Algorithem and Programme for Computation of Forces Acting on Line Supports

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Abstract

The correct design and selection of line supports is of great importance for successful operation and safety of transmission lines. For this purpose, various forces acting on the line supports must be estimated for normal and abnormal conditions of operation. The author develops algorithm and programme for optimal calculation of these forces, which the line supports should withstand.

The main programme MDFLS and fourteen subroutines are constructed for calculation the forces acting on the line supports. The subroutines (FSUS, FDES, and FCSTA) are for determining the forces from line conductors and (FGWSU, FSWDE, FSWSA) from ground wires at suspension, dead end and strain/angle line supports respectively. The other eight are subsidiary subroutines. The parameters of the conductors (homogenous or non-homogenous) are found by DPMPN and DPMPH. The physical-mechanical properties of the conductor are calculated using PMPL. The specific loadings are determined by RLOLC. The sag-tension calculations are prepared by subroutines CSCT, CSOP and SEQS. Subroutine FSPCB is for calculation of forces due to broken conductor at suspension support in the section. The elaborated programmes are written in FORTRAN 90 and adopted for personal computer.

Keywords: Line Support, Operating Condition, Forces, Tension, Span, Sag.

1. INTRODUCTION

This paper deals with, computation forces acting on line supports, a part of future proposed compound package of programmes related to mechanical design of transmission lines. Line supports of overhead lines ensure the necessary clearances.They should be cheap and stable to loadings, caused from atmospheric conditions and from operating conditions of the phase conductors and ground wires. [1, 9]

The phase conductors and ground wires are unequal loaded when in one or several spans from the section the specific loads are less or greater from these in the remaining spans. The reason of unequaled loading of the conductors is their ice covered. Usually at ice-covered conductors are covered uniformly with ice, but their release from ice may not occur simultaneously for all conductors and ground wires in all spans of the section. The conductor may be released from ice in one or several spans, while in other spans remains ice covered.

The unequaled loading of the conductors' causes: Approach of the conductors situated one above other phases. Approach of the phase conductors near ground wires; release of a conductor from skip terminals at large deflection of insulator strings by axis of electrical line; approach of a conductor near the cross arm of a support at deflection of insulator string.[3,4]

At broken off conductor operating conditions of electrical line are sharply varied. In normal operating condition suspension and strain supports are loaded with forces from the weight of a conductor and from wind pressure in the direction of electrical line , forces are approximately equal to zero. At broken off conductor appreciable forces are raised, which loaded the line supports. These forces are the biggest for the supports, which confined the span with broken off conductor.

If the conductor is broken off in one span of the section, the insulator strings are deflected and the supports are bended to direction of the spans, at which the entire conductor is preserved. By moving away from the location of the damage, the quantity of the support deformation and the deflection of the insulator strings are reduced. The forces in the conductor at abnormal operating condition are considerably less from its previous normal operating condition; the damages of a conductor are so high. [1, 5]

The overhead electrical lines are computed for abnormal operating condition with broken off conductor due to the following reason: In order to determine the forces, with which the conductors loaded the supports in abnormal operating condition; to determine the sag of a conductor in spans, in which the conductor is healthy. This sag is required, in order to calculate the distances between the conductors and the equipments located under them. [5, 6]

2. LINE CONDUCTOR INDEXES [2, 7]

The physical-mechanical properties of the line conductor are determined. These are: cross-sectional area, weight of the conductor, modulus of elasticity, temperature coefficient of linear expansion, permissible tensile stress, the stress at minimum temperature and the stress at maximum loading. The forces, which are loading the conductors of an overhead line are, their weight, wind pressure, weight of ice and combinations between these forces. Depending up on the given value of operating voltage of the line, the standard clearances are selected and the specific loadings (G_1-G_7) are calculated.

Critical span and temperature are calculated for finding operating condition for maximum stress in the conductor and maximum sag. The operating condition, at which maximum tension occurs in the conductor, is determined by a comparison of the actual span (given) with critical span. When actual span (l_a) is greater than or equal to critical span (l_{cr}), maximum tension in the conductor occurs at the operating condition of maximum loading and at actual span less than critical span, maximum tension in the conductor occurs at the operating condition of minimum temperature. With criteria, critical temperature (t_{cr}), operating condition is determined at which maximum sag occurs in the conductor in the span. When critical temperature is less than maximum temperature (t_{max}), maximum sag occurs at maximum temperature and at critical, temperature greater than or equal to maximum temperature, maximum sag occurs at ice covered conductor load (G_3) and air temperature-5° C.

3. MAXIMUM LOADING AND TENSION AT ABNORMAL CONDITIONS [1, 5]

At normal operating conditions, suspension and tension supports are loaded with the conductor weight and wind pressure while tension in the direction of electrical line are almost equal and their resultant is zero. When one of the conductors is broken off, the operating conditions of the electrical line will vary sharply and abnormal tension in the direction of the electrical line will load the supports and these tensile forces will gradually increase towards the nearest support to the damaged span, therefore, insulators will be deflected and supports will be bended to the direction of span at which whole conductors are preserved. The deformation of supports is gradually reduces towards the farest support from the location of broken off conductor.

Forces at abnormal condition must be calculated in order to determine loadings on the line supports, when the conductors are broken off. However the new sag must be calculated to determine the clearances between conductors and equipments located under the electrical line. Calculation of abnormal forces can be done in analytical manner by using Shanfer Pharmakovski method [1, 2]. The magnitude of the influenced force (T_{ab}) is calculated depending on critical span.

$$\text{At } l_a \geq l_{cr} \qquad T_{ab}=\sigma_{G3}\, S \tag{3.1}$$

$$\text{At } l_a < l_{cr} \quad T_{ab} = \sigma_{tmin} S \tag{3.2}$$

Where

σ_{tmin} , σ_{G3} - permissible tension in the conductor at minimum temperature and load G_3 (loading due to conductor weight when covered with ice).

S - The cross-sectional area of the conductor.

4. OPERATING CONDITIONS OF OVERHEAD LINES [5, 8]

The line supports are determined in normal and abnormal operating conditions. Normal operating condition is that at which phase and ground wire conductors in all spans of the section are healthy and parameters of an overhead electrical line are within permissible limits. All types of supports are determined for forces conditioned by the following two normal operating conditions:

1. Normal operating condition I, which is described with: phase and ground wire conductors with no ice; maximum wind pressure (perpendicular to the axis of the electrical line); air temperature 15º C.
2. Normal operating condition II, which is described with: ice covered phase and ground wire conductors; 25% of maximum wind pressure; air temperature-5ºC. In an abnormal operating condition such as broken off phase conductor or ground wire, wind pressure is assumed to be zero. The location and number of broken off conductors is standardized and depending upon the type of line supports [3,4]
3. Abnormal operating condition, broken off phase conductors provoked maximum bend moment in the elements of the line support.
4. Abnormal operating condition, broken off phase conductors provoked maximum torsion moment in the line support.
5. Abnormal operating condition with broken off ground wires and healthy phase conductors.

In the normal operating condition the following forces act on the suspension line support; vertical-from the weight of the conductors ground wires, insulators, cross arms and support itself; horizontal, perpendicular to the axis of electrical line from influence of wind; horizontal coincided with axis of electrical line-from forces of straining conductors from the two sides of suspension support; in normal operating condition this forces is equal to zero, since the conductors are pulled out for the entire section.

In the abnormal operating condition the following forces act on the suspension line support ; vertical-from the weight of the equipments of electrical line ; horizontal, coincided with axis of electrical line-caused from unbalanced forces in the conductors of individual spans ; suspension insulators with pin type insulators are not determined in abnormal condition, but they should stand loadings by axis of electrical line up to 150 Newton (at this force broken off the dressing is occurred; breakdown the insulator or hook). Horizontal, perpendicular to axis of electrical line force does not exist, because the velocity of the wind at abnormal condition is assumed to be equal zero.

The forces, which act strain supports in normal condition, are equal in magnitude and direction with these, which act on suspension supports. For abnormal condition more heavy computational conditions for strain supports-it is assumed a greater number of broken off conductors. Strain supports are calculated also in stringing condition with forces at side strained conductors.

In the normal condition the following forces act on the conductors, insulators, cross arms, support and others; horizontal, by axis y-from the strain force of conductors 2T sin ($\chi/2$) is assumed that in this direction the wind acts with maximum force on the conductors and the elements of the support; horizontal, by axis X-in normal condition this force does not act.

In the abnormal condition the following forces act on angle support: vertical, by axis Z-from weights of elements of electrical line ; horizontal, by axis X-from the component of the straining force of healthy conductors-$F_x=T_{ab}\cos(\chi/2)$; horizontal and coincided with axis Y-from the component of straining forces of healthy conductors $F_y=T_{ab}\sin(\chi/2)$.

On dead end supports more high forces act on from straining of the conductors and ground wires. In the normal operating condition vertical forces act on them from weights of conductor elements. Coincided with axis of electrical line, straining forces of conductors and ground wires act on them. The straining of the conductors from the side of distribution outfit is small and its opposed force is neglected. Perpendicular to the electrical line it is assumed that, forces are acted from wind pressure on the conductors and the elements of support. Forces, which loaded support in abnormal condition, are less from forces acting at normal condition. In some cases enclosed points of these forces are such that the support subjected to high torsion moments, which should be taken into consideration during its design.

5. FORCES ACTING ON LINE SUPPORTS [3, 4]

The forces, with which the conductors loaded the line supports of overhead transmission line, are computed at construction of new supports or for check of the loading on the existing support. The forces, which loaded a support are determined by their components along the axis of the three coordinate system X,Y and Z, where-axis X is along the direction of electrical line ; axis Y is perpendicular to the direction of the electrical line, and axis Z is along the axis of the support in the downward direction.

The forces, with which the conductors act on the specified support (say A) at flat terrain, are the following [5]:

$$F_1 \equiv \left| \begin{array}{l} F_{1X} = T_o' = \sigma_o' S \\ F_{1Y} = \dfrac{P_{1Y}}{2} \\ F_{1Z} = \dfrac{P_{1Z}}{2} \end{array} \right. \tag{5.1}$$

$$F_2 \equiv \left| \begin{array}{l} F_{2X} = -T_o'' = -\sigma_o'' S \\ F_{2Y} = \dfrac{P_{2Y}}{2} \\ F_{2Z} = \dfrac{P_{2Z}}{2} \end{array} \right. \tag{5.2}$$

$$F = F_1 + F_2 = \left| \begin{array}{l} F_X = F_{1X} + F_{2X} = (\sigma_o' - \sigma_o'')S \\ F_Y = F_{1Y} + F_{2Y} \\ F_Z = F_{1Z} + F_{2Z} \end{array} \right. \tag{5.3}$$

Where

T_o and T_o are the strain forces in the conductor in the spans (adjacent to the specified support) number 1 and number 2 respectively ; P_{1y} =GSl_1 and P_{2y} =GSl_2 -the forces from conductors at influence of wind on no-ice covered ($G=G_4$) or ice covered conductors ($G=G_5$) for spans number 1 and number 2 respectively; P_{1z}=GSl_1 and P_{2z}=GSl_2 -force from the weight of not iced ($G=G_1$) or ice covered conductors ($G=G_3$)for spans number 1 and number 2 respectively.

The forces from the weight and the wind pressure are distributed equally between the two supports, which are restricted the span. Therefore the specified support (say A) is loaded with half of forces from spans number 1 and number 2. The reactions of the forces in the attachment points of the conductor at the support (say A) are equal and opposite acting forces.

At normal operating condition of electrical line with suspension insulators horizontal component of tensile stress in the conductors is same for all spans of section. Therefore F_x=0 At conductors with pin type insulators in normal operating condition horizontal component of the tensile stress in conductor for the spans of the section is different, but the differences are small and can be neglected and therefore $F_x \approx 0$.

In abnormal operating condition of electrical line the component F_{2x} is equal to zero, if the conductor is broken off in the second span. The component $F_{1x} = T_{ab}$.

The suspension and strain line supports are determined for forces (5.3). For dead end line supports, forces from the conductors of one span are equal to zero. The forces, with which the conductors act on dead end line supports, are determined by (5.1).

At inclined terrain, for calculation the result force acting of the conductors in the attachment point, all acting forces are projected on coordinate axis and their projections are summing. It is obtained that

$$F_2 \equiv \left| \begin{array}{l} F_{2x} = -T_o'' \cos \alpha_2 \\ F_{2y} = \dfrac{P_{2y}}{2} - T_o'' \sin \alpha_2 \cos \varphi \\ F_{2z} = \dfrac{P_{2z}}{2} + T_o'' \sin \alpha_2 \cos \varphi \end{array} \right. \qquad (5.4)$$

Where

φ is the angle of inclination of the conductor due to wind pressure ;

α_2 is the angle of the slop of conventional horizontal span.

The angle α_2 can be calculated by

$$\tan \alpha_2 = \tan \psi_2 \sin \varphi \qquad (5.5)$$

Where ψ_2 is the inclination of the terrain from the right side of the support.

By similar way the components of the force for span number 1 can calculated:

$$F_1 \equiv \left| \begin{array}{l} F_{1x} = T_o' \cos \alpha_1 \\ F_{1y} = \dfrac{P_{1y}}{2} + T_o' \sin \alpha_1 \cos \varphi \\ F_{1Z} = \dfrac{P_{1Z}}{2} - T_o' \sin \alpha_1 \sin \varphi \end{array} \right. \qquad (5.6)$$

The result force, which is acted on the support:

$$F = F_1 + F_2 \equiv \left| \begin{array}{l} F_x = F_{1x} + F_{2x} \\ F_y = F_{1y} + F_{2y} \\ F_Z = F_{1Z} + F_{2Z} \end{array} \right. \qquad (5.7)$$

The reactions of the forces, with which the conductor acts for the support, are equal and opposite the acting forces in the attachment point of the conductor. The acting forces are calculated for equivalent spans of the specified support le1 and l_{e2} [4, 5]. They are large and small equivalent spans if the specified support is located higher and lower than the adjacent supports respectively. Small and large equivalent spans if the specified support is lower from the left side support and higher from the right side support or vice versa. The result force from the conductors on dead end support are determined by (5.7) for F_2=0.

At angle support the electrical line changes its direction with angle χ. For calculation forces, acting on angle support coordinate system is introduced with inception in the attachment point at specified angle support. It is assumed, that the direction of the wind is coincided with axis Y. The force, with which wind pressure acts on the conductors in the span with length l, is calculated by

$$P_y = G\, S\, l \cos(\chi/2) \tag{5.8}$$

The confront with the direction of the conductors, the component of wind is put with strain force T' or T''

The forces in the conductor in its attachment points to specified support are determined separately for spans number 1 and number 2. For that aim subsidiary coordinate systems are introduced with start point specified support and with axis: axis X_1, X_2 -with direction of the conductors in span number 1; and span number 2 respectively. Axis Y_1 and Y_2 are perpendicular to X_1 and X_2 respectively. For subsidiary coordinate systems forces are calculated, as at supports, located in straight line at flat terrain, and only the force from wind introduces its component on axis Y-equation (5.9).

The forces from conductor from spans number 1 and number 2 are respectively

$$F_1 \equiv \left| \begin{array}{l} F_{1X} = T_o' \\ F_{1y} = GS\frac{l_1}{2}\cos\frac{\chi}{2} \\ F_{1Z} = GS\frac{l_1}{2} \end{array} \right. ; \qquad F_2 \equiv \left| \begin{array}{l} F_{2X} = -T_o'' \\ F_{2y} = GS\frac{l_2}{2}\cos\frac{\chi}{2} \\ F_{2Z} = GS\frac{l_2}{2} \end{array} \right. \tag{5.9}$$

The result force from conductor in the attachment point is found by projection of the forces F_1 and F_2 on the axis of the basic coordinate system X Y Z.

$$F \equiv \left| \begin{array}{l} F_X = (T_o' - T_o'')\cos\frac{\chi}{2} + GS\frac{l_2 - l_1}{2}\sin\frac{\chi}{2}\cos\frac{\chi}{2} \\ F_y = (T_o' + T_o'')\sin\frac{\chi}{2} + GS\frac{l_1 + l_2}{2}\cos^2\frac{\chi}{2} \\ F_Z = GS\frac{l_1 + l_2}{2} \end{array} \right. \tag{5.10}$$

The forces, with which the conductors act on angle support in inclined terrain, are calculated, as for angle support in flat terrain. The components of the forces from conductor are calculated by (5.4) and (5.6). The difference is only in the direction of wind pressure, which is at angle χ/2 with respect to axis of the electrical line, and its component is determined by (5.8).

The components of the force F on the basic coordinate system are

$$F \equiv \left| \begin{array}{l} F_X = (F_{1X} - F_{2X})\cos\frac{\chi}{2} + (F_{2y} - F_{1y})\sin\frac{\chi}{2} \\ F_y = (F_{1X} + F_{2X})\sin\frac{\chi}{2} + (F_{1y} + F_{2y})\cos\frac{\chi}{2} \\ F_Z = F_{1Z} + F_{2Z} \end{array} \right. \tag{5.11}$$

6. COMPUTER PROGRAMME

The synthesis algorithm has been written in FORTRAN – 90, and run on a personal computer. Figure 1. shows the flow chart of the programme, which consists of one main programme MDFLS and fourteen subroutines.

The input data : Nominal voltage kv; climatic area – TEP is equal to one for specified standardized or equal to two for special climatic area; length of the span l; STC1 and STC2 are codes for the phase conductor and ground wire respectively; λ is the length of insulator string; G_i is the weight of the insulator; χ is the angle of deflection of the trace; ψ_1 and ψ_2 is the inclination of the terrain from the right side and left side of the line support respectively; l_1 and l_2 are the length of the spans adjacent to the specified line support.

The parameters of the line conductors are found by subroutines DPMPH and DPMPN [2]. The subroutine PMPL is used for calculation of physical-mechanical properties of the phase conductors (PF=1) and ground wires (PF=2).The specific loadings are determined by subroutine RLOLC. Subroutine CSCT is for calculation of critical values of span and temperature and CSOP is for determination of operating condition. SEQS is for solution equation of state and it is a subsidiary function to CSCT.

The forces acting from phase conductor on suspension, strain or angle and dead end towers are determined by FCSUS, FCSTA and FCDES respectively. The forces acting from ground wires on suspension ,strain or angle and dead end towers are determined by FGWSU, FGWSA and FGWDE.The subroutine FSPCB is used for calculation of the force loading line support at broken off conductors in the section.

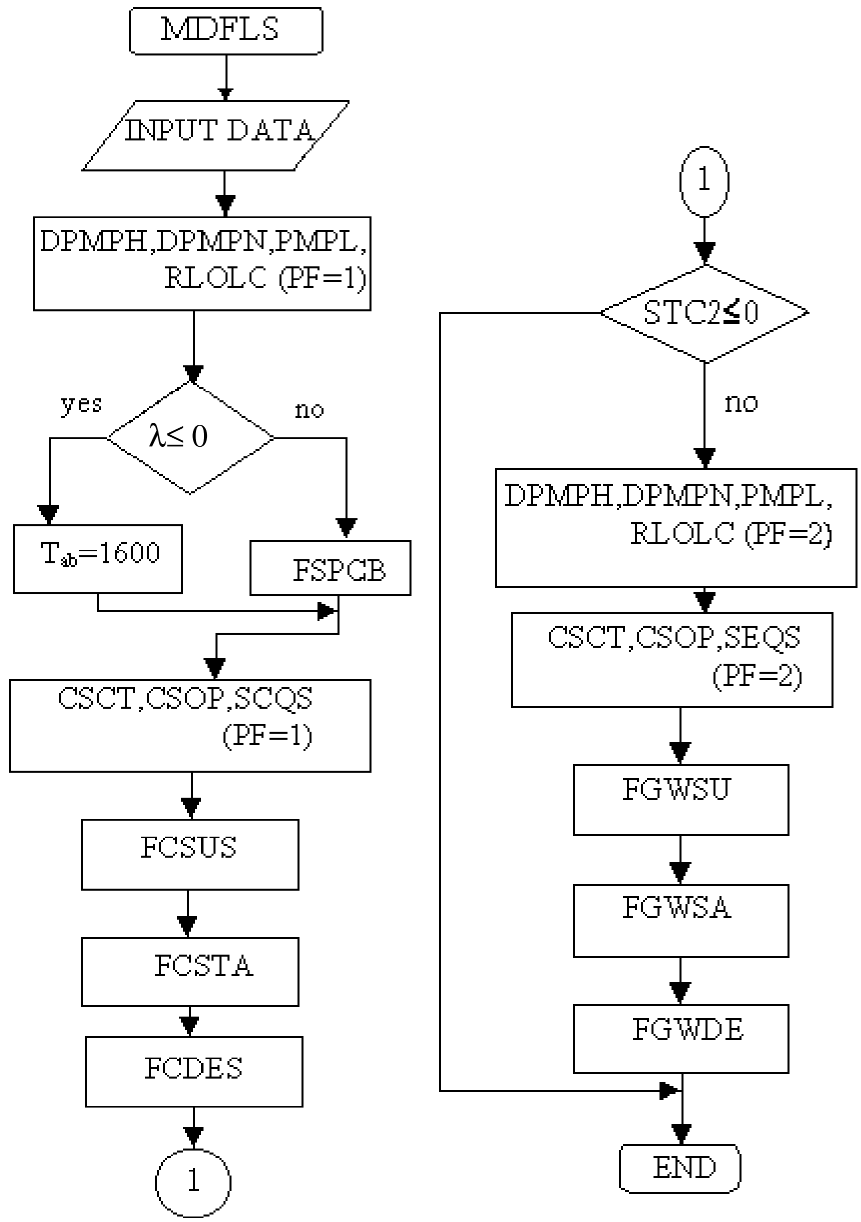

FIGURE 1: Flow chart of programme MDFLS

7. CONCLUSION

For selection and design of the line supports, loadings due to the conductors and wind pressure must be estimated for normal and abnormal conditions of operation. The selected supports should be mechanically strong to withstand these forces.

The elaborated programme enable obtaining the optimum solution of the problem, aiming to increase reliability of transmission lines and the calculated forces to be in consistent with the specified regulations within the permissible limits.Our country began construction of national system high voltage transmission lines 132 kv and in future 220 kv and 400 kv will be erected.

Such programmes are needed and necessary and their use have great benefits. They will give a precise solution, in short time, for one of the problems of mechanical design of an overhead transmission line.

There are some specific areas in our country, which are with high humidity. The future research direction in this field of the existing research paper is to investigate the effect of humidity in the design of line supports for these areas, e.g. the change in the clearances of line supports due to high humidity. This change results to different values of forces, distinguished from standard permissible range, acting on line supports. Therefore, new methodologies should be created and applied for design of line supports and computation of forces acting on them.

8. REFERENCES

[1] Vadhera S. S. "Power system analysis and stability", Khana Publishers Delhi, India, 1987, pp 142-163.

[2] Bahaidara A. S. "A new algorithm for mechanical design of overhead conductor". Journal for natural and applied sciences, vol.2 No 3 University of Aden, pp 33-40, 1997.

[3] Coombs R.D., "Pole and Tower Lines for electric power transmissions ". London Hill Publishing CO.Ltd. , 1963, pp 29-42.

[4] Cotton H., Barber H. "The Transmission and Distribution of electrical energy", The English Universities Press LTD, St Paul's House Warwick Lane London EC4, Third edition, 1970, pp 205-220.

[5] Nicolai Genkov. "Mechanical part of an overhead transmission lines". Public House "Technics", Sofia, 1974, pp 211-271.

[6] Nicolai Genkov. "Guidance of an overhead transmission lines". Public House "Technics", Sofia, 1983, pp 150-183.

[7] Peter Ivanov. "Mechanical part of an overhead transmission lines". Public House "Technics", Sofia, 1985, pp 37-48.

[8] Design Manual for High Voltage Transmission Lines, REA Bulletin 160-2, USA, Department of Agriculture, Washington DC.,2005 , pp143-180.

[9] Singh Y., P.K.Bhatia, O. Sangwan. "A review of studies on machine learning Techniques". International Journal of Computer Science and Security, Vol. 1 Issue 1. , 2007, pp 70-84.