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by

G.P. Smidovich, A.F. Chernigovskiy, V.B. Kuindzhi

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Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

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FLEXIBLE CONDUCTORS AND THEIR APPLICATION IN INDUSTRIAL POWER ENGINEERING.

Engineers G. P. Smidovich, A. F. Chernigovskiy, V. B. Kuindzhi GPI Elektroproyekt.

In systems of power supply of contemporary energy-consuming industrial enterprises for electric transmission from external sources of power (TETs [heat and power plant] or GPP [main step-down station]) to distribution points, located in centers of loads of enterprises, ever wider application find main-line conductors 6-10 kV instead of conduit run [L. 2-4].

Experience of operating conductors confirms their advantages in comparison with cable systems with respect to operational reliability, convenience in maintenance/servicing and safety in fire sense; fundamental initial costs of feeding electrical network are substantially lower and is reached considerable savings of cable production.

Appearing as if collecting mains of power source, carried out directly into zone of consumption, conductors allow connection of users at any point and under specific conditions in any stage of construction and exploitation of enterprise. The primary feeding main lines of system of power supply become to a certain degree independent variables from changes in technology or sequence of the construction of separate productions.

Supports of conductor can be installed independent of readiness of underground communications, provided by general plan; thus, conductor if necessary can be used for power supply according to temporary/time diagram, while execution of cable system depends on readiness of engineering communications, planning of territory, etc.

With rules of device/equipment of electrical devices (S I-2-25) and SNIP [Construction norms and regulations] [L. 1] one should widely use bare conductors of different performance instead of large number of cables. The advisability of applying the conductor 6-10 kV under the specific conditions must be revealed as a result of technical-economic comparisons with other versions of power supply. Transition from the radial cable systems to the main-line conductors is most effective on such industrial areas, where the large flow of the overhead lines would be oriented approximately in one direction. This position is characteristic, in particular, for the new planning resolutions of the chemical enterprises, where the basic energy-consuming productions are arranged/located along main communication corridor, created for all fundamental utility networks, including electrical [L. 5, 6].

In last decade in Soviet industrial power engineering wide application find open heavy-current symmetrical conductors both with rigid busbars, attached on supporting or suspension insulators [L. 2, 3], and with flexible wires on suspension insulators [L. 3, 4, 7, 8]. The rigid open conductors in comparison with the flexible have the smaller overall sizes, the larger capabilities of the industrialization of installation works and require a smaller quantity of standard sizes of special armature. At the same time flexible conductors in comparison with the rigid are considerably cheaper, they possess the increased (with the identical sections) capacity and the higher electrodynamic stability, caused by the flexibility of system and by the presence of hinged points of attachment, they do not have numerous welded joints, they require many times smaller quantity of insulators, which is extremely essential under the conditions of the contaminated atmosphere of industrial enterprises.

Main deficiency in flexible conductor - need for comparatively broad right of way for its installation. However, this right of way with the layout of the general plan of enterprise taking into account fire disruptions between the housings has, as a rule, sufficient overall sizes on the width for positioning/arranging the route of conductor without an additional increase in the disruptions between the projected/designed assignments.

Even at the end of 40's in USSR they began to use flexible conductors for connecting generators with transformers and transformers with switch houses (L. 7).

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These conductors were provided for the electric transmission up to small distances, with which it was possible not to be considered either with considerable inductive reactance, or the asymmetry of voltages on receiving end. There was also no need for the special system of their lightning protection [L. 8]. These questions are decisive during the development of the conductors of considerable length.

First flexible twin-circuit symmetrical conductor of industrial designation/purpose, designed for transfer of power up to 100 MVA up to distance of 1.6 km with voltage 10 kV [L. 9], was developed by GPI Elektroproyekt for enterprise of chemical industry and entered into operation in 1962. On the conditions of the general plan of enterprise the conductor was designed on the supports, combined with the pier of heat-materials ducts. However, operating experience showed that with this coincidence appears the need to frequently disconnect first one, then another of its circuit on the conditions of safety engineering to the period of the fulfillment of any works on the pier with the application of hoists. The difficulty of its maintenance/servicing, caused by the considerable height of the suspension of the phases above ground level (28 m), is another essential drawback in the conductor, combined with the technological pier.

Taking into account operational experience of first flexible conductor GPI Elektroproyekt developed its new construction/design on independent supports, with reduced overall sizes and improved characteristics and applied it for a number of projected enterprises of chemical industry of other objects. The overall sizes of conductor are considerably reduced also because of the application of a new system of the supporting attachment of phases (Fig. 1). Designation, type and the weight of supports are following:

(a) Номер	1	2	3	4	5	6
(b) Тип	(c) ПТ-II промежуточная нормальная	(d) ПТ-II+5 промежуточная повышенная на 5 м	(d) ПТ-II+10 Промежуточная повышенная на 10 м	(e) КТ-II, УТ-II концевая и угловая (в скобках данные для опоры УТ-II)	(f) КТ-II Концевая отпаечная	(g) ПТ-III промежуточная отпаечная
(h) Вес, т	4,4	5,9	7,5	14,1 (15,3)	21,8	9,1

Key: (a). Number. (b). Type. (c). PT-11 intermediate normal. (d). ... intermediate increased to ... m. (e). KT-11, UT-11 end and angular (in the brackets data for support UT-11) 14.1 (15.3). (f). KT-11 end sealing. (g). PT-111 intermediate sealing. (h). Weight, m.

Number of wires in phase of conductor is determined by calculations of economic current density according to projected/designed objects in accordance with SI-3-23 of PUE. The obtained sections were checked using the capacity in the emergency mode taking into account a promising increase in the loads on 20-25%. Wire is accepted aluminum without the steel core of brand A-600, which, as calculations showed, gives the most economical solution and the large stability under the conditions of aggressive medium. Conductor is developed in three performances with the phases, split to 6, 8 and 10 wires. The maximum transmitted power by the capacity in the emergency mode comprises respectively: with the voltage 6.3 kV - 62, 83 and 104 MVA; with the voltage 10.5 kV - 104, 138 and 173 MVA.

On conditions of guaranteeing normative levels of voltage in distant electrical receivers maximum length of conductor, similar to that described in [L. 9] (inductive reactance of phase 0.18 Ω/km), did not exceed with voltage 6 kV ~1 km, which was insufficient with power supply of a number of enterprises on generator voltage from TETs. Reduction in inductive reactance can be, as is known, achieved/reached due to convergence of split phases of one circuit and increase in the diameter of their splitting. The used previously system of the supporting attachment of phases with the independent suspension of each phase to the crosspiece of support during their symmetrical arrangement on equilateral triangle did not make it possible to substantially decrease the distance between centers of phases, or to increase the diameter of their splitting in the conditions for the permissible approximation of current-carrying parts to crosspieces of supports. The accepted during the development of small/miniature conductor new diagram of the supporting attachment of phases (Fig. 1, 2), in which lower phase is suspended on the string insulators to two upper, made it possible to reduce the distance between centers of phases from 3 to 2 m with a simultaneous increase in the diameter of phase splitting from 0.6 to 0.8 m. The approach of phases is accepted taking into account the guarantee of standardized/normalized distances between the wires and spans.

As a result of applying new supporting structure of phases inductive reactance of conductor was possible to reduce approximately to 1/3 (for example, for phase with section 6×600 mm^2 from 0.18 to 0.12 Ω/km), which considerably expanded possibilities of using flexible conductors.

Fig. 3 gives curves of dependence of maximum length of small/miniature flexible conductor on calculated value of transmitted power, for different values of cos φ [1].

FOOTNOTE [1]. Author's certificates No 245189, Bulletin of inventions No 19, 1969 and No 248027, Bulletin of inventions No 23, 19. ENDFOOTNOTE.

Curves are constructed on the basis of several averaged values of voltage in the beginning and end of the conductor, split to eight wires, and do not consider, it goes without saying, the specific conditions of the system of power supply, but it is possible to use them during the predesign evaluation/estimate of the applicability of conductors with the phases with the section 6×600, 8×600 or 10×600 mm_2.

Adopted new system of supporting attachment of phases, their splitting into 6, 8 and 10 wires, increase in diameter of splitting, application of high-strength insulating spacers caused need of developing special armature of following nodes of conductor: Retaining clip for phase splitting, spacer of interphase of insulating and spacer of interphase.

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This reinforcement is developed by PKV of Main Administration for the Mechanization of Construction, Soviet Ministry of Power Engineering and Electrification [Glavenergostroymekhanizatsiya] of Minenergo [Ministry of Energy] by assignment of GPI Elektroproyekt for the conductors with the phases, split to 6, 8, and 10 wires of brand A-600, and it is included in the catalog of reinforcement for the overhead electric power lines (Informstandartelektro, iss. 6).

Previously used for flexible conductors standard steel terminals/grippers created considerable magnetic losses - 12% of total losses of active power in conductor, and temperature of boat of terminal/gripper in the most unfavorable cases by 40°C exceeded temperature of corresponding wire. In the developed nodes of conductor the steel parts within the frame of the wires of phase barely create losses in view of the compensation of magnetic fields in this zone.

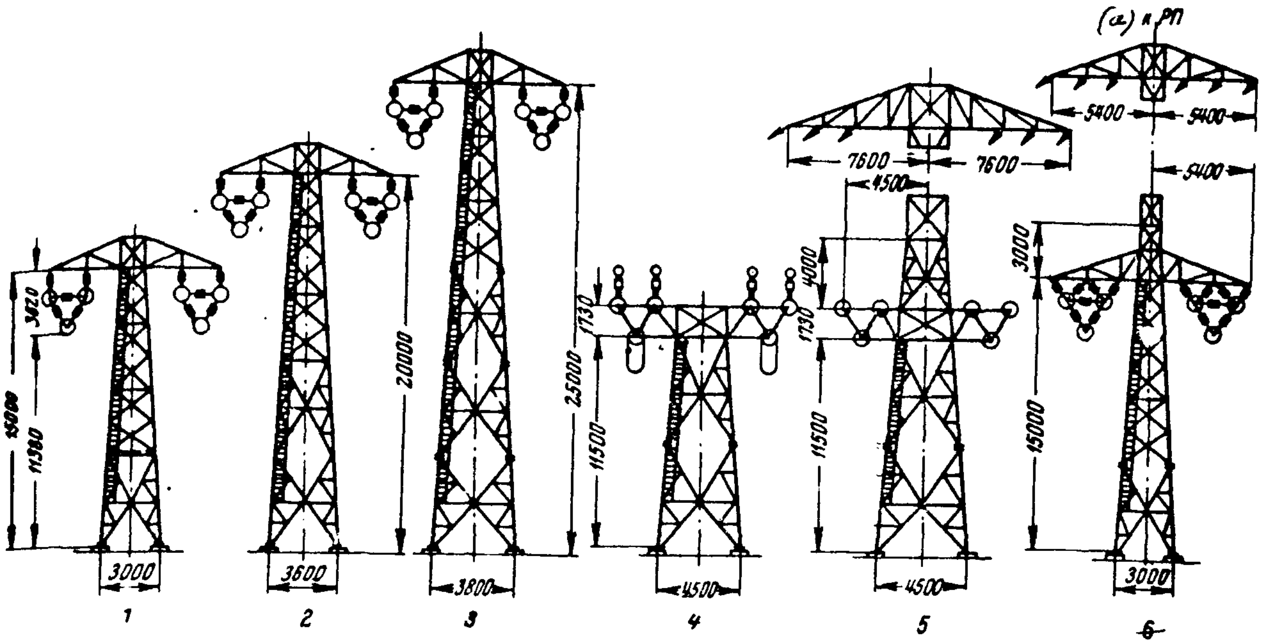

Fig. 1. Schematics of supports of twin-circuit flexible main-line conductor 6-10 kV.

Key: (a). to RP.

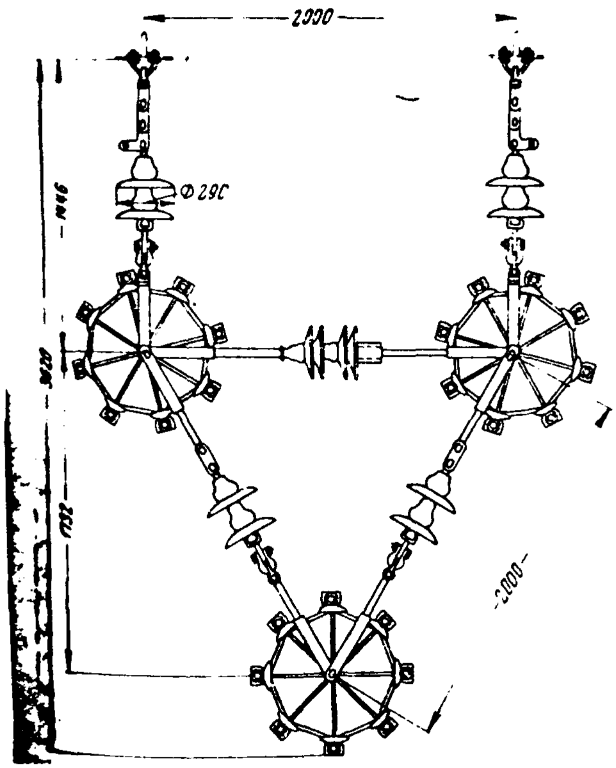

Fig. 2.

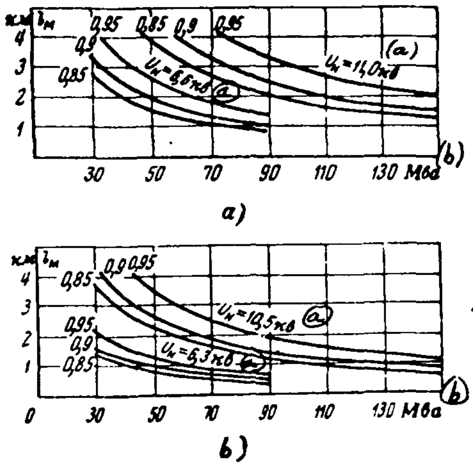

Fig. 3.

Fig. 2. Schematic of supporting attachment of phases of flexible conductor in small/miniature performance.

Fig. 3. Curves of dependence of maximum length of small/miniature flexible conductor on amount of transmitted power by conditions for permissible voltage drop in emergency mode. a) in the presence of regulating voltage on the busbars of the power source; b) in the absence of the possibility of regulating the voltage.

Key: (a). kV. (b). MVA

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The system of the attachment of phases, besides the above-indicated possibility of reduction of inductive resistance, provides the convenient suspension of all three phases to one crosspiece. Twin-circuit supports in this case have the simplest T-shaped diagram (Fig. 1).

Sealing device/equipment from bunched conductors of phase of conductor to RP is developed with application of standard pressed equipment terminals/grippers. Sealing is fulfilled, depending on the current strength, by two or three wires A-600 in the phase.

Depending on special features of this object RP are arranged/located in span under conductor (Fig. 4) or they can be built in production housing. The first diagram of layout of RP makes it possible to accomplish the simplest design of sealing from the conductor and has advantages with respect to the independence of the fundamental feeding nodes from the readiness of production installations. Construction of RP, built in the housing, is connected with the structurally complex assemblies of sealing and the weighted sealing supports.

Taking into account production potentialities of construction-assembly organization of system Minmontazhspetsstroy accepted solution about application for flexible small/miniature conductor of metallic supports of welded lattice frame. Supports are developed by institute of Ukrainian Central Scientific Research and Planning Institute of Metal Building Components

[Ukrproyektstal'konstruktsiya] of All-Russian Central State Construction Office [Gosstroy] of the USSR by assignment of GPI Elektroproyekt. The maximum normative stress of wires to the phase is accepted equal to 10 t. The length of spans on the wind strength of supports is accepted for the calculated climatic conditions of the II area downwind and ice-covered surface with the recurrence of 1 time in 10 years. Recurrence is accepted on PUE as for VL 110-330 kV, taking into account the increased requirements for the reliability of power supply of users, connected to the conductor. Calculated wind spans were determined equal at 6 wires in the phase - 88 m, with 8 wires - 66 m, with 10 wires - 53 m.

Supports are developed according to T-shaped diagram of following types: intermediate with raising braces to 2, 5, 7 and 10 m, intermediate sealing for RP, arranged/located under conductor, intermediate sealing for RP, built in production housing, angular to angle of rotation to 60°, end for one-sided perception of stresses on straight/direct run.

Intermediate supports are provided for installation on standard standardized beds ILLEGIBLE 110 kV on album of Energoset'proyekt [All-union State Planning, Surveying, and Scientific Research Institute of Power Systems and Electric Power Networks]. Angular and END supports are established/installed on the beds from cast-in-sito concrete.

Was simultaneously developed analogous ILLEGIBLE of lightened supports, designed for maximum stress 5 t to phase. These supports are used in ILLEGIBLE of conductors with the number of wires in the phase less ILLEGIBLE.

New construction/design of flexible conductor and its ILLEGIBLE in systems of power supply of industrial enterprises were developed taking into account the following ILLEGIBLE.

1. Effective GOST [All-Union State Standard] 13109-67 allows for ILLEGIBLE electrical receivers asymmetry of voltage, equal to 2%. With larger values is required checking of allowance for all electrical machines, installed in this network/grid.

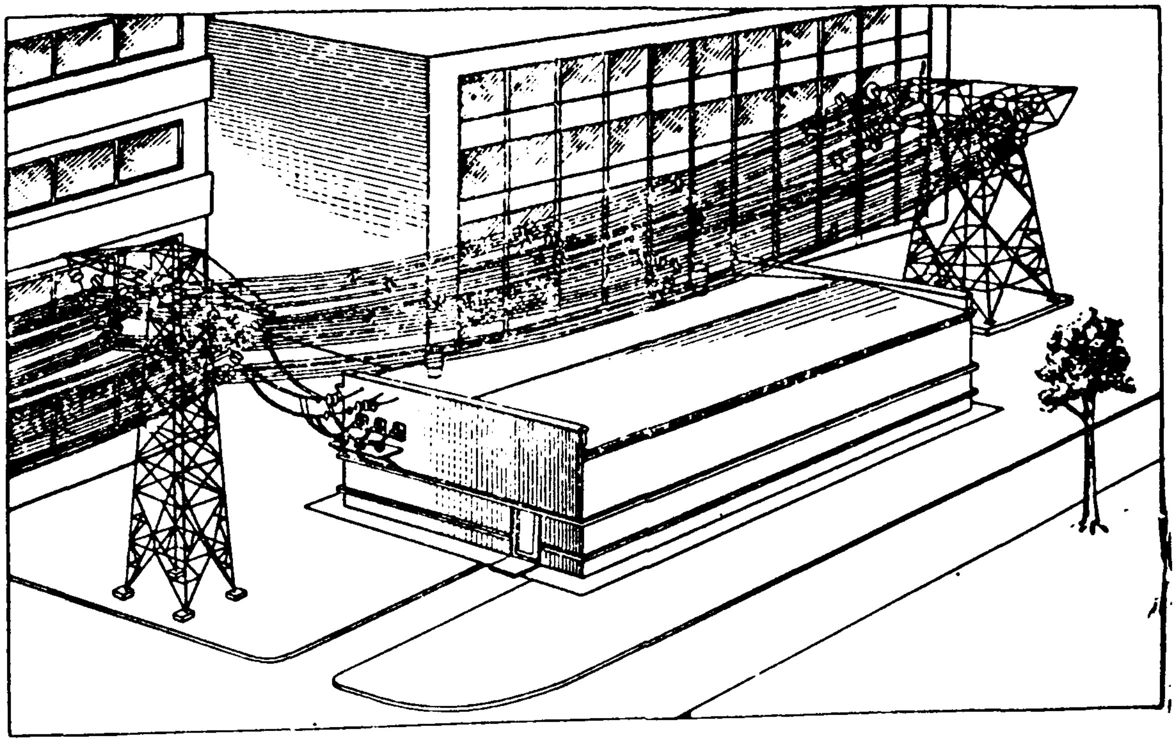

Fig. 4. *Arrangement of RP in span under conductor.*

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As showed check ILLEGIBLE the indicated asymmetry with the reciprocal location of the phases of two circuits, accepted for the small/miniature flexible conductor, is sufficiently low (about 0.7% on 1 km), so that in the majority of cases it is possible to disregard the mutual effect of circuits in the normal mode.

It is necessary to also perform calculation of voltages, induced at de-energized circuit of conductor from adjacent circuit during short circuit on latter, according to conditions of safety engineering with inspection and repair work on off circuit. For limiting the induced voltages - not more than 250 V (PUE, §II-2-24) is provided for the installation of the grounding shorts at the points of conductor, determined by the appropriate calculation. The distances between the shorts usually comprise: in the head section 150-200 m, at the end of the extended conductor 300-400 m.

2. For suppression of nonuniformity of current distribution in wires of split phase of conductor interphase transposition of wires was used. Each of the wires of phase at the length of the section of transposition completes one complete revolution along the flat helix relative to the axis of proper phase. Thus, by consecutive alternation at the length of the section of the transposition of arrangement in the circle/circumference of n wires of phase is achieved the alignment/levelling of the effects of external magnetic fields to each wire. The corresponding experimental check, carried out by the Leningrad experimental design department of VNIIproyektelektromontazh, confirmed the positive effect of the interphase transposition: the nonuniformity of current distribution, which reached 40%, is virtually removed.

3. Transient short-circuit current in head section of conductor, connected to powerful power sources, is equal to 200-300 kA and more. With these currents appear the considerable forces of interaction both between the phases of faulted circuit and between the wires of one phase. The electrodynamic stability of conductor is provided by the installation of the interphase spacers, which prevent crossing of the

wires of adjacent phases in the mode of short circuit, and interphase spacers - for limiting the additional stresses, which appear from the forces of interaction between the wires of one phase. The quantity and order of spacers in the spans, consecutively/serially distant from the busbars of the power source, are calculated by electrodynamic stability.

Checking for crossing and calculation of forces between wires of split phase are fulfilled on methodology, given in [L, 8]. The distance between the interphase spacers was determined from the formula, obtained as a result of the joint solution of the common equations of state of wire relative to the span distance for the conditions before and after the onset of the short circuit:

$$l_p = K \cdot \sigma_м \sqrt{\frac{(K-1)\sigma_м \cdot 24\beta}{\gamma_{к.з}^2 - \gamma_1^2}}, \qquad (1)$$

where l_p - distance between the spacers, $\sigma_м$ - maximum voltage in the wire in the normal mode, kgf/mm²; K=1.5 - coefficient of the permissible increase of the amplitude of pulse stress in the mode of short circuit with respect to maximum stress $T_м$ in the normal mode; $\beta = 159 \cdot 10^{-6}$ mm²/kg - coefficient of elastic elongation for aluminum; γ_1 - the specific load on the wires in the normal mode, which corresponds to maximum voltage in the wire, kG/m·mm²; $\gamma_{к.з}$ - specific load on the wires from the forces of interaction between the wires of one phase, kG/m·mm².

$$\gamma_{к.з} = \frac{P_к}{S}, \qquad (2)$$

where $P_к$ - force to the center of phase for 1 lin. m of one wire, kg;

S - section of wire, mm². According to [L. 7]

$$P_{\text{п}} = \frac{n-1}{n^2} \cdot \frac{2{,}04 \cdot I''^2_{(3)} \cdot 10^{-2}}{D} \text{ (1)} \quad (3)$$

Key: (1). kg/lin. m.

where n - quantity of wires in the phase of conductor; D - diameter of the beam of split phase, м; $I''_{(3)}$ - initial ultratransitory current three-phase short circuit, kA.

Between-phase and interphase spacers must be checked on mechanical strength in mode short circuit taking into account safety factor 1.7 (according to II-5-71 PUE-65).

4. Protection of open conductors of industrial designation/purpose from direct lightning strokes is fulfilled in accordance with requirements of §IV-2-185 and IV-2-186 PUE-65. As experiment of design showed, the most economical solution is the protection of conductors by two cables, suspended/hung in parallel to conductor along its both sides from separate lightning collectors. According to the recommendation of VNIIE [All-Union Scientific Research Institute of Electric Power Engineering] the zone of protection in this case is determined from the formula

$$h_a = h - h_x \geqslant \frac{a}{3}, \quad (4)$$

where h - height of the arrangement of cable (taking into account deflection); h_x - height of the supports of conductor; h_a - active height of cable lightning arrester; a - distance between the parallel cables.

Eight-year experience of operation of operating flexible conductor showed that it is necessary to also ensure protection of conductor and connected equipment from induced lightning surges. It should be noted that the considerable decrease in the wires above ground level, accepted in the conductor of new construction, will contribute to sharp reduction in the induced overvoltages.

5. During development of design of power supply with application of conductor important value acquires rational selection of its route, layout of engineering communications in main communication passage of enterprise [L. 4, 6], optimum arrangement of supports and lightning arresters, construction/design of intersections of conductor with different engineering installations. Therefore the design of conductor it is expedient to begin in the process of development of general plan.

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Conclusions.

Flexible main-line conductors can be recommended for application in systems of power supply of industrial enterprises on the level with conductors of other contemporary constructions/designs. Their use in each individual case must be substantiated by technical-economic calculation and correspond to operating requirements for this industrial object. Conductors with flexible conductors it is allowed to utilize with the high value of short-circuit currents on the busbars of the power source, and also in the case of the presence of the medium, contaminated by industrial escapes.

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