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RESEARCH ON TRANSPOSITION EFFICIENCY OF SCREENS OF THREE-PHASE CABLE LINES WITH CONSIDERATION OF MUTUAL PHASE DISPOSITION

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Abstract: Methodology that allows estimating the values of currents on the cable core screens and choosing the method of connection and grounding of screens is considered. To achieve the objective it is necessary to develop a mathematical model and to perform corresponding numeric calculations for the design and verification of efficiency of screen transposition taking into account the mutual phase disposition.

As a result of the work, it was determined that by grounding both sides of the screens and the location of the phase cables in a row it makes sense to transpose the cable line to equalise the current values in the screens to a mean value.

Key words: transmission line, mathematical modeling, induced current, transposition.

1. Introduction

The inductive mechanism of current flowing in the screen is related to the presence of current in the cable core. In case of grounding the screen more than in one point, a current in the core is induced due to mutual induction between the conductor and the screen. If left unchecked, the intensity of current flowing in the cable screen can be comparable to the current in the core [1].

In the three-phase group of single-phase cables, the selection of distance between the phases is determined by cable heating and cooling. One of the heat sources in single-phase cables appears due to the losses of active power in screens caused by the induced currents, that are the less the nearer to each other phases are laid.

2. Problem definition

The aim of this work is the development of a methodology that allows the estimation of current values in the cable screens and the choise of the way of cable screen connection and grounding. To achieve the objective it is necessary to develop a mathematical model and to perform corresponding numeric calculations for the design and verification of efficiency of screen transposition taking into account the mutual phase disposition.

3. Problem solution

When screens are grounded, the longitudinal current of industrial frequency is induced at both ends of the cable simultaneously the value of which is proportional to:

- current in core
- interaxial phase distance
- section of cable screen (inversely proportional to its resistance).

The interaxial phase distance and the section of cable screens are chosen at the planning stage. The transposition of cables also affects on the values of the induced currents in the bilaterally grounded screens.

The voltage drop on cores and screens of cables in the steady mode for a three-phase cable bus can be described by the system of equations (1) [2]: the voltage drops for a one-circuit cable bus can be corrected taking into account the uniqueness of mutual resistances $\dot{Z}_{KAB}$, $\dot{Z}_{KBC}$, $\dot{Z}_{KAC}$ for each pair of single-phase cables:

$$\begin{cases}\Delta\dot{U}_{cA} = \dot{Z}_c\dot{I}_{cA} + \dot{Z}_{cs}\dot{I}_{sA} + \dot{Z}_{KAB}\left(\dot{I}_{cB} + \dot{I}_{sB}\right) + \\ +\dot{Z}_{KAC}\left(\dot{I}_{cC} + \dot{I}_{sC}\right) \\ \Delta\dot{U}_{cB} = \dot{Z}_c\dot{I}_{cB} + \dot{Z}_{cs}\dot{I}_{sB} + \dot{Z}_{KAB}\left(\dot{I}_{cA} + \dot{I}_{sA}\right) + \\ +\dot{Z}_{KBC}\left(\dot{I}_{cC} + \dot{I}_{sC}\right) \\ \Delta\dot{U}_{cC} = \dot{Z}_c\dot{I}_{cC} + \dot{Z}_{cs}\dot{I}_{sC} + \dot{Z}_{KAC}\left(\dot{I}_{cA} + \dot{I}_{sA}\right) + \\ +\dot{Z}_{KBC}\left(\dot{I}_{cB} + \dot{I}_{sB}\right) \\ \Delta\dot{U}_{sA} = \dot{Z}_s\dot{I}_{cA} + \dot{Z}_{cs}\dot{I}_{cA} + \dot{Z}_{KAB}\left(\dot{I}_{cB} + \dot{I}_{sB}\right) + \\ +\dot{Z}_{KAC}\left(\dot{I}_{cC} + \dot{I}_{sC}\right) \\ \Delta\dot{U}_{sB} = \dot{Z}_s\dot{I}_{cB} + \dot{Z}_{cs}\dot{I}_{cB} + \dot{Z}_{KAB}\left(\dot{I}_{cA} + \dot{I}_{sA}\right) + \\ +\dot{Z}_{KBC}\left(\dot{I}_{cC} + \dot{I}_{sC}\right) \\ \Delta\dot{U}_{sC} = \dot{Z}_s\dot{I}_{cC} + \dot{Z}_{cs}\dot{I}_{cC} + \dot{Z}_{KAC}\left(\dot{I}_{cA} + \dot{I}_{sA}\right) + \\ +\dot{Z}_{KBC}\left(\dot{I}_{cB} + \dot{I}_{sB}\right)\end{cases} \quad (1)$$

where $\dot{I}_{sA}$, $\dot{I}_{sB}$, $\dot{I}_{sC}$ are screen currents of cable phases A, B, C; $\dot{I}_{cA}$, $\dot{I}_{cB}$, $\dot{I}_{cC}$ are core currents of cable phases A, B, C; $\dot{Z}_c$, $\dot{Z}_s$, $\dot{Z}_{cs}$ are internal resistance and mutual active-inductive cable resistances.

To estimate the influence of transposition of phase cables of a three-phase cable bus at grounding two sides of screens, we rewrite the last three equations of the system (1) taking into account that distances between the axes of phases A and B (s_{AB}), B and C (s_{BC}) are equal, and distances between the axes of phases A and C (s_{AC}) are twice as much: $s_{AC} = 2s_{AB} = 2s_{BC}$.

Let $s_{AB} = s_{BC} = s$, then the mutual resistances between the cables A, B, C are:

$$\dot{Z}_{AB} = \dot{Z}_{BC} = \dot{Z}_K,$$
$$\dot{Z}_{AC} = \dot{Z}_K - \dot{Z}_X,$$

where $\dot{Z}_X = jwM_X$; M_X is the difference of mutual inductances.

Thus, the voltage drop in the cable screens:

$$\begin{cases} \Delta\dot{U}_{sA} = \dot{Z}_s \dot{I}_{sA} + \dot{Z}_{cs}\dot{I}_{sA} + \dot{Z}_K\left(\dot{I}_{sB} + \dot{I}_{cB}\right) + \\ +\left(\dot{Z}_K - \dot{Z}_X\right)\left(\dot{I}_{sC} + \dot{I}_{cC}\right) \\ \Delta\dot{U}_{sB} = \dot{Z}_s \dot{I}_{sB} + \dot{Z}_{cs}\dot{I}_{sB} + \dot{Z}_K\left(\dot{I}_{sA} + \dot{I}_{cA}\right) + \\ +\dot{Z}_K\left(\dot{I}_{sC} + \dot{I}_{cC}\right) \\ \Delta\dot{U}_{sC} = \dot{Z}_s \dot{I}_{sC} + \dot{Z}_{cs}\dot{I}_{sC} + \\ +\left(\dot{Z}_K - \dot{Z}_X\right)\left(\dot{I}_{sA} + \dot{I}_{cA}\right) + \dot{Z}_K\left(\dot{I}_{sB} + \dot{I}_{cB}\right) \end{cases}$$

Taking into account additional and boundary conditions, we find it possible to determine the currents in screens at the location of cables in a row:

$$\dot{I}_{sA} = 0.5\left[\frac{-2\dot{Z}_K\dot{Z}_X - \left(\dot{Z}_{cs} - \dot{Z}_K - \dot{Z}_X\right)\left(2\dot{Z}_K + \dot{Z}_s\right)\times}{2\dot{Z}_K\left(2\dot{Z}_K + \dot{Z}_s - \dot{Z}_X\right) - \left(\dot{Z}_s + \dot{Z}_K - \dot{Z}_X\right)\left(2\dot{Z}_K + \dot{Z}_s\right)} - j\sqrt{3}\frac{\dot{Z}_{cs} - \dot{Z}_K + \dot{Z}_X}{\dot{Z}_s + \dot{Z}_K - \dot{Z}_X}\right]\dot{I}_{cB};$$

$$\dot{I}_{sB} = \frac{\left(\dot{Z}_{cs} - \dot{Z}_K - \dot{Z}_X\right)\left(2\dot{Z}_K + \dot{Z}_s - \dot{Z}_X\right) + \dot{Z}_X\left(\dot{Z}_s + \dot{Z}_K - \dot{Z}_X\right)}{2\dot{Z}_K\left(2\dot{Z}_K + \dot{Z}_s - \dot{Z}_X\right) - \left(\dot{Z}_s + \dot{Z}_K - \dot{Z}_X\right)\left(2\dot{Z}_K + \dot{Z}_s\right)}\dot{I}_{cB};$$

$$\dot{I}_{sC} = 0.5\left[\frac{-2\dot{Z}_K\dot{Z}_X - \left(\dot{Z}_{cs} - \dot{Z}_K - \dot{Z}_X\right)\left(2\dot{Z}_K + \dot{Z}_s\right)}{2\dot{Z}_K\left(2\dot{Z}_K + \dot{Z}_s - \dot{Z}_X\right) - \left(\dot{Z}_s + \dot{Z}_K - \dot{Z}_X\right)\left(2\dot{Z}_K + \dot{Z}_s\right)} - j\sqrt{3}\frac{\dot{Z}_{cs} - \dot{Z}_K + \dot{Z}_X}{\dot{Z}_s + \dot{Z}_K - \dot{Z}_X}\right]\dot{I}_{cB}.$$

From the forgoing it can be seen that

$$\dot{I}_{sA} \neq \dot{I}_{sB} \neq \dot{I}_{sC}, \text{ and}$$

$$\dot{I}_{sA} + \dot{I}_{sB} + \dot{I}_{sC} =$$
$$= \frac{\dot{Z}_X\left(\dot{Z}_s - \dot{Z}_{cs}\right)}{2\dot{Z}_K\left(2\dot{Z}_K + \dot{Z}_s - \dot{Z}_X\right) - \left(\dot{Z}_s + \dot{Z}_K - \dot{Z}_X\right)\left(2\dot{Z}_K + \dot{Z}_s\right)}\times$$
$$\times\dot{I}_{cB} \neq 0.$$

4. The calculation results

As an example, we conduct the simulation and numeral calculation of currents in screens in the normal symmetric mode for the single-circuit cable bus. The calculation is made for a three-phase cable bus of 800/150 mm^2 under the voltage of 330 кВ for single-phase version. Cables are connected either as a closed delta or in a row with a gap $\Delta s = 0.1$ m between the cables of a circuit.

The design model, which is regarded as a single-circuit line and implemented by using an application package Simulink in Matlab system, is shown in Fig. 1.

Model shown in Fig.1 contains the following basic elements:

- three-phase voltage source with linear voltage of 330 V;
- model of the cable line 1 km long consisting of three units connected according to the cable transposition diagram, which in turn is modeled as 12-terminal element (3 cores and 3 screens) [3].

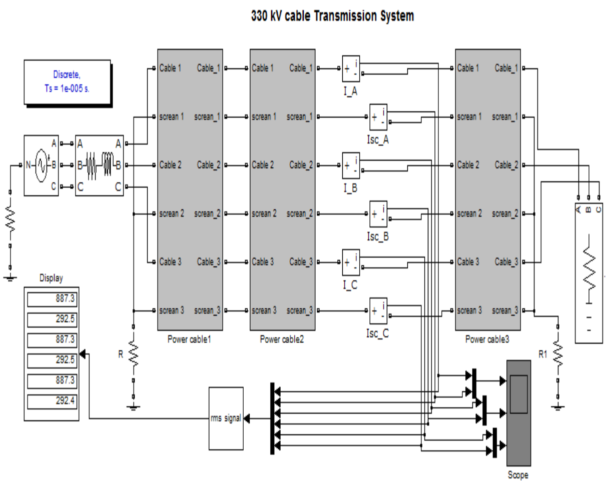
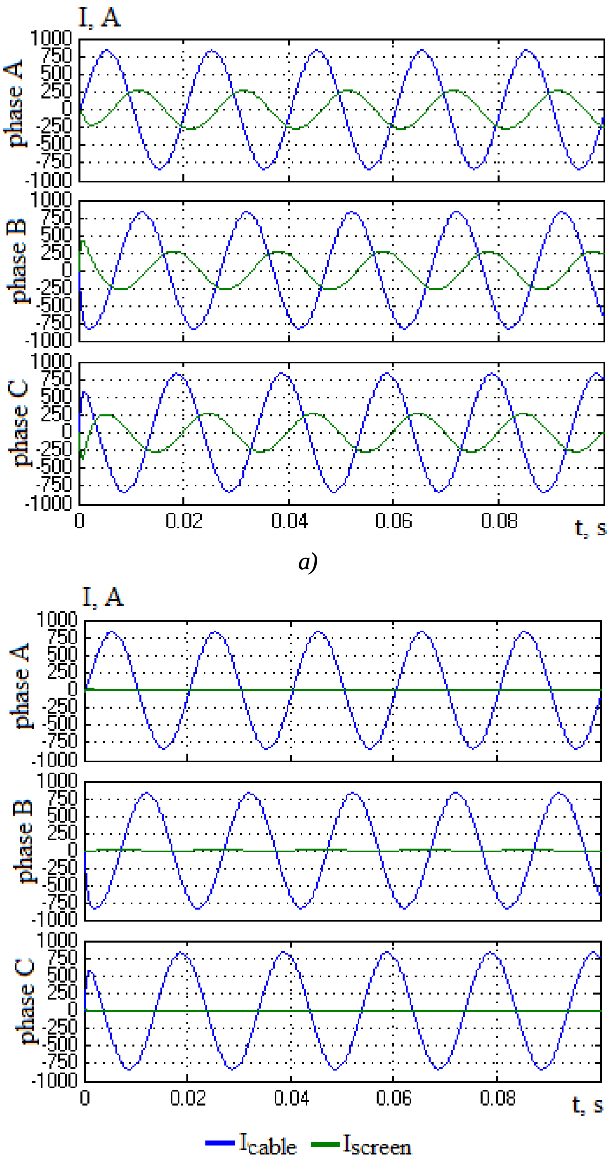


Fig. 1. Model of three-phase power transmission line cable.

The calculation of the electromagnetic parameters of the cables in the cable transmission lines is conducted with the use of the results from [4, 5]. The simulation results are shown as oscillograms in Fig. 2, 3.

In normal symmetric mode, for the delta laying method (Fig. 2, *a*), the reason for presence of currents in the screen was that nearby phases could not exert a compensative action as far as is necessary. In case of delta laying method and the application of complete cycle of transposition (Fig. 2, *b*) screens stop to belong to one certain phase of a cable and become common for all three phases, and a current can be neglected.

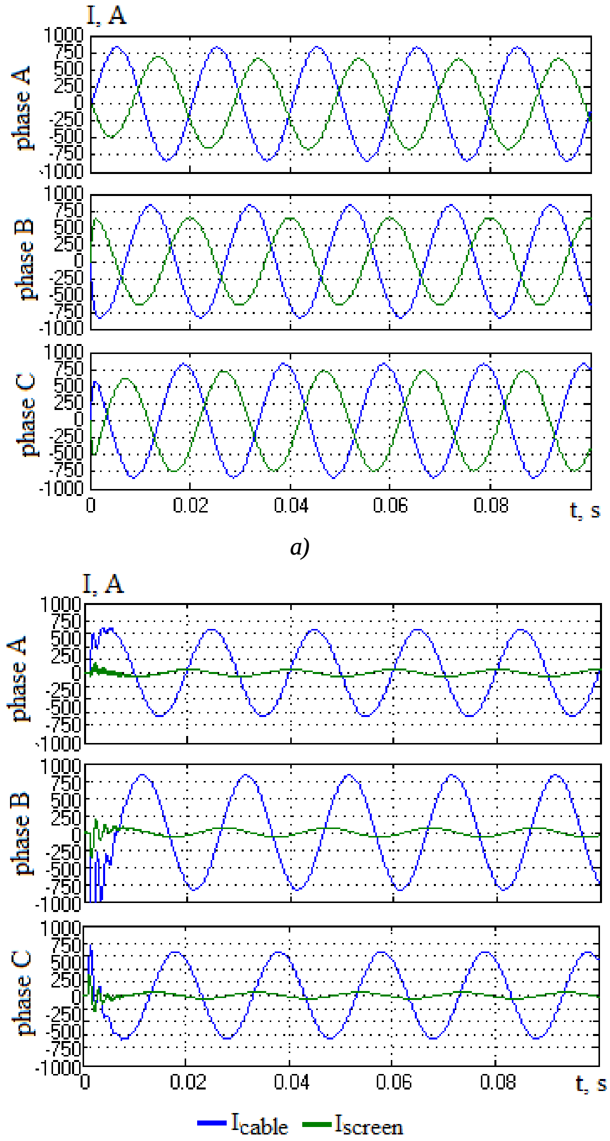


b)

Fig. 2. Oscillograms of currents in screens in relation to currents in the cable core, mutual phase location: delta (a); delta with transposition of screens (b).

While cable laying is performed in a row without transposition (Fig. 3, *a*), it is evident that increasing the distance between phases will increase the currents in the screens, and the currents can vary notably (in considered case – in 0.88/0.783 = 1,2 times).

In case of cable laying in a row it makes sense to execute the transposition of cables (Fig. 3, *b*), because it evens the intensity of currents in screens to some mean value (here – 0.16 p.u.), and reduces currents in screens as compared with a case without transposition of cables (0.16 instead of 0.88 p.u.).



b)

Fig. 3. Oscillograms of currents in screens in relation to currents in the cable core, mutual phase location: in a row (a); in a row with screen transposition (b).

The results of numeral calculations of currents in screens in relation to currents in cable cores are summarised in Table 1. Currents in screens are directly proportional to the currents in cores, and for convenience, they are given in Table 1 in corresponding relative units.

5. Conclusion

The methodology that allows estimating the intensity of currents on the screens of cables at transposition of three-phase cable bus is proposed, in case of grounding its screens from each side and if cables in the line are located in a row.

While bilateral grounding of screens if the phases are laid in a row (but not by delta connection), then according to Table 1, the transposition of cables will be useful. It will equalise the losses in screens to some mean value, so losses in one of the phases will be reduced, and, as a result, it will cause the decrease in general losses in a cable bus and, in theory, will extend the life of its isolation.

Table 1

Results of numeral calculations of currents in screens in relation to currents in the cable conductors

Mutual location of phases	Currents I_{cable} / I_{screen}, p.u		
	phase *A*	phase *B*	phase *C*
Delta	0.329	0.329	0.329
Delta with screen transposition	0.01	0.01	0.01
in a row $\Delta s = 0.1$	0.792	0.783	0.88
in a row with screen transposition $\Delta s = 0.1$	0.168	0.164	0.16

References

[1] A. A. Shcherba, A. D. Podoltsev, and I. M. Kucheriava, “Electromagnetic Processes in 330 kV cable Line With Polyethylene Insulation”, *Teknichna Elektrodynamika*, no. 1, pp. 9–15, 2013. (Russian)

[2] M. V. Dmitriev and M. R. Kiyatkina, “Transposition of 6–500 kV cable shields”, *Novosti elektrotekhniki*, vol. 74, no. 2, pp. 80–84, 2012. (Russian)

[3] V. Lobodzinskiy and L. Maślak, “Mathematical modeling of the three-phase high-voltage cable lines under the theory of multiterminal networks”, in *Proc. IEEE 16th International Conference on Computational Problems of Electrical Engineering (CPEE)*, pp. 96–98, Lviv, Ukraine, 2015.

[4] N. D. Tleis, *Power Systems Modeling and Fault Analysis Theory and Practice*, Elsevier: Amsterdam, Netherlands, 2008.

[5] I. M. Wedepohl and D. J. Wilcox, “Transient analysis of underground power-transmission systems. System-model and wave-propagation characteristics”, *Proceedings of the Institution of Electrical Engineers*, vol. 120, no. 2, pp. 253–260, 1973.

ДОСЛІДЖЕННЯ ЕФЕКТИВНОСТІ ТРАНСПОЗИЦІЇ ЕКРАНІВ ТРИФАЗНИХ КАБЕЛЬНИХ ЛІНІЙ З УРАХУВАННЯМ ВЗАЄМНОГО РОЗТАШУВАННЯ КАБЕЛІВ

Валерій Чібеліс, Вадим Лободзинський, Ольга Ілліна

Розглянуто методику, яка дає змогу оцінити величини струмів на екранах кабелів та вибрати способи злучення та уземлення екранів. Щоб досягти вказаної мети, необхідно розробити математичну модель, виконати чисельні розрахунки для моделювання та перевірки ефективності транспозиції екранів з урахуванням їх взаємного розташування. За результатами роботи визначено, що в разі уземлення екранів з двох сторін і розташування фазних кабелів в один ряд потрібно транспонувати кабелі лінії. Це вирівнює величини струмів в екранах до деяких середніх значень.

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