot\begin{vmatrix}\cos B\cdot\cos L\\ \cos B\cdot\sin L\\ \left(\frac{b}{a}\right)^2\cdot\sin B\end{vmatrix} \quad (20)$$

The components of the position vector of a point called "i" located on earth surface is gived by :

$$r_i = \begin{vmatrix}x_i\\ y_i\\ z_i\end{vmatrix} = \begin{vmatrix}\left(N_i+H_i^E\right)\cdot\cos B_i\cdot\cos L_i\\ \left(N_i+H_i^E\right)\cdot\cos B_i\cdot\sin L_i\\ \left[N_i\cdot\left(1-e^2\right)+H_i^E\right]\cdot\sin B_i\end{vmatrix} \quad (21)$$

To use GNSS technology is necessary to transform coordinates from the Clarke ellipsoid used as reference surface for Cassini-Soldner projection at coordinates $B,L,H^E$ in WGS84 system. 3D mathematical model of transformation with seven parameters has the following form:

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} X_0 \\ Y_0 \\ Z_0 \end{pmatrix} + m \cdot R(\alpha, \beta, \gamma) \cdot \begin{pmatrix} X' \\ Y' \\ Z' \end{pmatrix} \quad (22)$$

$$\underline{X} = \underline{X}_0 + m \cdot R \cdot \underline{X}' \quad (23)$$

where:

$X_0$ is translation between the origins of the two systems;

M is scale factor in ppm;

R is the orthogonal rotation matrix ($R^{-1}=R^T$);

α,β,γ is rotation angles about X',Y',Z' axes

Following these calculations are obtained XYZ Cartesian coordinates on WGS84 ellipsoid. To shift the obtained coordinates from the WGS84 ellipsoid to Hayford ellipsoid must to add the coordinate increases corresponding to shifts the origins of the two reference systems [1].

$$\begin{aligned} X_W &= X_H + \Delta X \\ Y_W &= Y_H + \Delta Y \\ Z_W &= Z_H + \Delta Z \end{aligned} \quad (24)$$

where:

$X_W, Y_W, Z_W$-Cartesian coordinates on WGS84 ellipsoid;

$X_H, Y_H, Z_H$- Cartesian coordinates on Hayford ellipsoid;

$\Delta X, \Delta Y, \Delta Z$- origins shifts between the two systems.

According to prof. Steven H. Savage from the University of Arizona, the three transformation parameters have the following values: $\Delta X$= -86m, $\Delta Y$= -98m, $\Delta Z$= -119m [2].

Conversion from Cartesian coordinates (X, Y, Z) to geodetic ellipsoidal coordinates and ellipsoidal height (B, L, $H^E$) is achieved by means of the following formulas:

$$B_i = \arctan\left[\frac{Z_i}{\sqrt{x_i^2 + y_i^2}}\left(1 - e^2 \frac{N_i}{N_i + H_i^E}\right)^{-1}\right] \quad (25)$$

$$L_i = \arctan \frac{y_i}{x_i} \quad (26)$$

$$H_i^E = \frac{\sqrt{x_i^2 + y_i^2}}{\cos B_i} - N_i \quad (27)$$

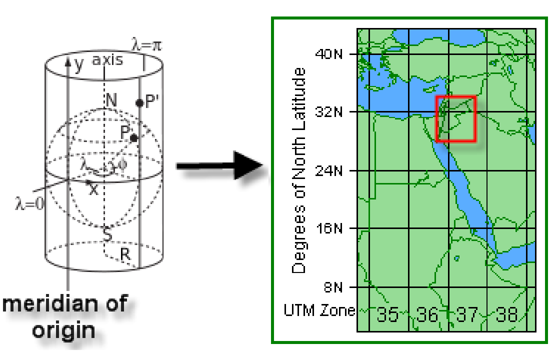



Fig. 4 Jordan Transverse Mercator projection

Jordan Transverse Mercator (JTM) projection is a system created by Jordan Royal Geographic Centre (RGJC).

Jordan Transverse Mercator projection (JTM) is a geodetic datum which uses the International Hayford as an Ellipsoid. This projection is with 6° zones, central meridian of 37° and scale factor in the central meridian of 0.9998 [9]. The National Geodetic Network is highly accurate (Doppler based geodetic network). Transformation parameters are not provided by the government authorities, but coordinates N and E in Jordan Transverse Mercator system can be determined by the following relations [8]:

$$E = F_E + k_0 \nu \left[A + \frac{(1-T+C)A^3}{6} + \frac{(5-18T+T^2+72C-58e'^2)\cdot A^5}{120}\right] \quad (28)$$

$$N = F_N + k_0 \left\{M - M_0 + \nu \tan\varphi \left[\frac{A^2}{2} + \frac{(5-T+9C+4C^2)A^2}{24} + \frac{(61-58T+T^2+600C-330e'^2)A^6}{720}\right]\right\} \quad (29)$$

where $F_E$ is false east and $E_N$ is false north:

Values of the coefficients can be calculated using the equation:

$$A = (\lambda - \lambda_0) \cdot \cos\varphi \quad (30)$$

$$T = \tan^2\varphi \quad (31)$$

$$C = \frac{e^2 \cdot \cos^2\varphi}{(1-e^2)} \quad (32)$$

$$\nu = \frac{a}{\sqrt{(1-e^2\sin^2\varphi)}} \quad (33)$$

where M is the distance along the meridian from the equator to latitude φ and can be calculated from the relationship:

$$M = a\left[\left(1 - \frac{e^2}{4} - \frac{3e^4}{64} - \frac{5e^6}{256} - \dots\right)\cdot\varphi - \left(\frac{3e^2}{8} + \frac{3e^4}{32} + \frac{45e^6}{1024} + \dots\right)\cdot\sin 2\varphi + \left(\frac{15e^4}{256} + \frac{45e^6}{1024} + \dots\right)\cdot\sin 4\varphi - \left(\frac{35e^6}{3072} + \cdots\right)\cdot\sin 6\varphi + \cdots\right] \quad (34)$$

where φ is the angle in radians and $M_0$ is the value of M calculated for up $\varphi_0$.

Points with known coordinates are in Cassini-Soldner coordinate system. Coordinate transformation in the new JTM was performed using software provided by the Jordanian government authorities. The software has implemented a number of transformation parameters whose values are not made public and allows the coordinate transformation between the Jordan Transverse Mercator, Universal Transverse Mercator and Cassini-Soldner systems.

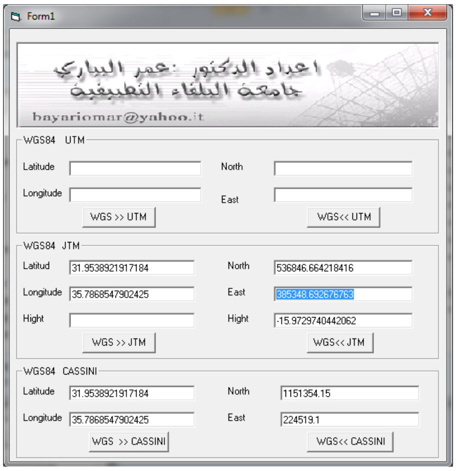



Fig. 5 Coordinate transformation

Stake-out works necessary for building OLE towers involves the sitting on the ground of the tower center, foundation footings and effective foundation platform in accordance with the coordinates indicated in the project.

For thickening of geodetic network, there were used the following instruments: total station Leica TC Series (R) 407® with angle accuracy of 7''and standard deviation ± (2mm + 2ppm) for distance measurement (IR: Reflector mode) and Leica GPS 1200+ Smart Rover with RX1210 controller having 3mm + 0.5ppm horizontal accuracy and 6mm + 0.5ppm vertical accuracy for static mode working and 10mm + 1ppm horizontal accuracy and 20mm + 1ppm vertical accuracy for RTK /Kinematic mode [5].

All these instruments cover the stakeout precision required for the component of the power transmission system.

For every tower platform it is necessary to have four-leg tower to same elevation and for the cases where the four-legs are at different elevations, the stake-out will be done according to the project.

For each tower were made diagonal profiles who showing the terrain model necessary for positioning of the towers.

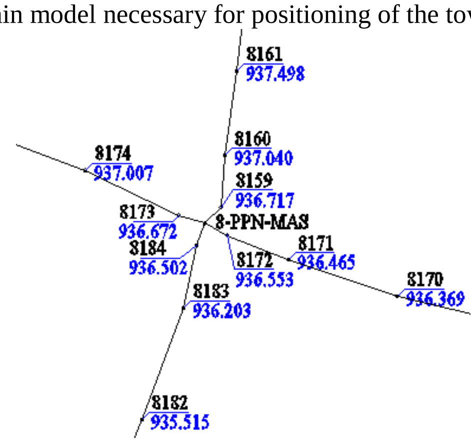



Fig. 6 Diagonal section profile

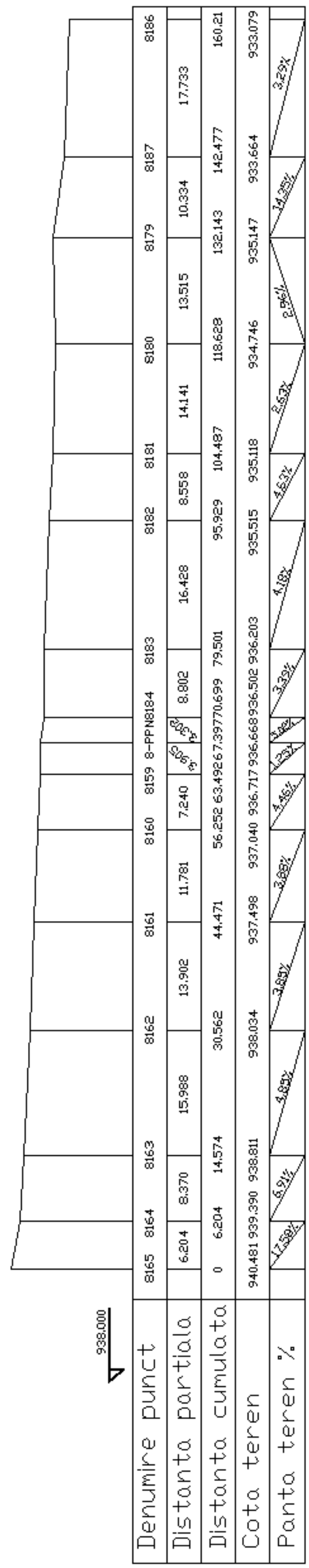
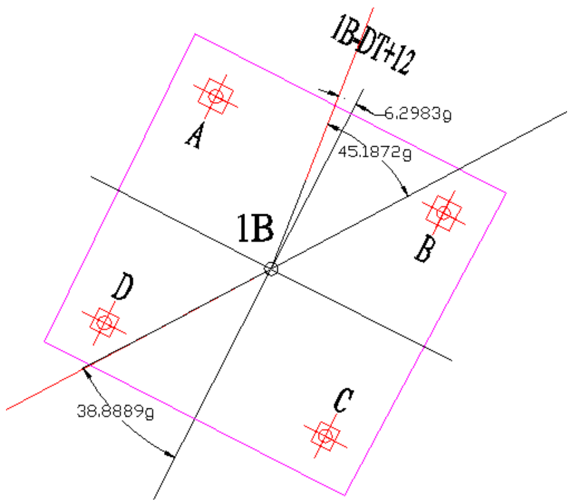



Fig. 7 Diagonal profile for tower number 8

Tabel 1: Coordinates tower platform 1B

| Nr. pct. | Y [m] | X[m] |
|---|---|---|
| 1 | 537192.496 | 385180.646 |
| 2 | 537214.762 | 385192.032 |
| 3 | 537203.574 | 385214.909 |
| 4 | 537180.499 | 385203.110 |




| Nr. pct. | Y [m] | X [m] |
|---|---|---|
| 1 | 537203.385 | 385209.843 |
| 2 | 537202.497 | 385211.579 |
| 3 | 537200.761 | 385210.691 |
| 4 | 537201.649 | 385208.955 |

| Nr. pct. | Y [m] | X [m] |
|---|---|---|
| 1 | 537186.453 | 385201.185 |
| 2 | 537185.565 | 385202.921 |
| 3 | 537183.829 | 385202.033 |
| 4 | 537184.717 | 385200.297 |

| Nr. pct. | Y [m] | X [m] |
|---|---|---|
| 1 | 537211.431 | 385193.109 |
| 2 | 537210.703 | 385194.533 |
| 3 | 537209.278 | 385193.805 |
| 4 | 537210.007 | 385192.380 |

| Nr. pct. | Y [m] | X [m] |
|---|---|---|
| 1 | 537194.997 | 385184.705 |
| 2 | 537194.269 | 385186.130 |
| 3 | 537192.844 | 385185.401 |
| 4 | 537193.573 | 385183.977 |

Fig. 8 Stake out sketch from tower 1B

## 6. Conclusions

In general, site surveying and stake out engineering works for the overhead lines involve well known procedures. However, particular situations require thoroughgoing studies and original solutions for the engineering surveys.

The paper presents the main types of works involved in developing OHL, highlighting the special situations that should be solved.

Therefore, the case study was analyzed the map projections underlying coordinates and reference systems that can be found in Jordan, such as: Cassini-Soldner Reference and Coordinates System and Jordan Transverse Mercator Reference and Coordinates System, and transformation methods between two reference systems based on different datums. It has been shown a worked example of transformation using a software application developed by Jordanian officials. Also, there were presented all other engineering works performed such as: planning and design the OHL and stake out the projected components.

## References

[6] Clifford J. M., et. al. – Grids & Datums – Hasemite Kingdom of Jordan, Photogrammetric Engineering & Remote Sensing, December 2006, pp. 1318;

[7] Popovici, Diana; Lolea, Mari, Curs universitar pentru uzul studenţilor, Facultatea de Energetica, Universitatea din Oradea, pp.6-7, 2011;

[8] Normativ pentru construcţia liniilor aeriene de energie electrică cu tensiuni peste 1000 V - NTE 003/04/00 – ISPE Bucureşti, 2014;

[9] Transelectrica, Power Tranmission Grid (PTG) Perspective Plan Period 2008-2012 and 2017 as a guide, p. 20, 2009;

[10] Moldoveanu, Alexandru - Proiectarea măsurătorilor geodezice inginereşti pentru realizarea LEA 132 kv-AMMAN SOUTH to BAYADER Al FUHEIS –lucrare de disertaţie , UTCB, 2014;

[11] Dragomir, Petre Iuliu – Bazele măsurătorilor inginereşti –CONSPRESS, 2009;

[12] Jonathan Iliffe and Roger Lott; *Datums and Map projections 2nd Edition;* Whittles Publishing, pp.39-89; 2012;

[13] International Association of Oil & Gas Producers – Surveying and Positioning Guidance Note, Number 7, part 2, May 2009, pp.37-39;

[14] Twinning Project Fiche - Reduce Discrepancies between the Physical Reality and the Graphical Cadastral Information in Jordan for the Department of Lands and , pp.6-7.