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Replacement of conventional ground wires with OPGW on 400kV overhead power transmission line, installation under live-line conditions - Polish expertise.

Abstract. This article presents installation methods for replacement of the conventional ground wires with Optical Ground Wires (OPGW) under live power transmission lines. The two installation methods: the tension stringing method and cradle block stringing method have been described in the article. Preparation for the installation work is preceded by the design of OPGW live-line installation and electromagnetic field analysis, which occur under live-line work. Positive experiences gained from OPGW installation projects execution, open a window of opportunity to use described techniques in wide range of live works on Polish power transmission lines.

First works under live overhead power lines have been carried out just a few years ago, they are new experience for operations as well as project execution but these works prospects improvement of power transmission and communication abilities of existing lines [1]. Full-scale replacement of conventional ground wires by OPGW are part of grid modernization and up to now these works have required planned outage of the transmission line. However these

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days Power Transmission Operators has been imposing restrictions to the planned outages. During weekends and holidays due to unexpected weather conditions these works are put into risk. To cope with difficulties regarding work organization there were techniques developed, which could allow for live-line woks. Expertise from various countries described in several articles [2, 3, 10,11,13,14] regarding methods of replacement conventional ground wires by OPGW under live-line conditions have been gradually adopted in Poland [1,4,5,6]. First positive experiences has been obtained on Swedish 400 kV overhead lines, where OPGW live-line installation project was executed on part of the line, which concerned lying the ground wire on the pulleys as well as pilot projects held in Poland regarding ground wire replacement with OPGW. Together with equipment purchase, personnel training for live work has been based on the expertise of Italian companies [2]. After the training, work experience has been gained on lines specially made accessible for this purpose by transmission lines operator. During 2009/2010 live works has been implemented with success on 400 kV line Gdańsk Błonia – Grudziądz and Kozienice – Miłosna. Technological design of OPGW live line installation has been based on rules given in authorized Live Work Technology Catalogue by National Grid Operator - PSE Operator S.A., for use on transmission lines under their jurisdiction (June 2009, Technology Data Sheet no 400LP051: Replacement and installation of conventional ground wires with OPGW using tension stringing method and cradle block stringing method on 400 kV power lines).

Replacement of conventional ground wires with OPGW according to international standards.

Consolidated rules in EU for electrical system operation, which are being formed lately are based on the following European Standards (having also Polish equivalents): EN 50110-1 and EN 50110-2 [9]. To qualify certain works as live works, it is not only to check distance to the potential, but in addition to this, several other parameters. Therefore rules for replacement of ground wires under live line conditions are given in special dedicated standards. The EN 60743 "Live working. Terminology for tools, equipment and devices" in chapter 14 describes fundamental elements of equipment, which will be used for wire replacement. From the other hand, where wire replacement have been qualified as live work, it does not necessary mean that many works forming part of the task cannot be done using other methods. Dedicated manual or technological design should describe in details which works related to the job task are live works, where special rules apply and which does not.

There were techniques and technologies developed all around the world which allow to replace standard ground wire with OPGW without outage of the transmission line. Simultaneously these works may be done over the objects/facilities/other live power lines, which this line is crossing. Requirements are standardized and given in the following technical reports (in Poland available in English):

- IEC/TR 62263: 2005 Live Working – Guidelines for the installation and maintenance of optical fibre cables on overhead power lines [7],

- IEC/TR 61328: 2003 Live working – Guidelines for installation of transmission line conductors and earthwires – stringing equipment and accessory items [8].

Apart from the reports given above, national requirements concerning execution of these technologies are based on the following standards:

- EN 61230 Live working — Portable equipment for earthing or earthing and short-circuiting.
- EN 61477:2002 Live working. Minimum requirements for the utilization of tools, devices and equipment.
- EN 62192 Live working. Insulating ropes.
- EN 60895 Live working. Conductive clothing for use at a nominal voltage up to 800 kV a.c. and ± 600 kV d.c.
- EN 61472 Live working. Minimum approach distances for a.c. systems in the voltage range 72,5 kV to 800 kV. A method of calculation.

Taking into account amendments to the standards, there were detailed regulations formulated and given in the:

- Instruction manual for work organization during replacement of ground wires with OPGW or standard type (AFL) as well as installation of fiber optic cables on live 220 kV and 400 kV power transmission lines. – Case study of ELTEL Networks Olsztyn S.A. no IT-3/LWN-PPN/13 from 27 April 2008r.,

As well as directly linked to the above instruction manual the:

- Detailed technological instruction for ground wire replacement on the 220 KV and 400 kV live power transmission lines – by ELTEL Networks Olsztyn S.A. [12]

Rules and requirements given in the international standards and included in the instructions are fully adopted by contractor companies during project execution, which proves professionalism in implementing world-wide expertise.

For replacement of conventional ground wires with OPGW on live-line conditions the two well known methods were implemented: tension stringing method and cradle block stringing method.

Tension stringing method

The installation of OPGW using tension stringing method on live power transmission lines is about unrolling the OPGW wire using puller and tensioner (see Figure 1). These devices shall have possibility to regulate tension on the wire and pulling speed during wire installation. Furthermore these devices shall have hydraulic brake, which automatically stops the puller and tensioner when tension set point is exceeded or when the wire is broken.

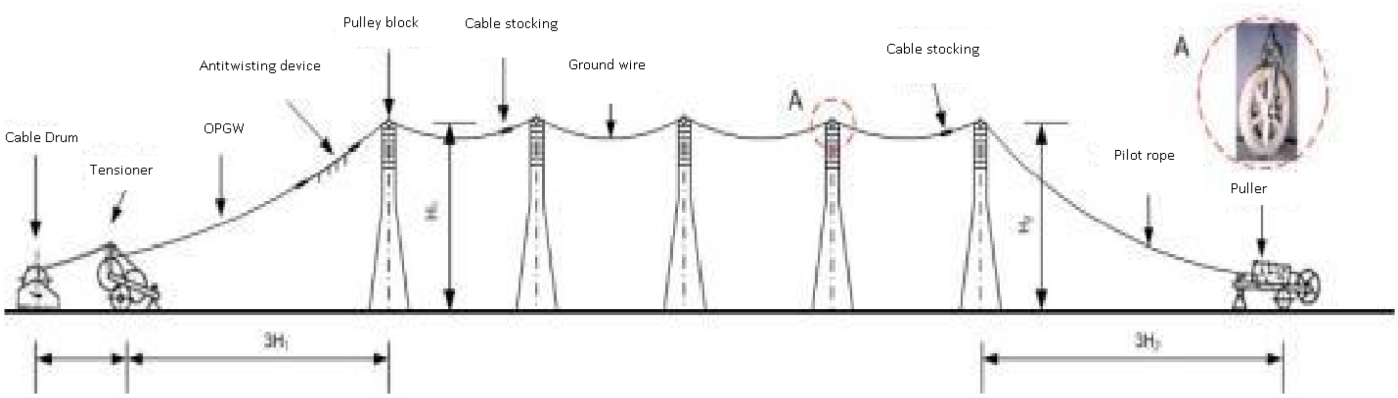

Figure 1 Replacement of conventional ground wire with OPGW using tension stringing method [1]

Controlling the tension on the wire and pulling speed, it is possible to keep the stringing force at the same level and to keep safe electrical distance between ground wires and phase wires.

During OPGW wires installation on live power transmission lines, an isolating ropes are used because of their light weight. On each tower of the tension section the pulley blocks are mounted, on which ground wire is lied. The ground wire, which is being replaced is used as messenger line for the OPGW wire. In this case it should be verified if existing on the line ground wire is in good condition, if there are no damages to the wire and that this wire will endure stringing force applied during replacement execution.

Isolating rope is pulled out from the last tower on the tension section to the puller and lied onto the pulley block at the tower where it is jointed to the existing ground wire with cable stocking. From the other side of the tension section OPGW wire is clamped to the existing ground wire with anti-twisting device and lied onto the pulley block. This makes possible simultaneously remove existing ground wire and install OPGW. Once the OPGW is on place, there is sagging procedure performed on the whole tension section. Next step is to clamp the OPGW wire at the tower using special equipment made for this purpose (see figure 2 for details).

To ensure high level of safety during project installation, especially in sections crossing important objects as routes or other power transmission lines the cradle block stringing method is used. This method is based on the installation of pulleys (cradle blocks), which are positioned on the existing ground wire every several meters. The pulleys used are usually vertical double pulleys or single pulley blocks. Vertical double pulleys are having 2 disks, each in separate chamber and sides, which may be opened. The upper disk of the double pulley is lied onto the existing ground wire, whereas lower disk is supporting pulling rope [1]. Pulleys are used for OPGW installation on the whole tension section but especially this method is used to secure important spans where above described tension stringing method is used as well as ground wire replacement in one span [2], [3].

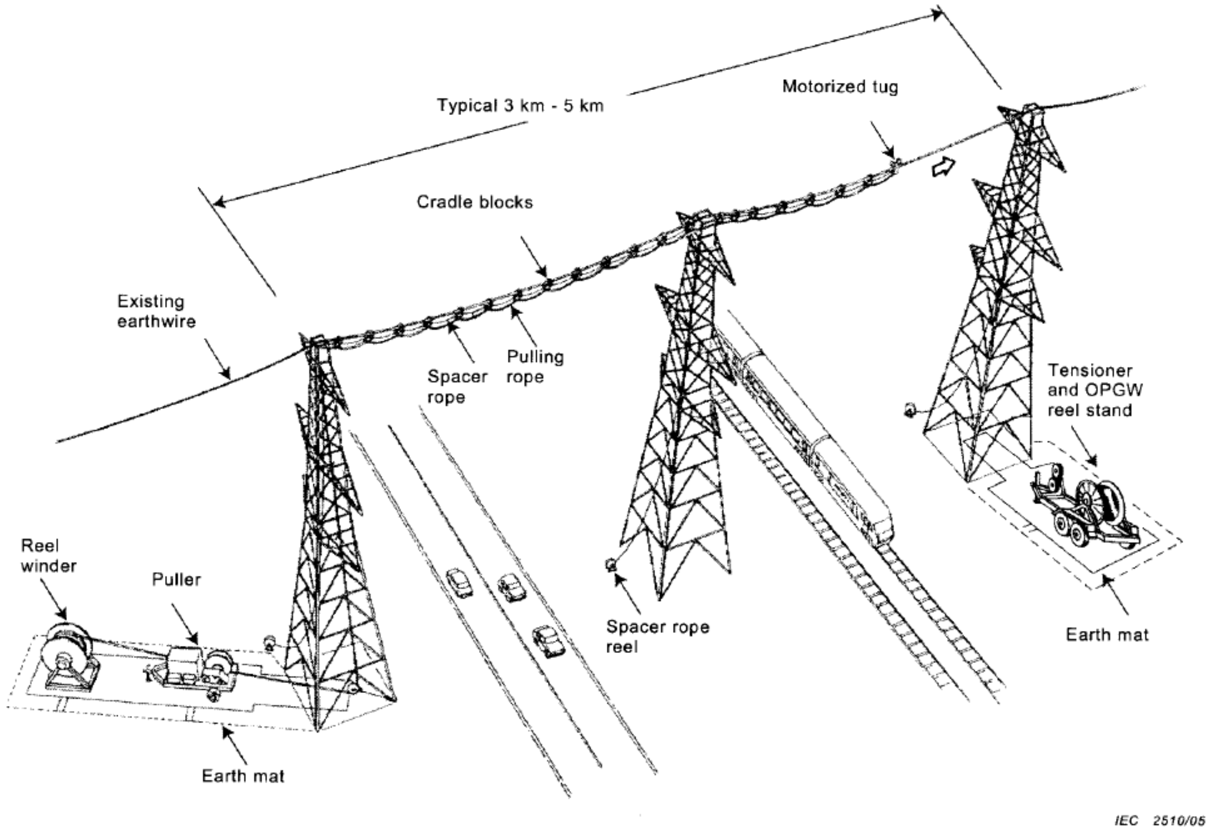

Figure 2 General layout presenting cradle block method for replacement of conventional ground wire with OPGW according to [7]

Figure 3 Cradle block method (double pulley method) training (picture by B. Dudek)

Figure 4 Laying out the ground wire on the pulley blocks (left) and work place with puller and cable drum battery – works executed in Sweeden (picture by B.Dudek)

Cradle block (double pulley) stringing method

Pulleys (cradle blocks) are used among other things to keep controlled and safe distance (clearance) between ground wire and conductor. The motorized multi-span cradle block tug, radio-controlled, which slides over the ground wire to be replaced and pulls insulating rope, which is used to position several pulleys in 10 – 15 m distance from each other. On consecutive towers cradle block tug is passed over to the other side of a tower with high caution using special safety tether. Once the rope is extended on whole span or spans it is tensed. During tensing the rope, the pulleys turn by 180^{O} inverting the position both the rope and existing ground wire. This job task requires high level of skills and is a subject of personal training (see figure 3). Also other elements of the technology require mastering and may be trained abroad (works on the first on the world 400 kV power line in Sweden) as well as in Poland on the lines especially made available for this purpose by National Grid Operator.

Pulleys are used in places, as it has been described already, where power line is crossing other lines (usually lower voltages), various classes of roads as well as railway electric traction. Thanks to using the pulleys, lower tensile force need to be applied to the wires and rope, keeping the sags within desired clearance margin.

In some countries this technology is used as main method of replacing ground wire with OPGW on the whole tension section, however in other countries it is only used after it is required as a result of risk assessment performed to keep extreme high caution with respect to objects, which the power line is crossing. For pulling rope it is taken that nominal braking load is 10 times higher than the allowed tensile force, which is applied to the rope.

Alternative technology for pulleys method is to use special construction pulleys with two ropes. In this method pilot rope and spacer rope is mounted to the cradle block tug and extended on the whole length of tension section sliding over the existing ground wire. After the ropes are on place and pulleys are positioned in regular intervals the puller is stringing new OPGW wire using pilot rope. Once the OPGW is tensed the pulleys are turned by 180^{O}. Afterwards, existing ground wire is unclamped from the tower construction and connected to the pilot rope. Simultaneously OPGW wire is sagged and clamped to the tower. Last step is to remove the ropes and pulleys.

Pulleys are used for works on one span of the power transmission line, usually during replacement of existing OPGW, which is damaged. In this case motorized cradle block tug is also used to pull pilot and spacer (supporting) rope, but it may be smaller and lighter because there is no need to string long and as a consequence heavier ropes.

The replacement of damaged OPGW with new wire consist of the following stages given below:

1. Motorized cradle block tug sliding over the OPGW is pulling the pilot and spacer rope. Over the spacer rope pulleys are deployed at regular intervals.
2. Puller is stringing new OPGW wire with pilot rope. Tension on the OPGW wire is all the time kept by the tensioner and/or OPGW cable drum.
3. Pilot rope is tensioned, which causes turn of the pulleys by 180O and puts OPGW above the existing ground wire (in some cases the same result is made with tensioning of the OPGW wire). Afterwards the OPGW is sagged and clamped to the tower construction.
4. Damaged OPGW wire is unclamped from the tower and mounted to the braking machine (another function of motorized cradle block tug), which secures the wire, pulleys and ropes from excessive acceleration and at the same time keeping the clearance distance within desired margin. Damaged wire and ropes are removed and pull off to dedicated cable drums.

Described above methods for ground wire or damaged OPGW wire replacement with new OPGW are used in many countries all around the world.

Requirements for safety of installation

Live working technique is based on the multipurpose rule of proceeding in choosing the methods of risk reduction. First of all it shall be considered to eliminate electric shock hazard. Provided that this is not possible then the risk shall be limited to an acceptable minimum.

It should be accepted that, risk will be present during whole work process, therefore it shall be analyzed by efficient means at the same time increasing the safety with adequate protection equipment.

Earthing requirements

To perform safely installation of conventional ground wires or OPGW the following requirements shall be ensured: all equipment including tensioner and puller shall have galvanic connections (shall be bonded) and shall be earthed, wires shall be earthed using sliding devices, work place shall have earthing mesh (mat) for potential equalization as well as pulley blocks shall be earthed on the towers (Figure 5).

- Equipment earthing

  All devices, which are used for the installation shall have at least one earth attachment point, usually at some convenient point on the frame. To the frame of each device there should be an earth bar welded (by the manufacturer) for the purpose of earth terminal connection to the earth mesh and sliding earthing devices.

- Wires and pulley blocks earthing

  All ground wires should be earthed with sliding earthing device, which is installed directly on the wire just by the tensioner, in turn for earthing pulley blocks earthing terminals and earth wires are used (see Figure 5 for details)

a) b) c)

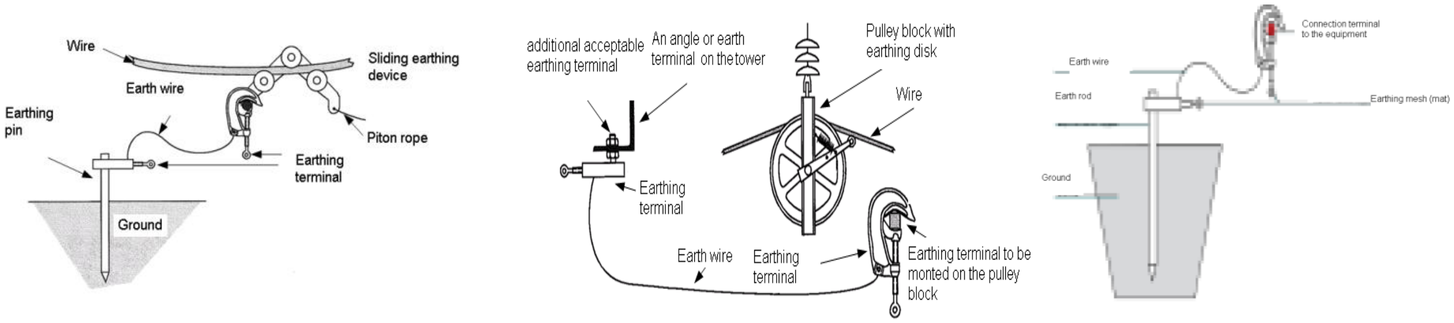

Figure 5 Work place earthing layouts

a) by sliding earthing device b) by pulley block with earthing disk c) by earthing mesh (mat)

- Earthing mesh (mat)

  Earthing mesh is made of bare wires connected to each other, which create metallic grid (mesh) and is earth grounded with earthing pins. Earthing mesh is laid under tensioner work place or puller work place (Figure 6)

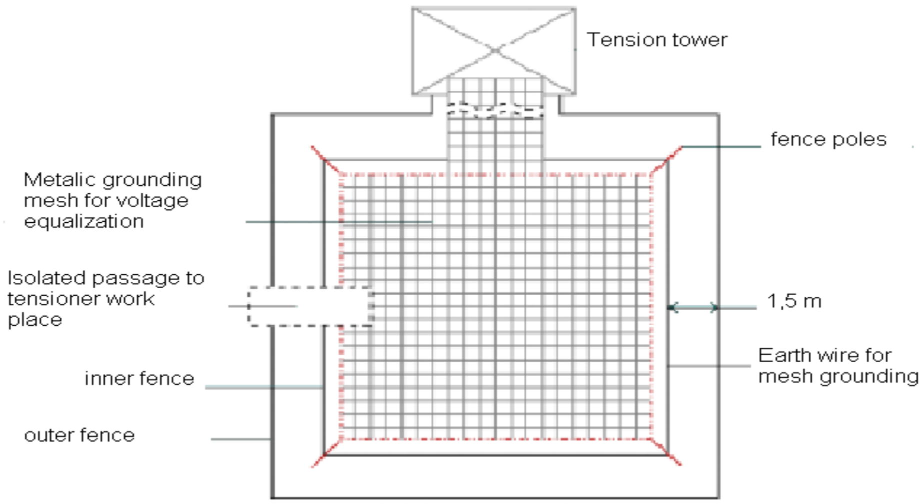

Figure 6 Earthing mesh design

Working zone requirements

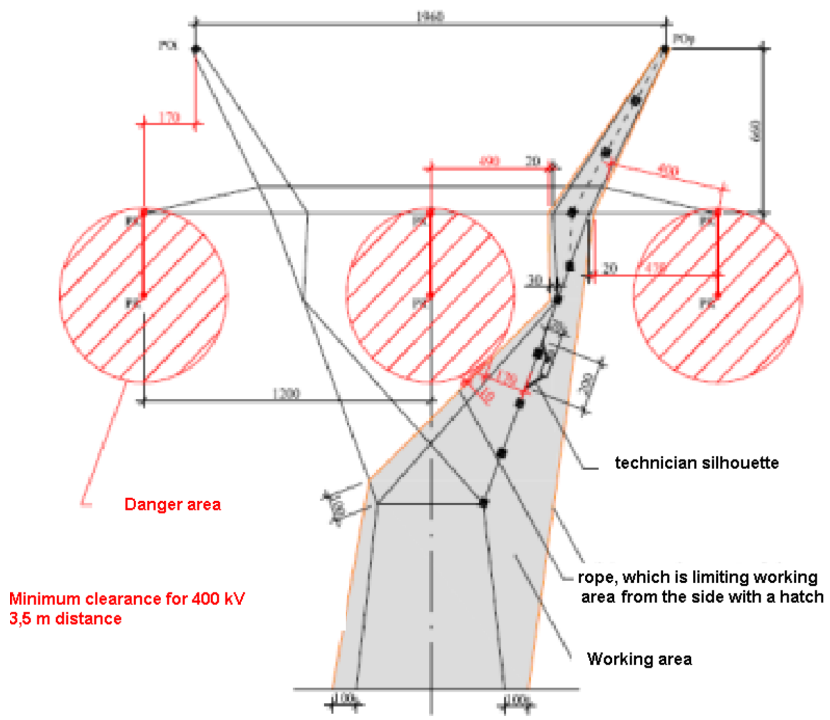

Figure 7 Working zone for 400 kV power transmission line

Working zone on the power transmission line shall be restricted only to the areas, which make possible reaching top of the tower, where ground wire will be replaced (figure 7). Marking out of the working area is for the purpose of bypassing danger zones with minimum clearance, to make sure nobody will reduce safety distance to the live parts by accident. Furthermore personal protection for the technicians shall be applied.

Requirements regarding avoiding the effects of electromagnetic field

Health and life protection of the staff during works related to the installation of OPGW wires on the power transmission lines is the most important matter of all regarding live line working. Technicians working on the live line shall be protected against effects of electromagnetic field, and danger of accidental voltage recovery one the line. This is ensured by installing adequate earthing system in working zone, utilization of correct work methods as well as personal protective equipment.

On the wires, which are being installed or devices used as well as on the ropes used for wire pulling electric charge may appear as a result of one or more factors as:

- Electromagnetic inductance from live conductors on the line, where works are being executed or adjacent lines,
- Electrostatic charge on wires or pilot rope as a result of atmospheric conditions or from live high voltage power transmission overhead lines AC and DC,
- Accidental contact of the wire, which is being installed to the live wires of the line,
- Faulty operations, thereby on the line voltage surges occur,
- Lightning strike to the installed wire or device as well as any other part of the installation arrangement.

Hazards resulting from lighting strike, OPGW wire contact with live conductor are dangerous temporarily and well known however hazards resulting from electromagnetic induction are permanent and occur continuously during live line work, their nature is not yet fully recognized.

Work team experiences working abroad on live overhead power transmission lines during installation or replacement of ground wire with OPGW or Optical fibres installation indicate, that technicians climbing at the tower (or being at the tower) wearing casual cloth were feeling uncomfortably at the live conductor height due to voltage induction.

To determine level of electromagnetic influence, the characteristic for the power transmission line electromagnetic field analysis has been performed ,which are build on the standard frame towers.

Induced voltages will be the highest as a result of short circuit currents, especially during asymmetric ground faults. Thus calculating induced voltages only the worst case has been considered, which is during asymmetric ground faults.

Values of induced voltages from the adjacent line currents are calculated for the following arrangement of wires.

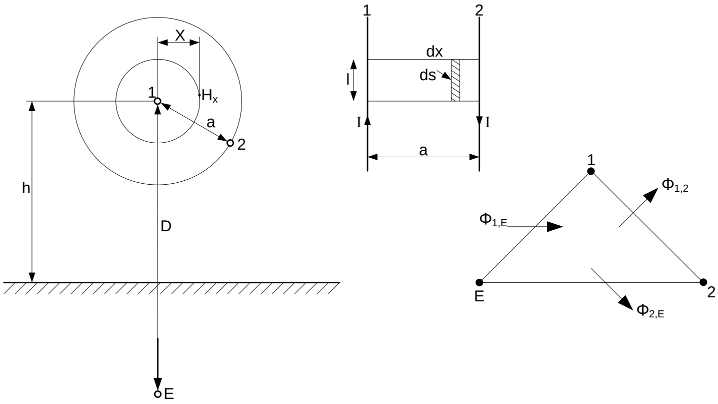

Figure 8 Wire arrangement taken for the induced voltages calculation

Where: 1 – live conductor, 2 – wire, where induced voltage occurs, a – distance between wires, l – parallel line segment length in [km], h – average wire attachment height, E – alternate conductor in ground, D – calculated length of the conductor 1 from the alternate conductor E in ground [m]

Value of the induced voltage U2 (for a12 up to 100 m) is determined on the basis of the following formula:

$$U_2 = (0{,}1446 \cdot \log \frac{D}{a_{12}}) \cdot l \cdot I \ \ [\mathrm{kV}] \qquad (1)$$

Where: I – current flowing in the conductor 1 in [kA], a12 – distance between conductors 1 and 2 (up to 100 m) in [m],

Value of the induced voltage U2 (for a12 over 100 m) is determined on the basis of the following formula:

$$U_2 = \frac{0{,}1446}{2} \cdot \log[(\frac{D}{a_{12}})^2 + 1] \cdot l \cdot I \ \ [\mathrm{kV}] \qquad (2)$$

Example calculations has been done for parallel 400 kV lines with distance from 100 m to 1000 m from each other, for chosen lengths of closeness: 1; 3 and 5 km. Each line angle different from parallel route is causing decrease of electromagnetic influence. Given in the table 1 below results from the calculations are for ground resistivity of 200 Ωm.

Table 1 Example calculation values of induced voltages of two parallel power transmission lines,

a_{12}	Induced voltage [kV]								
	Parallel Line length with I_{SC}=3 [kA]			Parallel Line length with I_{SC} =5 [kA]			Parallel Line length with I_{SC} = 10 [kA]		
	1 [km]	3 [km]	5 [km]	1 [km]	3 [km]	5 [km]	1 [km]	3[km]	5[km]
100	0.49	1.46	2.43	0.81	2.43	4.05	1.62	4.86	8.09
500	0.19	0.58	0.97	0.32	0.97	1.62	0.65	1.95	3.24
1000	0.09	0.28	0.47	0.16	0.47	0.79	0.31	0.94	1.57

Subdue of the voltages and current induction is possible using different types of earth grounding. Level of extension of the temporary earth grounding depends on the assessment of the electrical hazard. For installations of new OPGW wires on the remote areas from the live power lines and in when storm is unlikely to occur only minimal requirements needs to be applied for the earth grounding. This minimum means that all devices in working are of the puller and tensioner are galvanically connected and earth grounded. Moreover sliding earthing devices have to be applied on the pulling and tensioning devices. Workers on account of electric charge resulting from electromagnetic conjunction shall wear protective clothing, current conductive, where all parts are connected especially, including shoes.

Example of wire replacement on live 400 kV power transmission line

In May 2010 a project was executed regarding replacement of ground wires in tension section 147 – 154 on 400 kV live power transmission line Kozienice – Miłosna. In spans 147 – 148 and 148-149 double pulleys were used, on the other spans tension stringing method has been used. To keep safety distances (minimum required clearance) and appropriate stringing forces there were calculations performed and 150-151 span has been chosen to control sags using theodolite by geodesy team. Example abstract from the stringing chart is given in table 2. Full stringing chart is generated for range of temperatures from -25°C to 40°C.

Table 2 Calculated values of stringing forces during OPGW wire installation

Description	Calcualating stringing forces during installation					
	Minimal stringing force			Maximal stringing force		
	10 [°C]	15 [°C]	30 [°C]	10 [°C]	15 [°C]	30 [°C]
Sag [m]	14.0	14.1	14.7	11.2	11.4	12.0
Wire lentgth [m]	415.26	415.29	415.39	414.82	414.84	414.93
Horizontal tension [MPa]	66.24	65.41	63.07	82.23	80.79	76.82
Maximal tension [MPa]	66.85	66.02	63.71	82.72	81.29	77.35
Stringing force [kN]	5.602	5.533	5.339	6.932	6.812	6.481

Figure 9 Plan view of tension section 147-154 of the 400 kV Kozienice – Miłosna power transmission line

Plan view of the tension section of the Kozienice – Miłosna power transmission line , on which existing ground wire has been replaced is presented on Figure 9. In turn on figures 10 and 11, scheme of the wire replacement is presented as well as deployement of pulley blocks on towers type ON 120 Y52 series, which were limiting the tension section.

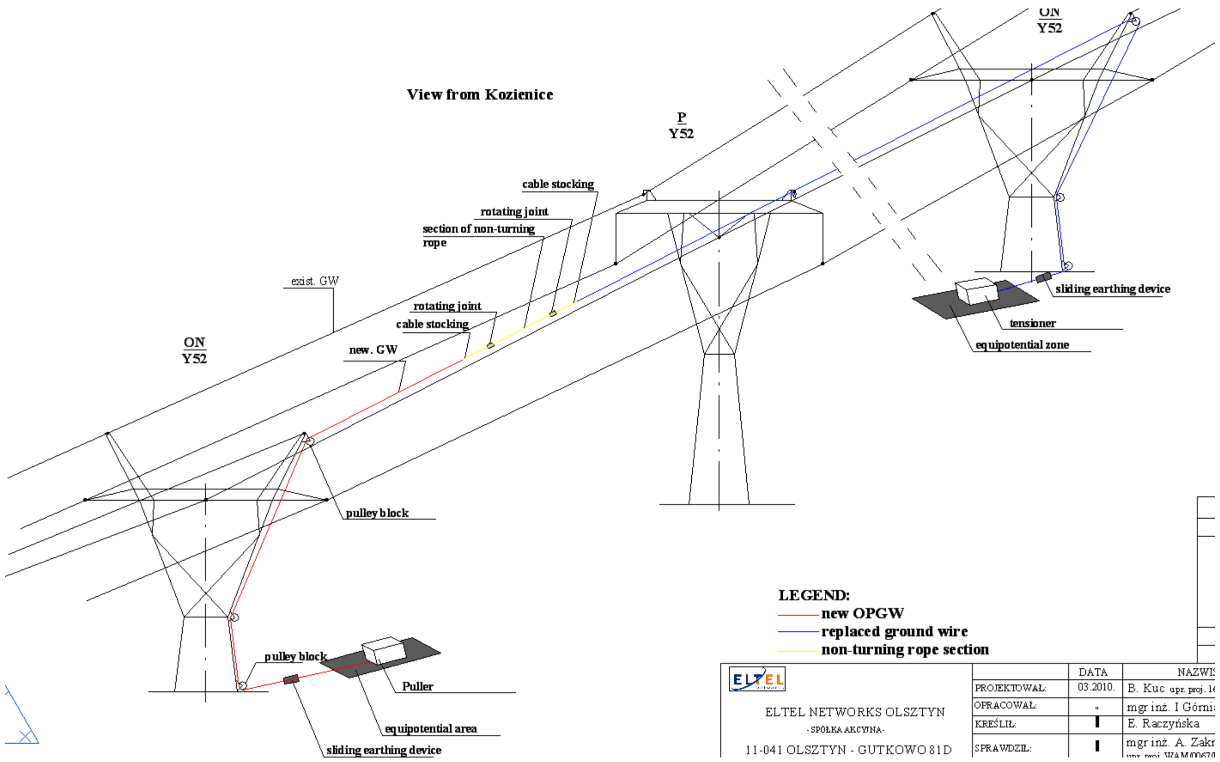

Figure 10 General layout of wire replacement on the 400 kV Power transmission line Kozienice - Miłosna

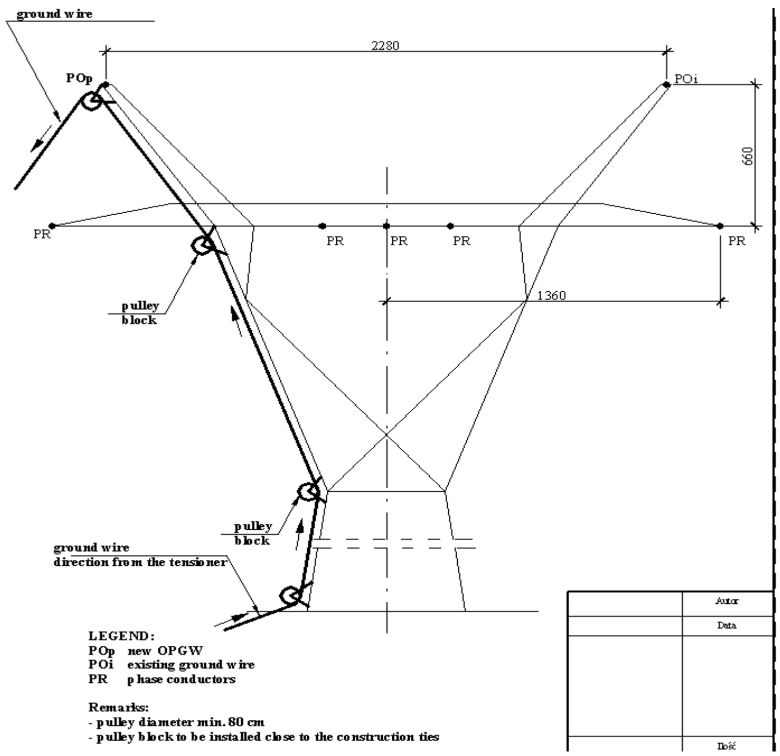

Figure 11 Installation of pulley blocks on the ON 120 type Y52 series tower executed on 400 kV power transmission line Kozienice - Miłosna

This technology was developed and executed by Eltel Networks Olsztyn S.A. during period from May till October 2010. Due to weather conditions, some problems during installation occurred, which was caused by weather anomalies especially during summer (high air temperatures - above $30^{O}C$)

Summary

Cost of the installation (labor) using live working methods as described in the article is comparable with cost of works on the power transmission line with planned outage. However benefits from performing these works without outage of the transmission line, continuity of electricity sales and as a rule not decreasing level of power grid security are compensating with surplus cost required for the technology described in the article. These technologies are also beneficial for contractors, who are able to plan in details all activities, which are independent of possibilities of canceling/shifting planned outage in cases of operators' needs. In an age of economy it may be counted for solutions, which benefit for all parties, thus requiring verification of heretofore costs parts of technical progress. This verification may be a result of market opening to special services, which allow for the companies to attain reimbursement of capital investment.

First applications of technologies of replacing conventional ground wire with OPGW in Poland on 400 kV live power transmission lines (Gdańsk Błonia – Grudziądz oraz Kozienice – Miłosna) has given positive outcome. Gained expertise may be used in other similar works on power transmission lines in Poland as well as other countries.

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