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PROBLEMS RELATED TO SELECTED METHODS AND TECHNIQUES OF AS-BUILT SURVEYS OF LOW- AND MEDIUM-VOLTAGE ELECTRICITY CONNECTORS WITH A PRACTICAL DISCUSSION

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ABSTRACT:

The aim of the paper was to analyse problems related to the inventory (as-built survey) of low and medium voltage power lines. Measurement methods and techniques were analysed as well as the influence of the network type (low and medium voltage) on the as-built survey procedure. For this purpose, information obtained from five as-built survey reports of medium and low voltage using different measurement methods was also used. Three of them were sample as-built survey of low voltage cable lines measured by tacheometric method, one as-built survey of medium and low voltage lines measured by GNSS method and one of low voltage cable made by indirect method using cable locator and measured by GNSS technology. The paper analyses the differences arising from the accuracy of the measurement, the difficulties encountered during the implementation, the time-consuming nature of the work performed, taking into account safety aspects for the persons performing the work.

1. INTRODUCTION

As-built surveys are one of the surveying works aimed at completion of the investment stages of construction. As-built inventory is made at the time of completion of the work by the investor in order to obtain updated data on the location of land utilities and objects (Kadex 2022). As-built measurements can be performed only by a surveyor with appropriate qualifications, and although he is not a full participant of the investment works, he plays a very important role in this process (Sejm 1989). From the initial stages of the investment a surveyor takes part in its execution and is responsible for preparation of documentation enabling completion of works or obtaining necessary information about the property. The documentation made in the investment process is part of the construction project, at the final stage it allows the investor to accept the work and to complete the construction in accordance with the regulations (Sejm 1994). The as-built inventory process itself includes the designed object together with the technical infrastructure and underground utility networks of the area where the investment was made (Dybeł and Kampczyk 2018). The application of an appropriate measurement method depends primarily on the location of a given object and the accuracy with which the measurement should be made. The as-built inventory covers underground and aboveground infrastructure networks, single-family buildings located entirely on the plot of land, as well as construction facilities for which a building permit has been granted (Geodetic.co 2022). As a result of measurements and data compiled from the site, a technical report is prepared, which is submitted to the relevant office, and then - after its review and approval - the data is entered into the register related to the registration and development network (Mierzejowska 2017).

It is also worth noting that the inventory is one of the elements underpinning the operation of the thematic subsystem, enabling the creation of a site information system and allowing for the control and reconciliation of development. The main reason the inventory data is collected is the issue of safety, regulating at a later time the location of utilities in order to expand them or more easily remove failures. Location of such facilities is important as utility networks are mostly located under the surface of the land, so they cannot be directly located after a period of time. As-built surveys can be divided into two types: current and final surveys. As-built measurements are primarily for linear objects that will be backfilled during the work. However, the final measurement is performed after the completion of the work, e.g., location and depth of sewage wells. The measurement includes the construction objects and the landforms that have changed during the construction (abc-budowy 2022). Problems related to such measurements include first of all lack of uniform nomenclature, which is caused by the definition of land development elements appropriate for the specification of a given branch, written in appropriate regulations (Buśko and Przewięźlikowska 2011). In addition, often in practice the location of objects does not coincide with the previously prepared documentation, e.g. through the inventory of cables after their backfilling without measuring (Kruk 2011). In the event of inconsistency between the development of the infrastructural network and the agreed design, the investor shall immediately submit the map with the inventory results to the competent administrative, architectural and construction authorities in order to take the appropriate steps (Hycner 2003).

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Therefore, the quality of the work done translates into the quality of the infrastructure and spatial information, which is a source of knowledge for citizens and administration (Gocał 2010; Borowiecki and Ślusarski 2010). In many cases, the conditions associated with a particular project force small changes during construction, which are important for the building or even for the investor, but completely irrelevant from the point of view of the environment (Przewięźlikowska and Krzyżek 2016). Attention should also be paid to databases related to the register of land development networks, which may be characterized by low data quality or accuracy (Siejka and Ślusarski 2013).

The paper is divided into five parts. The introduction briefly describes the role of the surveyor in the process of as-built inventory and the problems associated with it. The next part describes the different types of connections, their marking, division and measuring methods and techniques. In the practical part, example of as-built inventory of low and medium voltage power connection is given. The last chapter is devoted to the analysis of problems connected with the inventory and possibilities of its improvement. The aim of the paper is to illustrate in more detail the performance of an inventory of the power grid. On the example of acquired materials, three problems were analysed such as measurement methods divided into direct and indirect methods. Technologies of measurements divided into tacheometric measurement and GNSS measurement and problems related to the inventory of low and medium voltage lines were analysed. The GNSS technology it is also used in a variety of geodetic applications (Nistor, Suba, and Buda 2020; Nistor and Buda 2016) but also in atmospheric applications (Sorin Nistor, Suba, and Buda 2020a; S. Nistor and Buda 2015).

2. MEASUREMENT METHODS

There are 9 methods of acquiring the location of the utilities which include: direct surveying with reference to the matrix, cable tracer surveying, vectoring, photogrammetric surveying, direct surveying with reference to field details, industry data, documentation from coordination meetings, other acquisition methods than those listed above and an unspecified acquisition method (MRPiT 2021a).

The most accurate method is direct measurement with reference to the geodetic control network. In practice, the most common methods used are direct measurement with reference to the geodetic control network, cable tracer measurement and direct measurement with reference to field details. The remainder is based on data obtained from other less common sources. Currently, the most popular measurement method when performing inventory is RTK-GNSS (Real Time Kinematic Global Navigation Satellite Systems) (Maciuk 2018). Another less popular measurement technique is tacheometric measurement which allows measurements in difficult conditions when RTK-GNSS measurement is not possible (e.g., urbanized areas). The inventory methods, which is no longer so common and was used earlier is the survey method.

As-built measurement is divided into situational and ascension measurement. In the situational measurement the following are subject to inventory: newly erected buildings, structures and architectural objects, road structures, manholes for sewage and telecommunication networks, and vehicle charging points. The following are subject to height measurements: manhole covers and manhole bottoms, ground ordinates, road and river facilities for the purpose of making cross-sections, e.g., for the cross-section profile. In highly urbanized areas, some surveying departments require height measurements of underground infrastructure. We also perform height measurements in mining geodesy to determine the level position of galleries, ceilings and other mining objects.

Conduits and facilities constituting land development networks include all kinds of underground and aboveground facilities, the required measurement accuracies are 0.05 m (building structures and facilities and field-marked pickets); 0.02 m (sewer lines and facilities) and 0.10 m (earthen structures, flexible or electromagnetically measured underground land development network facilities and non-field-marked pickets (MRPiT 2021b).

2.1 Direct method

This is otherwise the basic and most accurate measurement method, by means of which the measurement is made directly with the inventoried device before its backfilling. However, during the inventorying of direct measuring devices, field excavations are made in order to locate the exact position of the cable. Currently, the measurement techniques used in this method are mainly tacheometric measurements and RTK techniques. In recent years total station surveys have been superseded by RTK measurements due to the development of satellite technology and GNSS reference station networks. The accuracy of obtaining this type of data is related to the accuracy of the measurement and the class of the reference network (total station) or the accuracy of the measurement (RTK). It can be assumed that the total station measurement is error-free, and the accuracy depends on the class of the reference network. Most often we refer to the detailed network, which accuracy is mp $\leq$ 0.05 m. For measurements made with the use of the RTK method the accuracy for the horizontal component is 2-3 cm, and for the height component - 5 cm. (Lachapelle et al. 2018).

2.2 In-direct method

In the case of indirect measurements, the localization of devices is done with electromagnetic or electronic detectors (detectors, Figure 1). These measurements can be divided into active and passive methods. The measurement with the passive method allows locating live cables. Locating this wire is possible through the waves that the wire emits. This method makes it possible to obtain accurate information about its location. The active method is used for networks that are not live and those that are connected to the power grid. Detection of these wires is possible through the signal generated in the cable and other forms of wire. The accuracy of such measurements depends primarily on the accuracy of the locating equipment and on the depth of the cables, the type of soil and the presence of other infrastructure, and is about 10% (Infopomiar 2018). Based on the information obtained it has to be stated that none of the companies from which we were able to obtain data, provide in their catalogues or in the technical data sheets of the locators, precise data regarding the accuracy of the measurement due to the potential liability for the measurement results. In spite of relatively high measurement errors with this method, in some cases this method is the only one possible to locate and consequently track the location of underground utilities due to the safety of the equipment and persons performing the measurements when there is no possibility of temporarily taking

the equipment out of service and making the necessary excavations.



Figure 1. Example of electricity network inventory using digital electronic detector type EZiCAT made by GeoMax (GeoMax AG n.d.)

By using locators, it is possible to obtain information about current location of the object and the depth at which they are located. However, in order to inventory the network using locators, it is necessary to refer to the state coordinate system using the techniques described in the indirect methods. The locator itself only shows the place where the cable is located without providing the coordinates necessary to do the work. During the locating process, points on the ground and data on the depth of the located cable are marked. The marked points are then measured with a total station or RTK. Therefore, according to the law of transmission of errors, assuming the error $m_t = 10\ cm$ with reference to the national surveying grid (total station) or $m_r = 5\ cm$ RTK height measurement error. The accuracy of determining the location of the net located at the depth of 50 cm is 10%, which means the detector's error $m_w = 5\ cm$. According to the law of the propagation of errors, the error for the tacheometric method is:

$$m_{mt} = \sqrt{m_t^2 + m_w^2} = \sqrt{10^2 + 5^2} = 11.2\ cm$$

And for RTK technique:

$$m_{mr} = \sqrt{ms_r^2 + m_w^2} = \sqrt{5^2 + 5^2} = 7.1\ cm$$

The same calculations, e.g., for a water supply network located at a depth of 2 m, are respectively $m_{mt} = 22.4\ cm$ and $m_{mr} = 20.6\ cm$, so it is significantly less accurate than direct measurement before backfilling the trench.

3. OBJECTS CHARACTERISTICS

Four sample inventories of LV lines (low voltage) and one inventory of LV and MV lines (medium voltage, Table 1) were used in this work. For the tacheometric and GNSS methods, were presented sample inventories of LV overhead-cable lines, while for the indirect method (use of a detector), were presented inventories of internal power line.

Job ID	Year	Network type	Measurement method	Number of points	Object
1	2007	*LV*	Tacheometry	16	Overhead and cable connection to the cable junction
2	2008	*LV*	Tacheometry	11	Cable connection to the cable junction
3	2007	*LV*	Tacheometry	20	Overhead and cable connection to the cable junction
4	2021	*LV*+MV	GNSS	84	Cable connection with cable coupling and transformer station
5	2022	*LV*	GNSS + detector	13	Internal power line (cable) from the cable connector to the building

Table 1. Characteristics of the analysed geodetic jobs

As examples of objects that are the subject of the inventory, have chosen overhead lines and LV cable lines, because in one report, it is possible to present the methodology for carrying out work related to the above-ground objects, such as overhead lines, cable connectors, and cable sections that are ultimately buried and require measurement during construction. Preparation for all methods starts with the same administrative procedure and requires processing of the acquired data before going into the field. For the total station method, it requires locating the surveying grid points and, if necessary, laying out polygonal lines. For the GSNN method there is no need to locate the reference network points; however it is necessary to obtain the appropriate GSNN signal quality. For the indirect method it is additionally necessary to have locators of tele-technical and other cable lines adapted to the terrain conditions and the type and thickness of soil.

4. RESULTS

After analysing examples of survey made by each method practical problems and advantages of using the surveying method and GNSS can be noticed. In the case of the total station method, the problem is the necessity of finding control network points, which are often located in distant places or are impossible to find or are partially destroyed during earthworks or field works on agricultural areas, the necessity of establishing polygonal sequences in areas with larger buildings, trees or in difficult terrain conditions. Another obstacle is the greater amount of work within the framework of intimate works and obtaining the results only in the office after processing the data obtained from measurements. The advantage of using this method is primarily independence from obtaining a complete GNSS signal which makes the measurement independent of signal quality, electromagnetic interference, the need for a current SIM card from the operator who has signal coverage in the area and is resistant to hackers who in extreme situations could disrupt the operation of the system. In addition, the measurement can be performed in areas of warfare, where the signal can be disrupted or disabled, and the survey operator can be tracked by the enemy information system. This method fulfils its tasks and sometimes it is the only one which can be used when conducting works far from civilisation, where there are no cellular networks such as archaeological and geological works. The tacheometric method allows to measure very high and dense buildings, where GSNN signal does not reach. In case of using the GSNN method the main disadvantage is the necessity of obtaining an appropriate signal, which in difficult terrains makes it impossible or extends the measurement time considerably. In areas with poor mobile network coverage, it requires the surveyor to have several SIM cards from different operators and forces to switch or exchange them in the device

depending on the equipment. For very high accuracy surveys, the GSNN method may not be sufficient due to lower accuracy. The advantages are simple operation, no need to find the reference points and the possibility to start the survey as soon as you are in the field. The big advantage of this method is significantly expanded accompanying software, which in many cases allows for quick data acquisition for the person who ordered the work. The modern operating system allows, in the course of surveying, to make calculations e.g., of volume, length and other data and to combine them automatically with photographic documentation or orthophotomap and to send the data directly to the office in order to process the materials, which in many cases shortens the investment process and is not without significance for the ordering party.

Figure 2 shows the differences in the LV cable marking in direct (a) and indirect (b) measurements with the use of the detector. Figure 2a is analogue (handwritten) without scale, while Figure 2b is digital with scale, which makes it more legible.

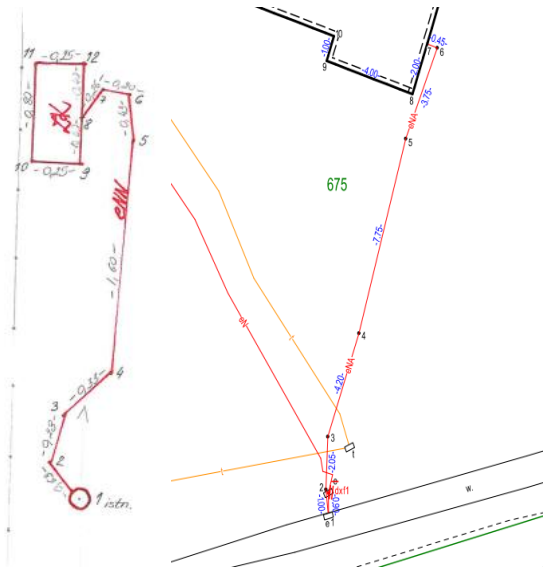


Figure 2. Examples of point placement sketches of: a) total station (Job ID 2); b) detector + GNSS (Job ID 5)

Another difference that can be observed is the fact that with a total station or GNSS we directly measure the point. However, in the case of indirect measurement method, first locate the location of the object using a locator and on the ground are marked auxiliary points that are tracked using a total station or GNSS receiver, which further increases the error of measurement.

Differences resulting from the way cables are marked depending on the voltage and so for medium voltage cables we adopt the designation *eS* (electric cable, medium voltage) and for low voltage cables are marked *eN* (electric cable, low voltage). The difference is illustrated in the field sketch (Figure 3). In addition, the figure below illustrates the difference between the drawn route of the cable laid directly in the ground and that laid in a protective tube. The cable laid in the ground is drawn with a thinner line and the cable laid in the pipe with a thicker line. Additional information on the method of cable laying is provided in the tabular list, which is an integral part of the survey and on the map. The aforementioned tabular list is not required today by all geodesic departments.

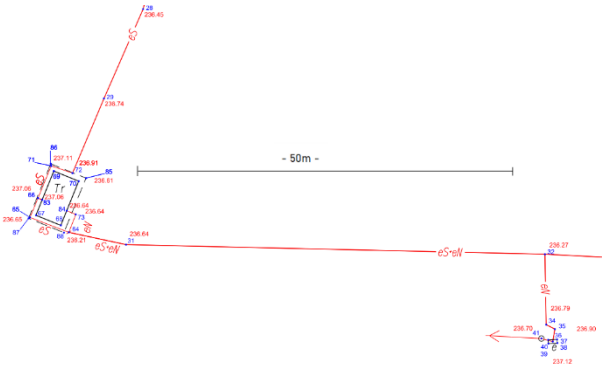
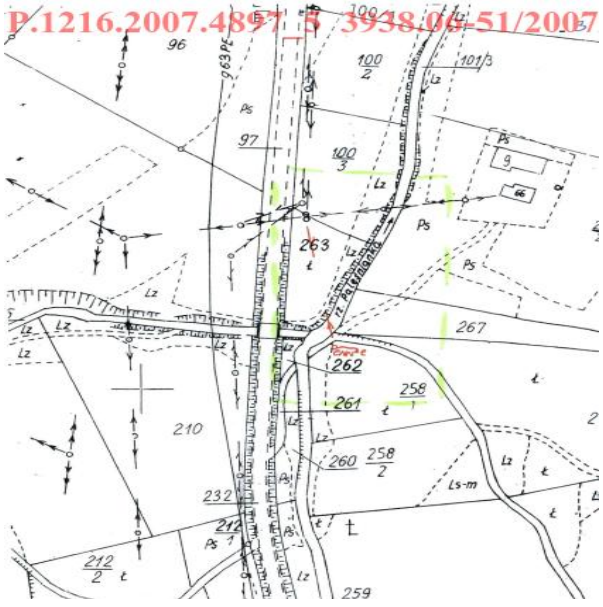


Figure 3. Example draft showing the marking of cables of low (eN) and medium (eS) voltage (Job ID 4)

Recent years and the progress of computerization have forced significant changes in the way of making surveying reports. For many years, this was done by mapping the map on the first draft and on the map matrix. This work was done manually on paper versions of the maps, which was very time-consuming and required high accuracy and attention, as well as the necessity to physically acquire the materials in the surveying department and then, after processing, physically transfer them to the city hall office.

At present, the acquisition of materials is done electronically, and the works are carried out in digital version using computers and sent electronically to the county office. Digital versions of maps and survey reports are more legible and allow reducing errors, increasing accuracy and streamlining the process of entering current changes into the database. Digital data acquisition allows multiple surveyors to work on adjacent parcels of land, which in the case of physical data acquisition, when one surveyor physically downloaded the matrices, prevented another surveyor from working until they were returned to the county. Figure 4 shows differences in execution and legibility of maps made by traditional method versus digital method.



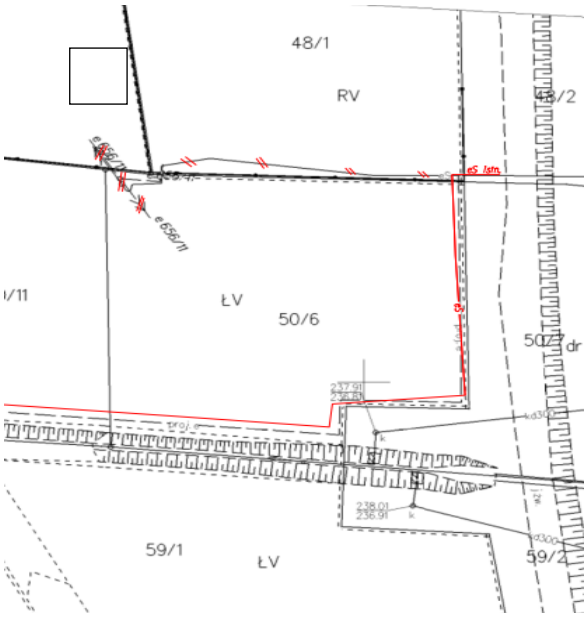


Figure 4. Example of a map made using: a) traditional method (Job ID 1); b) digital (Job ID 4)

5. SUMMARY

Five surveys made with different measuring methods were analysed in this paper. For this purpose, data obtained from the Tarnow district office based on a request for access to data were used. The data was filtered in terms of content using the necessary information for the purpose of the work. Three surveys of low-voltage connections using the total station method, one survey of medium- and low-voltage network and transformer station using the GNSS method were used. To illustrate the work using the indirect method, one inventory of the internal low voltage cable line located with the help of cable locator and frozen with GNSS method was used. Sketches and text files from the above-mentioned survey were also used.
During a survey with the direct method, we measure a device in direct contact with the measured device (before backfilling), which can cause certain hazards for the person carrying out the measurement, because cables and other devices can be located at considerable depths and risk being buried by nearby masses of earth. When surveying by the indirect method, we encounter additional difficulties caused by tele-technical devices, groundings, as well as metal pipelines. High mineralization of the ground or the presence of metallic debris in the ground can be a significant obstacle, making it difficult to locate the cable. After analysing the given measurement methods, it can be concluded that the direct method is more accurate, as it is not burdened with any error resulting from the use of a locator. However, the main advantage of the indirect method is the measurement of devices located in the ground under the surfaces of roads, squares, sidewalks and under other devices and networks performed at a later time, which enables map updates without the need for excavation.

In the case of the tacheometric method specific difficulties are dense buildings, which force the creation of polygonal sequences, which increases the time-consumption and the risk of errors. And also, atmospheric conditions that affect visibility, too much or too little sunlight, obstructions of visibility, smoke, dust or haze and rainfall, snow and high temperatures that create the phenomenon of mirages. However, for the GNSS method additional problems are difficulties with communication with base stations during GNSS measurements and obtaining a good quality signal from a sufficient number of satellites. Complications caused by signal interference by the presence of additional parasitic signals emitted by neighbouring power lines. A general problem for the implementation of the work for each method are terrain difficulties resulting from the terrain, the lack of access or accessibility, woods and bushes, the presence of marshy areas, as well as steeps and landslides, artificial terrain obstacles encountering supervised areas and areas with limited access, areas with the presence of heavy traffic, as well as areas where there are livestock or aggressive pets.

After analysing the data of measurement techniques, it should be concluded that the best method due to the ease of implementation and the possibility of avoiding most errors and reducing the number of people needed to carry out the inventory is the GNSS method. Currently, all inventories are referenced to the state grid using GNSS.

In this paper, inventories of low and medium voltage networks were analysed. In the case of low-voltage cable lines, measurements can be made on live cables, while in the case of medium-voltage lines, measurements should only be made when the line is de-energized. Be careful not to damage the insulation of the cable with the tip of the pole. In addition, medium voltage cables are located at greater depths than low voltage cables. In the case of overhead lines of both low and medium voltage you must take special care not to touch or come too close to the pole which can cause an electric shock. For example, on low-voltage lines, the lowest voltage devices are the pole disconnectors, which are installed on poles 3.2 - 3.5 m above the ground.

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