High Voltage Power Transmission Line in Undermined Areas

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Summary

The line structures situated in the undermined area are impacted and endangered by the underground mining. The present article focuses on impacts of mining on the high voltage transmission lines. Theoretical calculations are illustrated by a practical example for specific conditions including the evaluation of the behaviour of this line structure within the subsidence basin. We discuss the behaviour of the transmission towers, their movements, i.e. not only subsidence but also inclination, which result in stress or, on the contrary, in bending of the conductors and if the allowable stress of the conductors is surpassed, it could damage the conductors.

Keywords: words: subsidence, horizontal shift, inclination, high voltage transmission line, distance between conductor suspensions, bending of the conductor

Introduction

The impact of the underground mining on the surface manifests itself by the movement of the surface when individual points on the surface perform three-dimensional movement towards the centre of the extracted surface. Movements in the roof of a seam can be explained by the fact that after the extraction of a part of the deposit, an empty space is created which immediately or after a certain period of time, as a consequence of a concentrated stress in the surrounding rock, will fill again with bigger or smaller fragments of rock or an elastic convergence of the roof and the bedrock will occur. The three-dimensional movement is decomposed into a vertical movement referred to as subsidence and a horizontal component of the movement, referred to as shift. In consequence of a different subsidence of two points, the horizontal terrain slopes and a different shift of two points produces a compression or extension of the terrain between those two points. Different slope of the terrain causes its curvature.

If any transmission towers are located in the undermined area, it is obvious that the movement of the tower foundations connected with the terrain and accompanied with the inclination of towers will have an impact on the distance between the suspension structures of the conductors and subsequently also on the mechanical stress affecting the conductors.

2. Methodology of forecast calculation of impacts of the undermining on high voltage power transmission line

2.1. Change of distance between the transmission towers

It is necessary to divide any line structure, and so the high voltage power transmission line, into individual sections for the terminal points of which the subsidence and horizontal shift are calculated and from these values the deformation of individual sections is derived [1]:

1. The calculation of the deformation consists in determining the coordinates of X, Y and the height H of the foundations of high voltage transmission towers. The position and the height can be determined from the map documentation by interpolation.
2. For thus determined points we calculate the subsidence and horizontal shift produced by the extraction of planned working faces.
3. We determine the original horizontal distance of the section s_0 and the slope distance ℓ_0 according to the following formulas:

$$s_0^2 = \left(Y_{i+1} - Y_i\right)^2 + \left(X_{i+1} - X_i\right)^2 \qquad (1)$$

$$\ell_0^2 = s_0^2 + \left(H_{i+1} - H_i\right)^2 \qquad (2)$$

where X, Y are the coordinates and H is the height of the foundations of the transmission towers.

4. We subsequently calculate the section distance ℓ_s shortened or prolonged by the subsidence

$$\ell_s^2 = s_0^2 + (\Delta H + \Delta s)^2 \tag{3}$$

where $\Delta H = H_{i+1} - H_i$ is the height difference of the foundations of towers and $\Delta s = s_{i+1} - s_i$ is the difference of their subsidence.

5. It is necessary now to calculate the difference in the shift of tower foundations in the axis of the power transmission line v_0 in the direction σ_0 and perpendicularly to the axis of the power transmission line v_q by a recalculation from the general direction σ to the shift in the axis of the power transmission line

$$tg\sigma_0 = \frac{\Delta y}{\Delta x} \tag{4}$$

$$v_0 = v.\cos(\sigma_0 - \sigma) \tag{5}$$

$$v_q = v.\sin(\sigma_0 - \sigma) \tag{6}$$

6. We determine the angle γ between ℓ_0 and ℓ_s which is the angle by which the terrain changes its slope due to different subsidence

$$\sin\gamma = \frac{\Delta s}{\ell_s}\sin z \tag{7}$$

where z is the zenith distance of the original slope distance ℓ_0

7. The next step is to determine the new distance between the transmission towers ℓ_v according to the following formula:

$$\ell_v^2 = \ell_s^2 + \Delta v_0^2 + 2\ell_s \Delta v_0 \sin(z + \gamma) \tag{8}$$

where Δv_0 is the difference of shifts in the axis of the power transmission line.

8. Finally, the new distance ℓ_c between the foundations of the towers is calculated by the addition of the lateral shift Δv_q of the section

$$\ell_c^2 = \ell_v^2 + \Delta v_q^2 \tag{9}$$

2.2 Impact of the inclination of transmission towers on the distance between the conductor suspensions [2]

The inclination of a transmission tower depends on the position of its foundations in the subsidence basin. Contrary to the distance of the tower foundations, the original distance of the conductor suspensions is influenced by the value of Δh given by the uneven height of the suspensions so the original distance ℓ_{0z} of the conductors suspensions will be

$$\ell_{0z}^2 = s_0^2 + (\Delta H + \Delta h)^2 \tag{10}$$

The inclination of towers i has the direction σ_i similar to the horizontal shift of the foundations σ. The shift of a conductor suspension in the height h over the foundations will be

$$v_i = i.h \tag{11}$$

Similarly to the tower foundations, the shift of the suspensions is converted to the longitudinal and lateral shift of the axis of the power transmission line according to the formula

$$v_{0i} = v_i \cos(\sigma_0 - \sigma_i) \tag{12}$$

$$v_{qi} = v_i si(\sigma_0 - \sigma_i) \tag{13}$$

The new distance ℓ_s of the suspensions of the power transmission line can be calculated as follows:

$$\ell_s^2 = (\ell_v + \Delta v_{0i})^2 + (\Delta v_q + \Delta v_{qi})^2 \tag{14}$$

The difference between the original distance of the suspensions and the distance after the undermining will be:

$$\Delta\ell = \ell_s - \ell_{0z} \tag{15}$$

3. Mechanics of the exterior power transmission line

The exterior power transmission line is subject to atmospheric conditions that cannot be exactly determined. The atmospheric conditions include the temperature, which may vary from –30°C to +40°C. Also the effect of the wind as another factor of the impact on the exterior power transmission line is very changeable. Strong gusts are very dangerous as the conductors can be torn and transmission towers broken. In cases of big fields, even lower wind speed (6 m/s) has an impact. Standing waves form on the power transmission line and the conductors oscillate. This has a negative effect on clamps and ties where the conductors are bended. The power transmission line must be designed so that it remains intact in critical situations and the conductors are projected in order to resist the effect of the wind force, icing during winter time, oscillation of conductors and of the own gravitational force of the conductors.

The calculation of the mechanical stress on the exterior power transmission line is based on the assumption that if a conductor is suspended between two points, it sags into the curve of bending, which can be analytically expressed by means of a catenary or a parabola which is more suitable for the calculation and differ slightly from the catenary in the case of small and middle spans (up to 400 m). To determine the analytical expression of the curve of bending we suppose that the weight of the element of the conductor is stable and is defined by a homogenous weight distribution on the connecting line between the suspension points [3].

We can say that a conductor is stationary if the sum of the forces having effect on it is zero and if the sum of the moments of force about any point is zero as well [3].

The high voltage conductor is usually constituted by the AlFe type cable where the supporting element is the steel core and the current is conducted by the aluminium coating. The bending of the cable, with regard to its vibration, is determined so that it is as small as possible but in the same time that its strain isn't surpassed (85% of the specific strength of the conductor).

The intensity of acting forces is expressed as follows: the vertical force F_v is the weight of one half of the conductor and is defined by the relationship [6]

$$F_v = \gamma' . \frac{a}{2} \tag{16}$$

where γ' is the specific weight of the conductor in $N.mm^{-2}.m^{-1}$ and a is the span in meters.

The horizontal force F_h equals 85% of the allowable stress.

The maximal bending of the conductor is calculated according to the following relationship

$$f_m = \frac{a^2 \gamma . z}{8 . \sigma_H} \tag{17}$$

The following relationship applies on the length of the cables of the conductor [3]

$$d = a + \frac{8}{3} . \frac{f_m^2}{a} \tag{18}$$

The preceding mathematical relationships apply on suspensions in the same height. The vertical bending calculated for the slope distance of the suspensions must be reduced to the perpendicular of the connecting line between the suspensions. Having the maximal bending f_m for the horizontal distance calculated s_0 between the suspensions of the conductors, we can calculate the angle of the slope of suspensions

$$\gamma = arctg\left(\frac{\Delta H + \Delta h}{s_0}\right) \tag{19}$$

and the bending perpendicular to the connecting line between the suspensions

$$f_\gamma = f_m . \cos\gamma \tag{20}$$

The length of the conductor d_γ with uneven height of suspensions is

$$d_\gamma = \ell_0 \left[1 + \frac{8}{3} . \left(\frac{f_\gamma}{\ell_0}\right)^2\right] \tag{21}$$

We have thus calculated the basic parameters of the conductors of the high voltage power transmission line necessary for the calculation of its bending and strain before its undermining.

After the undermining occurs, the distances between conductor suspensions change according to the formula (14). As the length of the conductor hasn't changed, the increased distance causes an increase of stress in the cable of the conductor and

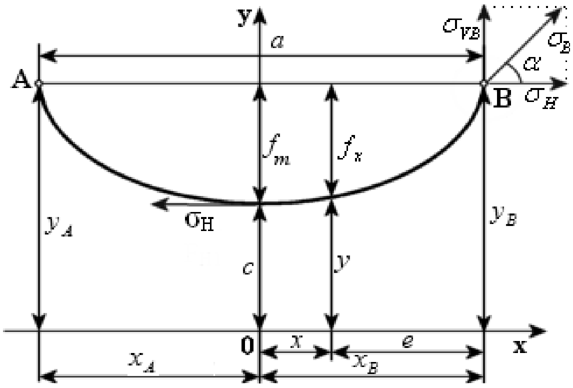

Fig. 1. Symmetrical suspension and the bending of the conductor [3]

Rys. 1. Symetryczne zawieszenie i ugięcie przewodu [3]

where:

σ is the stress in the conductor [MPa]

f_m is the maximal bending of the conductor [m]

a is the length of the span [m]

c is the parameter of the curve [m]

a decrease of its bending and vice versa. The new bending of the cable f_p is calculated as follows

$$f_p = \sqrt{\frac{3}{8}.\ell_s(d_\gamma - \ell_s)} \tag{22}$$

The new stress of the cable σ_p is calculated according to the following formula [6]

$$\sigma_P = \frac{\ell_s^2.\gamma.z}{8.f_P} \tag{23}$$

4. Example of the calculation for specific conditions

The high voltage power transmission line 220 kV is conducted on transmission towers 300 m distant one from each other in the height of 45 m above the surface. All transmission towers are anchor towers, the conductor suspensions are fixed. The conductors are comprised of 120 AlFe 6 type cables and a normalized stress of 96 MPa and allowable stress of 114,4 MPa apply on it [6].

The power transmission line is undermined by three flat working faces of the total surface area of 600 × 800 m, with effective thickness of 2 m on a caving with the extraction coefficient $a = 0{,}85$ from the depth of 900 m. The mean limit angle of extraction is 61° which corresponds to the radius of the full area of extraction of 499 m. Figure 2 depicts the power transmission line situated perpendicularly in the middle of the scheduled length of working faces. This facilitates the calculations as the lateral motion and the inclination are not relevant.

On the basis of the calculations by the Knothe's method, the presumable subsidence, shift and inclination of the transmission towers were determined as

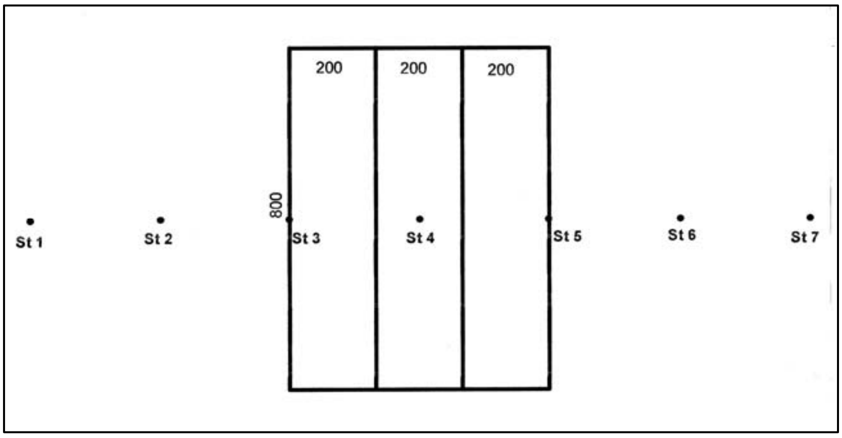

Fig. 2. Situation of working faces and extra high voltage transmission towers

Rys. 2. Rozmieszczenie ścian wydobywczych i wież linii wysokiego napięcia

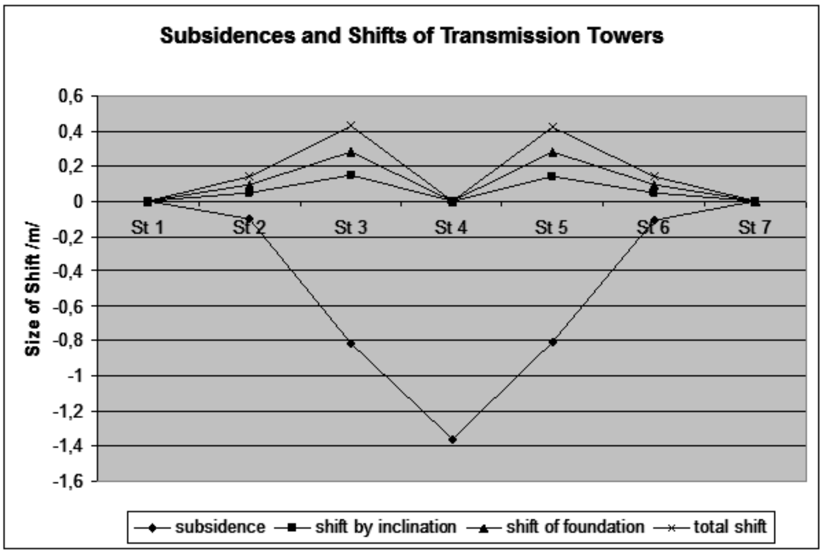

Fig. 3. Calculated shift and subsidence of the transmission towers

Rys. 3. Obliczone przesunięcie i osiadanie wież transmisyjnych depicted in diagram in Fig. 3. The Diagram depicts clearly that the shift of the conductor suspensions is far more impacted by the shift of the towers foundations than by their inclination. The previous practice did not take into account the shift of transmission towers.

Diagram in Fig. 4 shows that the most important prolongation of the distance between the suspensions occurred in the section 2–3 by 0.269 m and that the most important shortening between the suspensions occurred in the section 3–4 by –0,518 m. In general we can observe that over the extracted area the distances are shortened and outside the borders of the basin they are prolonged.

In consequence of the shortening of distances between conductor suspensions, the bending increases by up to 2.3 m to 14 m. The prolongation of distances, on the contrary, results in decreasing of the bending by 1.4 m to 10 m (see Fig. 5). Given the height of the suspension of 45 m, the different bending of the conductor is not substantial.

Diagram in Fig. 6 shows the normalized stress for the 120 AlFe 6 type cables which is the initial stress to determine the maximal bending of the cable. As a consequence of the undermining, the bending of the cable increases or decreases which manifests itself by decreased or increased stress of the cable that shouldn't surpass the allowable stress (113.4 MPa). Within the sections 2–3 (109.7 MPa) and 5–6 (109.0 MPa) the stress approximates the allowable stress and in the case of unfavourable circumstances (wind gusts, icing) the allowable stress can be surpassed and cables can be damaged. To avoid such situation, the suspensions are not fixed and 5 to 6 supporting towers (without fixed cable sus-

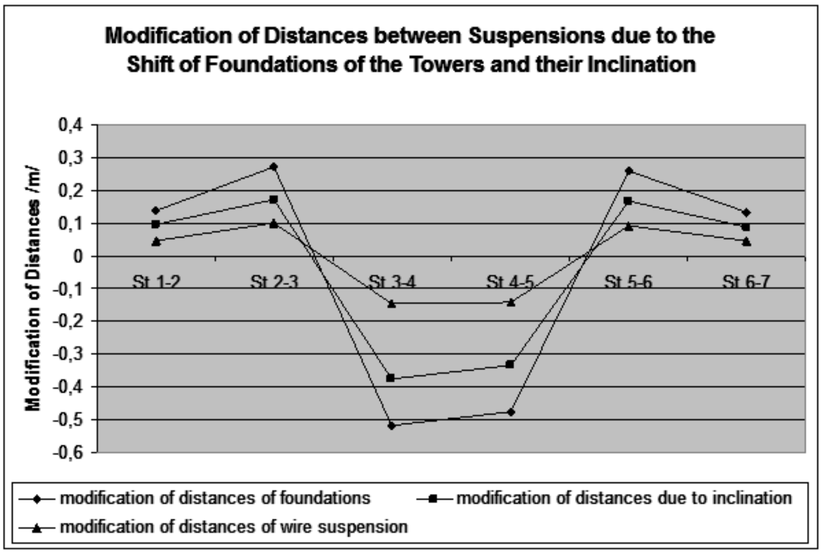

Fig. 4. Modification of distances between suspensions due to the shift of foundations of the towers and their inclination

Rys. 4. Zmiana odległości pomiędzy punktami zawieszenia z powodu przesunięcia fundamentów wież i ich nachylenia

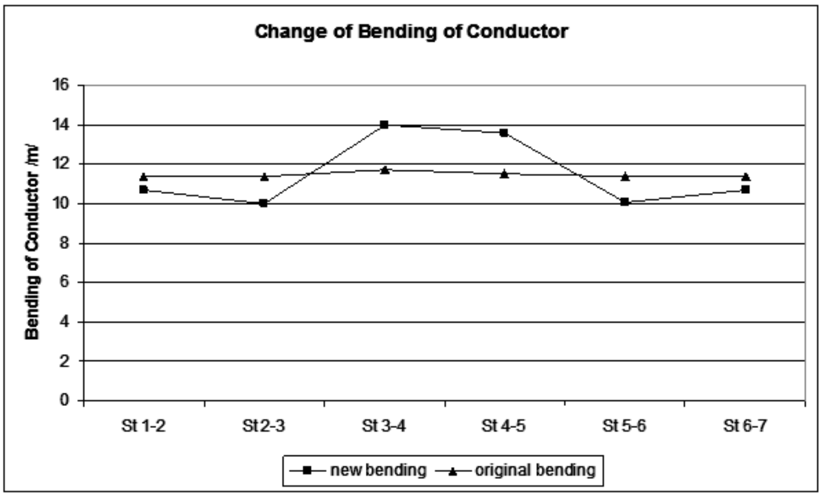

Fig. 5. Bending of the conductor between suspensions

Rys. 5. Ugięcie przewodów pomiędzy punktami zawieszenia

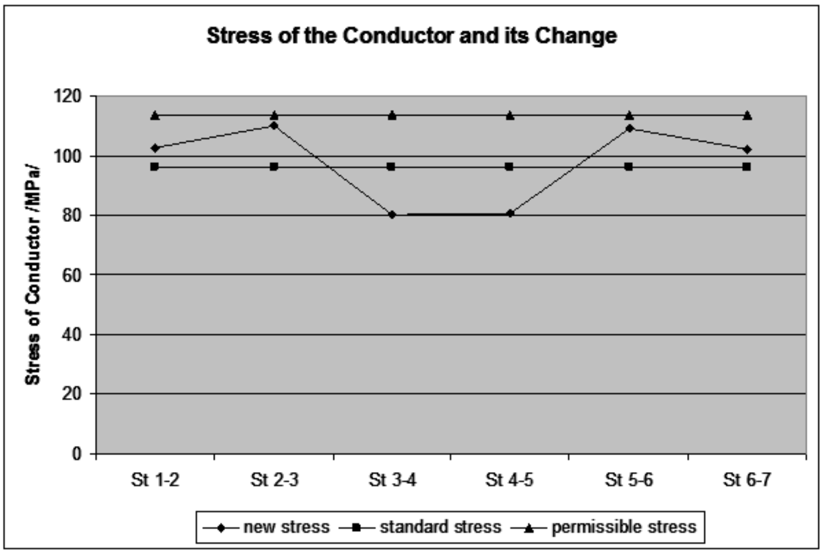

Fig. 6. Stress of the conductor and its change

Rys. 6. Ugięcie przewodu i jego zmiany

pensions) are usually inserted between anchor towers, which allows the compensation of the stress of the cable between the anchor towers. In our case if only towers no. 1 and 7 were anchor towers, the total stress could be expected to be the mean of calculated values, i.e. 97.35 MPa. Even if this stress is higher than the original one, it doesn't amount to the abovementioned values.

Conclusion

The article focuses on the necessity to deal not only with the impact of the inclination of transmission towers on the change of bending and stress of conductors, but also with the shift of the towers foundations which tilt as a consequence of the undermining. The power transmission lines are usually straight and supporting towers are inserted between anchor towers which compensates the different stress arising from the shortening or prolongation of distances between the beam structures. As for potential failures of the high voltage and extra high voltage due to the undermining, this calculation is necessary and it allows the dangerous sections of the power transmission line to be determined.

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Linie wysokiego napięcia na terenach górniczych

W projekcie linii energetycznych zlokalizowanych na terenach eksploatacji górniczej należy uwzględnić wpływ i zagrożenia wynikające z lokalizacji. Artykuł jest poświęcony wpływie górnictwa podziemnego na linie przesyłowe wysokiego napięcia. Przedstawiono obliczenia teoretyczne dla przypadku rzeczywistego dla szczególnych warunków, przedstawiono ocenę wpływu osiadania powierzchni na linię przesyłową. Omówiono zachowanie się wież transmisyjnych, ich przemieszczeń a także odkształcanie przewodów w wyniku szkód górniczych i odkształcania powierzchni.

Słowa kluczowe: osiadanie, przesunięcie poziome, nachylenie, linie przesyłowe wysokiego napięcia, odległość między punktami zawieszenia przewodów, ugięcie przewodu