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IMPROVING RELIABILITY AND SHORT-CIRCUIT PROTECTION OF POWER LINES FOR ROAD LIGHTING
(INTERCHANGE OF EXPERIENCE)

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ABSTRACT

A technique for choosing circuit breakers for the effective protection of outdoor illumination power lines on highways against short circuits and to increase power supply reliability is presented. The technique is based on the principle of electric circuit sectioning.

The technique allows determining places to install protection devices graphically and using calculations in long lines of road lighting illumination.

Keywords: outdoor illumination power line, road lighting and highways lighting, electric power supply system, short circuit protection

1. INTRODUCTION

Road safety is directly connected with the reliable and effective operation of outdoor illumination power lines (EIPL). A review of publications on this subject has confirmed the relevance of increased EIPL reliability and of ensuring high performance of light source characteristics for luminaires with an uninterrupted power supply [1–7].

Methods exist for choosing conductors and placing protection devices (PD) in power lines of high and low voltage [8] but they are effective for power supply systems and electric power lines connecting a transformer substation (TS) with the loading. In long power lines with a distributed load, especially of low power, this technique does not allow choosing an effective short circuit protection. EIPLs of highways are among such lines. Such EIPLs are, as a rule very long, up to several kilometres, and have low power distributed along the whole length. Short circuit (SC) mode in EIPLs on highways has a feature: SC current at the end of the line is, as a rule, less or closer to the loading current at the end of the line. In this case, automatic circuit breakers installed in the 0.4 kV distributing device at the TP do not disconnect the loading, if SC occurs at the end of the line.

In this article, a technique for selecting PD on long power lines with a distributed loading is given. The technique is based on sectioning of the lines. The whole power line is divided into sites (sections), each of which is protected by its own automatic circuit breakers.

2. FORMULATION OF THE PROBLEM

When developing the technique, the first task was to compute CS current at point *i* of the line at a distance of l_i from TP and to find node *j* of the connected loading at a distance of *lj* from TP, where it is possible to install a PD for effective protection of the line section $l_j - l_i$. For this technique, two conditions should be met:

– To provide an acceptable PD response time, CS current should be not lower than the PD rated current of a preset multiplicity:

$$I_{sc} \geq K I_{rp}; \tag{1}$$

– the PD rated current should be not lower than the loading rated current in node *j*:

$$I_{rp} \geq I_{rj}.$$

3. CALCULATION METHOD FOR THE SOLUTION

SC current is calculated in accordance with a national standard (GOST) [9]. The replacement circuit of the electric power supply system contains a TP transformer and power line replacement circuits. When calculating complex impedance of the replacement circuit, resistance of switching devices, contacts and other elements which comprise the electric power supply system are also taken into consideration.

Active and reactive resistances of the transformer's positive sequence are calculated based on the rated values, for example according to the formulae given in [10]. Negative sequence resistance of the transformer and positive as well as negative sequence resistance of other replacement circuit elements are selected in accordance with GOST [9].

In 0.4 kV networks, minimum currents appear at non-symmetric SCs. Therefore as a criterion for PD choice, single-phase SC current $I^{(1)}{}_{sc}$ is accepted:

$$I^{(1)}{}_{cs} = \sqrt{3}\,U_{av} \,/\, \sqrt{(2R_{\Sigma}+R_0)^2+(2X_{\Sigma}+X_0)^2}, \tag{2}$$

where U_{av} is the average value of low voltage, which for a 380 V circuit is equal to 400 V; R_{Σ} and R_0 are total active resistances of positive and negative sequences of the electric power supply system replacement circuit, Ohm, respectively; X_{Σ} and X_0 are total reactive resistances of positive and negative sequences of the electric power supply system replacement circuit, Ohm, respectively.

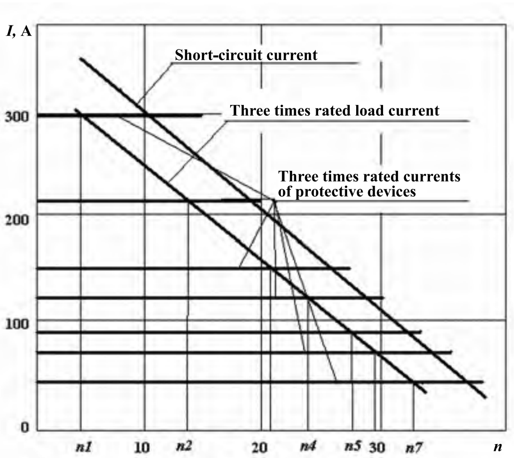

Fig.1. Distribution of short circuit and loading currents in power line nodes

To determine node *j* for PD installation, formula (1) is used. After right part of formula (2) is substituted into the left part of formula (1), the following inequality is obtained:

$$\sqrt{3}\,U_{av} \,/\, \sqrt{(2R_{\Sigma}+R_0)^2+(2X_{\Sigma}+X_0)^2} \geq KI_{rp}.$$

If loading rated current is expressed in it using node *j* power, the following inequality will be obtained:

$$\sqrt{3}\,U_{av} \,/\, \sqrt{(2R_{\Sigma}+R_0)^2+(2X_{\Sigma}+X_0)^2} \geq \geq (3P_{rj}n) \,/\, \sqrt{3}\,U\cos\varphi, \tag{3}$$

where P_{rj} is power in *j* node, W; *n* is node number from the connection point in the TP to node *j*; $\cos\varphi$ is a power factor. When designing, the power factor is accepted to be equal to 0.85; *U* is rated voltage of the electric power supply system**,** 380 V.

The result of solving the inequality (3), after substituting parameters of the electric power supply system and replacement circuit into it, the loading node (n), in which PD should be installed, can be determined. Assuming the solution of this inequality, distance from SC point in node *i* to PD *j* unit, such a calculation will be at possible. Node choice errors for PD installation using inequality (3) are caused by the fact that PD rated current is selected of a standard number of currents of automatic switches or of automatic circuit breakers manufactured for use in electric circuits. If the difference between loading rated current I_{pj} in node *j* and standard rated current I_{rp} in a PD is essential, KI_{rp} value can exceed SC current. Substitution of the PD rated current into the right side of inequality (3) is also not practical as there will be no relation in the inequality with loading parameters. Using the considered technique, the author proposes the following solution. Node number from TP to node *j*, in which PDs should be installed, is determined as follows:

$$n = \left(P_{\Sigma} - I_{rp}\sqrt{3}\,U\cos\varphi\right) / P_{rj}, \tag{4}$$

Table 1. Results of choosing installation node and parameters for protection devices of an outdoor illumination power line

Highway #1					
Length of highway sections, km	0.585	1.193	1.73	2.566	3.055
Wire cross-section, mm^2	150		120		
Phase-zero loop resistance, Ohm	1.314	2.44	3.67	4.63	6.69
Rated current, A	87.7	70,9	55	38.4	17
SC current, A	527	284	189	150	103
Automatic circuit breaker current, A	100	80	60	50	25
Support numbers for automatic circuit breakers to be installed	89	72	56	39	17

where P_{Σ} is total loading of the electric power supply system, W.

PD rated current is selected as follows: CS current is calculated at the end of the line, PD rated current is chosen to be no more than 1/K of CS current. After the selected protection rated current value is substituted into formula (4), the value of *n* can be determined. A final choice of node *j* is made using inequality (3): if it is not met, then the value of *n* should be corrected. An experience of solving these tasks has showed that if inequality (3) is not met, the value of *n* should be reduced by choosing node *j*-1. Further CS current in node *j* is calculated, the node for PD installation is selected, and the protection interval is determined. Calculation for the whole power line is performed in this manner. The last node for PD calculation and installation is the TP low voltage switch-gear device.

4. A GRAPHIC METHOD FOR SOLVING THE TASK

The node choice task for PD installation of a power line site can also be solved graphically.

SC currents and threefold rated current in distributed loading nodes for automatic circuit breakers with characteristic *A* are presented in Fig.1. In Fig.1, lines corresponding to the least acceptable number of SC currents for switches with characteristic *A* are also presented. The intersection point of PD threefold rated current line with dependence line of threefold loading current in nodes corresponds to the *n* value, which is a lower boundary for the node, where PD installation is practical. And maximum permissible PD installation node is the point of intersection of the lines corresponding to PD threefold rated current with an SC current line. The effective range of a PD installed for example in n_1 point is up to n_2 point, etc. The loading node for a protection device has to be installed, should be selected between the two above mentioned dependencies to have a sufficient SC response safety factor and a reserve for a small overload in the node. If the graphic method of the task solution is used, the line is plotted according to the selected PD as CS response time is regulated by the Rules of Electrical Facilities Maintenance and by characteristic of the selected PD.

5. PRACTICAL IMPLEMENTATION OF THE TECHNIQUE

The technique was applied when designing and constructing a EIPL of a highway 6 km long, part of the city road network of Samara. The EIPL has four highway sites, each about 3 km long. As a result of the sectioning, each site is separated into 4–5 sections, each of which is protected by an automatic circuit breaker group with rated currents corresponding to the response conditions.

Calculation results for one section are given in Table 1. The sections are connected using mast contact breakers, in which automatic circuit breakers with parameters selected according to this technique are installed. As a result of the sectioning, each EIPL section with luminaires is protected against CS currents by its own automatic circuit breakers. Besides, in case of CS emergence in the middle or at the end of the line, the main part of the luminaires will work, because only some of the luminaires will be switched off, which are in the CS current coverage area.

6. CONCLUSION

The technique considered in the article allows achieving the following:

1. To determine places for PD installation by graphic and calculation methods in a long EIPLs of highways;
2. To increase PD efficiency when appearing SC in a EIPL;
3. To increase the working reliability and efficiency of electric equipment for highway EIPLs;
4. To ensure the normal functioning an EIPL in case of an accident at the EIPL end.

Efficiency and performance ability of the technique proposed in the article is confirmed by an implemented project: a highway EIPL successfully operating in Samara.

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