DESTRUCTION OF TRANSMISSION TOWERS AND METHODS FOR INCREASING OF RELIABILITY OF EXISTING POWER LINES

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ABSTRACT

This paper deals with the examples of powerline steel towers'destruction and their analysis. It proposes the methods for increasing in reliability of existing lines by means of strengthening in steel structures and providing with a set of special reserve towers to reduce the restoration period for weak lines. An algorithm is given for probablistic design and estimation of tower element with criterium of buckling and desired level of reliability of line. That algorithm is effective for calculation of the desired additional strength of decisive steel elements of lattice towers.

KEYWORDS

Existing power line, tower, destruction, reliability, strenghthening, spesial reserve tower.

SOME EXAMPLES OF LINE DESTRUCTIONS

The nomerous information springs produces the inconsolable facts about increasing an intensity of breakages on the 110-500 KV line steel structures in the various world regions (Kiessling, 1985; Grass and Seppelt, 1989). They are often the result in heavy transmission towers failures which lead to enormous economic and social damage. They occured generally becouse of inconsiderate or abnormally high meteorological loadings with changing climate on the Earth for the last time (hurricane wind, colossal icing in combination with strong wind and etc.). For example, the series of wind-icing failures of overhead line towers on December 1990 in Midlands of Great Britain was happened suddenly and proved to be very heavy.

Moreover, there are powerline breakages in the severe climatic conditions with strong winter wind and temperature. For example, in January 15, 1988, brittle fracture of pressed-steel guy clevis at one tower appeared to have caused the 500-KV line failure when 17 towers were knocked out by 38-m/s storm winds in California (Reason, 1988).

In the 1980-90s, at the Western Siberia in Russia the winter storm winds struck a good many high voltage electric transmission towers. For instance, in autumn-winter season 1986-1987 years, 26 defective erected steel towers were dustructed with storm winds in Tyumen's region. It's very likely that a 220-kV tower destruction happened due to buckling of legs with non-tighted bolts of lattice knots and legs (Fig. 1).

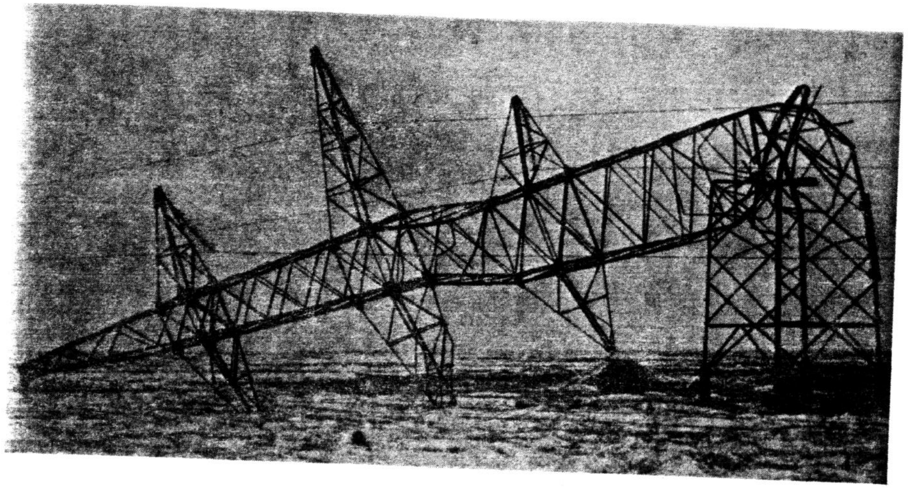

Fig. 1. Destructed polar tower in October 22, 1987.

Next, in February 7, 1990 two 110-kV towers, produced from frail steel, were broken with overstrain of compressive legs under 30-m/s strong winds and severe frost near the Polar town Vorkuta (Komi Republic, Russia).

On February 8-10, 1991, more than one hundred of power line poles of the various types were destructed with 29-m/s winds in the same locality. In February 10, the heavy breakdown of transmission stell rope tower occured on the polar line of the 220-kV (Fig. 2). Apparently that breakage was the result of brittle failure in a bolt knot of traverse eliments near column. It's very likely that brittle failure happened becouse of weaken rope guyes with frostly expansion in ground under insufficiently heaped anchor foundations. A few of forsed outages happened on February 9, that were indicated reeling tower. Becides that tower fell down perpendicularly to wind direction with unbroken guyes.

The above-mentioned examples have shown that increased wind loads and buckling of compressive elements with low quality of manufacture and erection on difficult routes are the main causes of destructions on line towers.

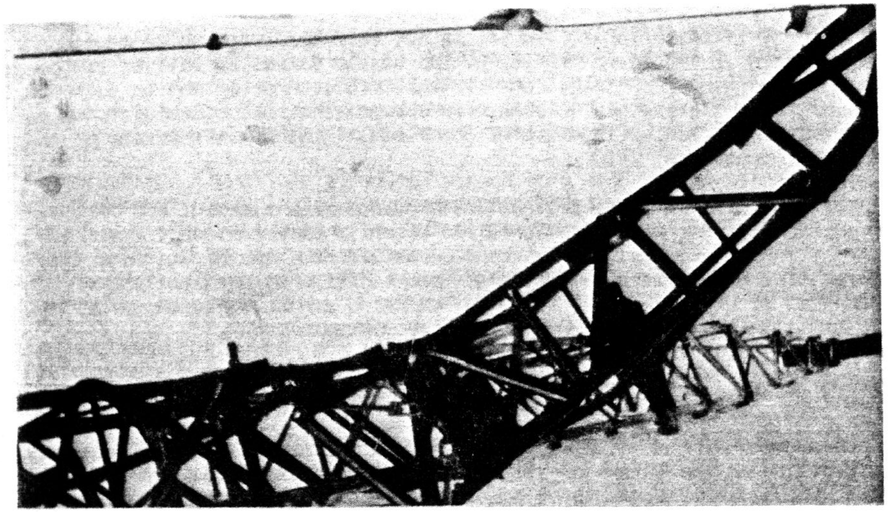

Fig. 2. Fallen guyes-tower (view of top and traverse)

BASIC APPROACH

Although transmission lines are built using a vary large number of components, they should be designed as a complete system becouse the failure of any component usually leads to a loss of power transmitting capability (Channum and Orawski, 1986). Thus, the one-circuit owerhead line can be presented as system of n sequentially united components (intermediate towers) or N elements of towers according to reliability theory.

The tower breakdowns on specific power line or system form a certain flow w or intensity v of adverse weather failures. It was recognized that failures flow w follow an exponent law, criterion or reliability condition is:

$$P(t=T) = \exp(-w\,T) \geqslant P(L) \qquad (1)$$

where $P(L)$ is a desired level of reliability for system during a certain time equaled to operation life of line T. That reliability is a probability that a system performs a given task under a set of conditions during a certain time t. Probability of function of system under wind loads is determined for i -th component with minimum probability value, i. e.

$$P(L) = \min P(i) \;; \qquad i = 1, \dots, n, \dots, N \qquad (2)$$

or for latice towers $P(L)$ is equal to $P(s)$ as minimum value of reliability for decisive element. It was calculated (Orawski, 1991), that $P(s) = 0.99$, when operation life of line (T = 50 years) equal to return period of design wind loads.

Consequently, if criterion (1) is not fulfilled with above-mentioned limitations, there is appears a problem of increasing in reliability of specific existing power line. Traditionally, that problem can be solved with strenghthening of structural elements or expensive construction a second power line and including into operation of additional springs of energy-supply with consumers.

It is more economical if powerlines are provided with a set of the special reserve towers (SRT) which are installed urgently on weak line instead of wrecked permanent towers. The SRT considerably reduce the duration of line restoration and consumers damage these lead to raise of availability or reliability of existing power line. The examples are known to be effective SRT's utilisations in Italy, Germany, USA and Russia.

PROBABLISTIC RE-COMPUTATION OF TOWER ELEMENTS

To make a conclusion about a possibility of normal exploitation of weak specific line in the future or its strenghthening it is necessary to re-compute the decisive elements of some lattice towers with the largest wind-weight spans. The statistical analysis for monthly maximums of wind speeds showed that its are near to normal distribution in some regions. For example, the histogram and density function for monthly maximums of wind speeds for polar meteorological station in Vorkuta during 45 years observations are given in Fig. 3. The statistical estimate of these approximation has been made satisfactorialy with chi-square criterion.

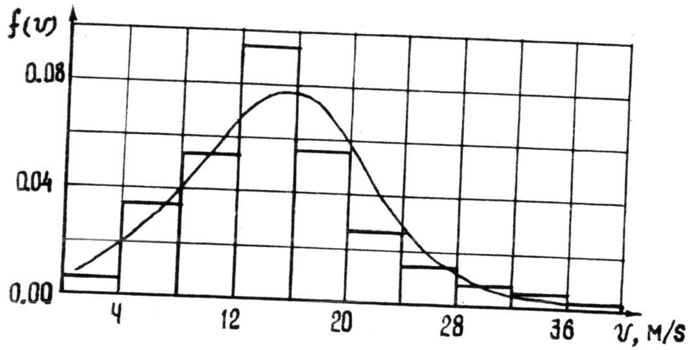

Fig. 3. Histogram and density function for monthly maximums of wind

The stability condition for decisive steel element of lattice tower is:

$$\sigma = Q/Af \leq R \quad (3)$$

where σ : compressive strain
Q : internal axial force
f : coefficient of longitudinal crook
A : sought cross-section area of decisive element
R : strength characteristic of steel

Consequently, force Q, strength R and area A or dimensions of elements are random variables with normal distribution functions. Let's introduce a random variable $x = R - \sigma$. The probability for non-destruction of decisive tower element with stability condition is:

$$P(S) = P(x > 0) \quad (4)$$

As admitted, R and σ are independent and non-negative probablity quantities which have densities of distribution $r(R)$ and $q(\sigma)$. The distribution's density of probability for quantity x can be written as (Kapur and Lamberson, 1977):

$$f(x) = \int_0 r(x+\sigma)\, q(\sigma)\, d\sigma \quad (5)$$

or

$$f(x) = \begin{cases} \int_0^{+\infty} r(x+\sigma)\, q(\sigma)\, d\sigma & \text{for } x > 0 \quad (6) \\ \int_{-x}^{+\infty} r(x+\sigma)\, q(\sigma)\, d\sigma & \text{for } x < 0 \text{ or } x = 0 \quad (7) \end{cases}$$

or for (4) $$P(S) = \int_0^{+\infty} f(x)\, dx = \int_0^{+\infty}\int_0^{+\infty} r(x+\sigma)\, q(\sigma)\, dx \quad (8)$$

If Q and R have a normal distribution then the expression (8) can be as:

$$P(S) = \Phi[(\bar{R} - \bar{Q})/(S_R^2 + S_Q^2)^{1/2}] \quad (9)$$

where $\Phi(Z)$: integral of probability or

$$\Phi(Z) = (1/\sqrt{2\pi}) \int_{-\infty}^{Z} \exp(-t^2/2)\, dt \quad (10)$$

where $$Z = (\bar{R} - \bar{Q})/(S_R^2 + S_Q^2)^{1/2} \quad (11)$$

Z : standart of normal probability value
$\bar{R}$: mean firmly
$\bar{Q}$: mean force
$\bar{S}_R$: mean deviation firmly
$\bar{S}_Q$: mean deviation force

The calculation of geometrical dimensions for pipe cross-section or external diameter D and thickness t it is necessary that criterion of indestruction probability P(S) takes place. Let's introduce the coefficient $C = (D - t)/D$. Thus, compression strain is:

$$\sigma = 4Q/D^2(1 - C^2)f \quad (12)$$

The force Q and diameter D are the random values with certein numerical parameters $\bar{Q}$, S_Q and $\bar{D}$, S_D. If permit that diameter $\bar{D}$ is equal to some part a, then $S_D = \bar{D}(a/3)$.

The linear part of Teylor's row is used for approximate definition of mean $\bar{\sigma}$ and variance S_{σ}^2, they are determined as follow:

$$\bar{\sigma} = 4\bar{Q}/(1 - C^2)\bar{D}^2 f \qquad (13)$$

$$S_{\sigma}^2 = [d\sigma/dQ]^2 S_Q^2 + [d\sigma/dD]^2 S_D^2 \qquad (14)$$

Thus,

$$Z = \frac{(1 - C)\bar{R}\bar{D}^2 f - 4\bar{Q}}{\sqrt{[\pi(1 - C^2)S_R f]^2 \bar{D}^4 + [8\bar{Q}(a/3)]^2 + (4S_Q)^2}} \qquad (15)$$

The decisive equation (15) for mean $\bar{D}$ can be written as:

$$b_1\bar{D}^4 - b_2\bar{D}^2 + b_3 = 0 \qquad (16)$$

where

$$b_1 = [\pi(1 - C^2)f]^2[\bar{R} - (ZS_R)^2] \qquad (17)$$

$$b_2 = 8\pi(1 - C^2)\bar{Q}\bar{R}f \qquad (18)$$

$$b_3 = 16\bar{Q}^2 - Z^2\{[8\bar{Q}(a/3)]^2 + (4S_Q)^2\} \qquad (19)$$

The equation (16) allow to calculate a mean $\bar{D}$ from desired value P(s) with corresponding quantity Z, which is choosen from the normal distribution standart table. The calculation of mean $\bar{D}$ is accomplished in the following order. At first, numerical value f is setted and flexibility λ of decisive compressive element is calculated according to Standart (SNIP 2-23-81, 1991). Then an intermediate mean $\bar{D}$ is found from equation (16) and next more exact value f is determined with iteration's method. That flexibility is written as: $\lambda = l/i$, where l and i are accordingly the considerated length and radius of inertia for pipe element cross-section.

For example, calculation of mean $\bar{D}$ is carry out with next initial data: P(s) = 0.95 (Z = 1.94), $\bar{Q}$ = 0.02 MN, S_Q = 0.002 MN, a = 0.021, C = 0.8, $\bar{R}$ = 200 MPa, S_R = 20 MPa, mean l = 2 m. As the result of it is given f = 0.325 and equation (16) is written as: $5257\bar{D}^4 - 11.8\bar{D}^2 - 0.00623 = 0$.

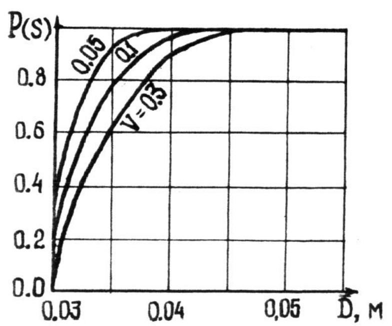

Fig. 4. Dependences of $\bar{D}$ - P(s) for different coefficients V

The solution of latter equation gives the maximum real root as: $\bar{D}_1$ = 0.037 m. The results of calculation are diven in Fig. 4. They confirm about strong influence of numerical value P(s) and coefficient of variation V for random variables Q, R, D (V=Const) on mean $\bar{D}$.

It is necessary to compare the mean $\bar{D}$ with real diameter of decisive pipe element of existing power lines as to to make the conclusions about desired additional strenth of steel element and methods of it strengthening.

APPLICATION OF SPESIAL RESERVE TOWERS

A method for determination the quantity of spesial reserve towers (SRT) with desired lewel of reliability for existing power lines has been proposed. The one-circuit line as system of sequently connected components is given with reliability theory. These components are the intermediate destroing towers which are substituted immediately with sliding components of emergency stock or SRT by means of helicopters. In E&PCo "Komienergo" were designed and made the SRT for 35-500 kV powerlines of two basic types such as tower SRT1 for permanent establishment on line instead of wrecked tower and tower SRT2 for repeated installations during the restoration periods of damaged tower.

As discussed earlier, power line may be presented as reserved system which includes the n working and m reserve equivalent components and submitted to exponent law (Gnedenko and etc., 1966). For example, the expression for probability and availability of functioning for powerline reserved with SRT1 and SRT2 can be accordingly written as:

$$P(t) = [\exp(-nvt)]\sum_{K=0}^{m}(nvt)^k/K! \qquad (20)$$

$$K = \sum_{K=0}^{m}(nv/g)^k \Big/ [\sum_{K=0}^{m}(nv/g)^k + n^m\sum_{K=m+1}^{m+n}(v/g)^k \prod_{j=1}^{K-m}(n-j)] \qquad (21)$$

where v : intensity of permanent tower destruction
g : intensity of tower restoration
K : coefficient of availability for reserved system with restored working components and reserved by means of SRT2.

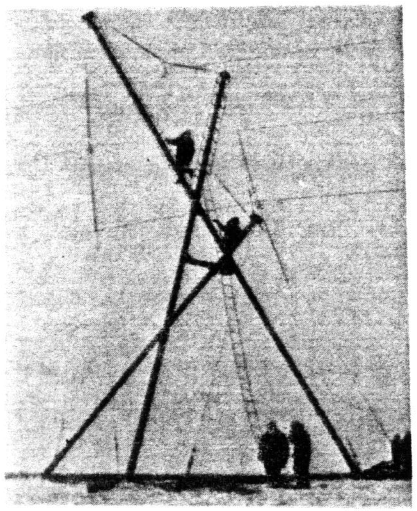

Fig. 5. Installation of SRT2-220

It was calculated that quantity of SRT1 is approximately equal to 1 % at the total quantity of towers or one-two towers SRT2 on 100 km power line (Senkin, 1991). Consequently, the application of SRT'towers is very effective for restoration of destroyed weak lines. Our north SRT2 has a wide-base X-formed steel structure with synthetic insulators and three own surface light foundations. For example, February 13, 1991 it was used to restore 220-kV line near Polar town Vorkuta. The crane-helicopter transported a ready steel-pipe SRT2-220 (weight - 30 kH) at a distance of 400 km and put up it near destroyed line for 4.4 hours. Then SRT was transfered to under conductors with tractor (Fig. 5). On April 6, SRT2 was replaced with permanent tower. Now a few of SRT1-2 is successfully using on the north powerlines in Siberia and Republic of Komi.

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