M. I. Burbelo, Dr. Sc. (Eng.), Prof.; S. M. Melnytchyk; O. O. Emelianov

APPLICATION OF DIRECTIONAL CURRENT PROTECTION FOR DETECTION OPEN PHASE LOADING MODES IN THE GRIDS WITH EFFICIENTLY GROUNDED NEUTRAL

The paper analyzes the values, directions and relations of conventional power of zero and negative sequence in longitudinal asymmetry modes. The possibility of such values application for protection of grids with efficiently grounded neutral is proved.

For the protection against open-phase modes the directed protection of conventional power of negative sequence, operating after determining the argument of these powers in p-reset sectors of complex plane is suggested to use.

Key words: *open-phase modes, relay protection, conventional power of negative sequence, pulsating power.*

Problem statement

In accordance with the requirements of Clause. 3.2.106 of Rules of Arrangement of Electrical Installations [1] for lines of 110 kV in the grids with efficiently grounded neutral relay protection(RP) devices against interphase short circuit and earth shortings must be provided. Protection against the modes of longitudinal asymmetry on such lines is not provided by normative documents. In case of open-phase modes arising faulty, redundant operation of relay protection devices of adjacent elements of electric grid and disturbances in the functioning of electric equipment – motors and transformers is possible.

In the process of development of relay protection (RP) devices the method of symmetrical components [2] found wide application, one of the principle postulates of this method is the statement that the place of asymmetric fault rise is the source of powers of zero and negative sequences. If sufficient current is available, the fact of open-phase mode occurrence is determined by current directional protection of zero sequence (CPZS). At the substation, from which several lines leave, the faulty line can be detected by the direction of vector $\underline{I}_0$ relatively $\underline{U}_0$:– power $\underline{S}_0$ at the damaged overhead transmission line (OL) will be directed from the line to the bus of substation, and at others, non damaged OL, vice versa, it will spread from the buses of substation in the lines. Such protection in case of short circuit with short circuiting on the ground operates also efficiently, both in radial and in closed circular grids. By the value of the current $\underline{I}_0$ the distance to the place of short circuit can be found and determine where the failure occurred: at own OL or at the lines, which leave the adjacent substation. If open-phase mode occurs at sufficient values of current we can detect on the side of which OL that leaves the buses of substation the failure took place. However, application of CPZS in many cases is characterized by insufficiently high sensitivity.

In relay protection devices, manufactured by the company Schneider Electric for detection of wire break on the line the relation I_2 / I_1 is suggested to use. Similar algorithm is applied by the company General Electric. Using such method when the break took place at one of two parallel lines, we can determine which line is damaged and which one is operational. Value of I_2 at both lines will be the same, but I_1 at the damaged line will be less than at operational line. Correspondingly, relation I_2 / I_1 for the damaged line will be greater than for operational line.

But application of such an approach for transit substations with small own demand is rather problematic, because the I_2 / I_1 relation at both lines – damaged and operational – will be very close by value and this will not provide the possibility for selective operation of the protection [3].

Substantiation of the results

We will analyze the possibility of detection of open- phase loading mode on the example of distributed circular grid 110 кV (Fig. 1). We will perform only the analysis of powers of zero sequence $\underline{S}_0 = 3\dot{U}_0 \overset{*}{I}_0$, conventional power of zero sequence $\underline{S}_{10} = 3\dot{U}_1 \overset{*}{I}_0$ which are transmitted by lines, and conventional power of zero sequence of the transformers $\underline{S}_{10\text{T}} = 3\dot{U}_1 \overset{*}{I}_{0\text{T}}$. Usage of the powers will provide the possibility to perform the comparative analysis.

Table 1 contains the results of circular network calculation in case of phase A L-3 break. For convenience, data, regarding the broken line are marked with half-bold type. The calculation is performed applying the method of symmetrical components, using the following data: power of the system $\text{S}_s = 1000\,\text{MW·A}$ ($X_{s1} = X_{s2} = 13.2\,\text{Ohm}$, $X_{s0} = 1.4X_{s1} = 18.5\,\text{Ohm}$); linear resistances supports of the lines of direct, reverse and zero sequences $Z_{lin.1} = Z_{lin.2} = 0.125 + j0.41$ Ohm/km.; $Z_{lin.0} = 0.274 + j1.38$ Ohm/km; power of the transformers $\text{S}_{NT} = 16$ MW·A ($\overset{*}{u}_{sh} = 0.105$); power of loads $\text{S}_{l1} = 10\,\text{MB·A}$ ($\cos\varphi_l = 0.866$), $\text{S}_{l2} = 5\ or\ 10$ MW·A ($\cos\varphi_l = 0.866$).

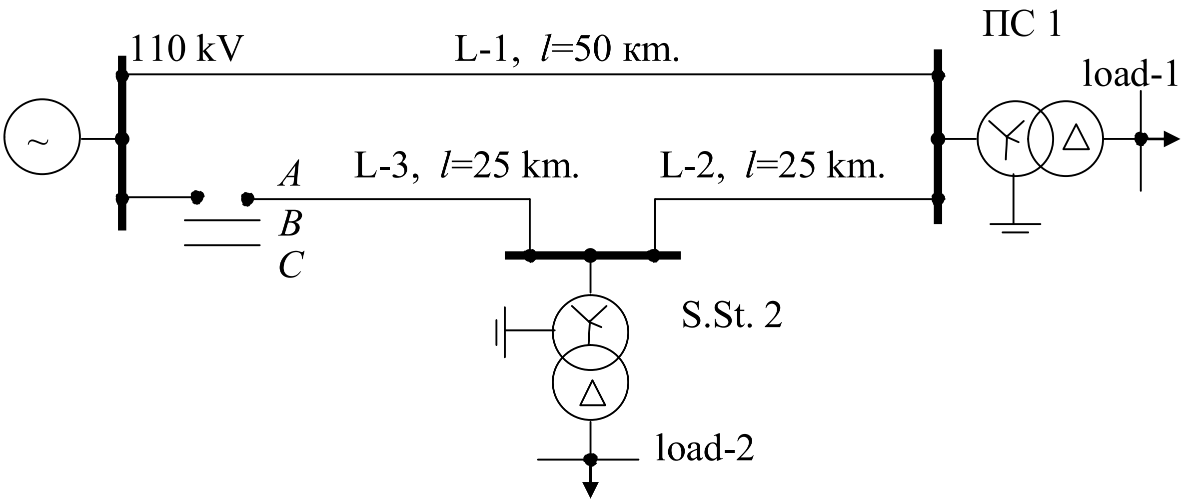

Fig. 1. Calculation scheme of circular grid

Table 1

Results of open-phase mode in case of *A* phase break of line L-3

Substation, line	Load	$\underline{S}$, MW·A	$\underline{S}_0$, кV·A	$\underline{S}_{10}$, MW·A	$\underline{S}_{10\text{T}}$, MW·A
S.St-1, L-1	$S_{l2} = S_{l1}$	12.2 ∟28°	3.7 ∟-101°	0.8 ∟28°	-0.7 ∟39°
	$S_{l2} = 0.5S_{l1}$	9.6 ∟29°	1.8 ∟-101°	0.6 ∟28°	-0.5 ∟39°
S.St.-1, L-2 (L-**3**)	$S_{L2} = S_{L1}$	-2.3 ∟26°	**6.7 ∟84°**	**-1.5 ∟33°**	**-0.7 ∟39°**
	$S_{l2} = 0.5S_{l1}$	0.3 ∟48°	**3.3 ∟84°**	**-1.0 ∟33°**	**-0.5 ∟39°**
S.St.-2, L-2 (L-1)	$S_{l2} = S_{l1}$	2.3 ∟26°	0.9 ∟-58°	1.5 ∟33°	-1.3 ∟41°
	$S_{l2} = 0.5S_{l1}$	-0.3 ∟48°	0.4 ∟-58°	1.0 ∟33°	-0.9 ∟41°
S.St.-2, **L-3**	$S_{l2} = S_{l1}$	7.5 ∟30°	**1.6 ∟126°**	**-2.7 ∟37°**	**-1.3 ∟41°**
	$S_{l2} = 0.5S_{l1}$	5.3 ∟30°	**0.8 ∟126°**	**-1.9 ∟37°**	**-0.9 ∟41°**

From the given table it follows, that phase L-3 break can be detected by the argument of power

$\underline{S}_0$, application of which provides the possibility of selective operation of protection in circular grid. Taking into account the fact, that power argument $\underline{S}_0$ varies in fixed sectors from 84 to 126 electrical degree and from -101 to -58 electrical degrees , that correspond to damaged and non-damaged lines and these sectors remain the same in case of damage of any phase, the damaged line can be detected by the value of argument and provide the selectivity of damaged line switching can be provided, having built directly dependent characteristic of switching time on the argument of this power. Argument of this power is greater at L-2, S.St.-1 than at L-3 S.St.-2, which is damaged. This characteristic is stable at different relations of powers. However, sensitivity will not be sufficiantly high ($\underline{S}_0$=800 V·A at $\underline{S}$=5.3 MV·A).

Break of the phase can be detected by power argument $\underline{S}_{10}$ (angle of current $\dot{I}_0$ phase shift relatively voltage $\dot{U}_1$) as the direction of this value for damaged line of circular grid changes into opposite relatively power $\underline{S}$ direction. Taking into consideration that power argument $\underline{S}_{10}$ is in fixed sectors, corresponding to damaged and non-damaged lines of this power more than at L-3 S.St.-2 than at L-2 S.St.-1, using power $\underline{S}_{10}$ or current $\dot{I}_0$ selective disconnection of damaged line L-3 can be provided.

To provide selective operation of the protection by the power $\underline{S}_{10}$ or current $\dot{I}_0$ reverse dependent characteristic of operation time on the modulus of these values must be provided. Sector, determined by the argument $\underline{S}_{10}$, $\dot{I}_0$, that corresponds to damaged and non-damaged phases, changes into 120 electric degrees depending on the fact, what phase is damaged. But as these sectors are much more narrower, than for $\underline{S}_0$ power, then realization of such protection by means of microprossesor is possible. Sensitivity of the protection using $\underline{S}_{10}$ increases, as compared with the fact that informative is power $\underline{S}_0$ ($\underline{S}_{10}$=1.9 MV·A at $\underline{S}$=5.3 MV·A).

Additional condition that can be used for detection of the damaged line, is the direction of power $\underline{S}_{10\text{T}}$ at the given substation. If $\underline{S}_{10\text{T}}$ is within the same sector that $\underline{S}_{10}$ of the controlled line, then the line is damaged. The given condition is necessary for the lines, where the change of power transmission direction takes place.

Table 2 contains the results of open-phase mode calculations in case of phase *A of* line L-2 break,it is seen from the Table that uniformity of vectors $\underline{S}_{10}$ of the controlled line and $\underline{S}_{10\text{T}}$ of S.St. transformer is main criterion of wire break detection for lines with the reverse of power transmission direction.

Table 2

Results of open -phase mode calculations in case of phase *A* of line L-2 break

Substation, line	Load	$\underline{S}$, MV·A	$\underline{S}_0$, кV·A	$\underline{S}_{10}$, MW·A	$\underline{S}_{10\text{T}}$, MV·A
S.St.-1, L-1	$S_{l2}=S_{l1}$	8.4 ∟29°	0.3 ∟-101°	0.3 ∟32°	-0.2 ∟43°
	$S_{l2}=0.5S_{l1}$	7.7 ∟29°	0.8 ∟-101°	0.4 ∟32°	-0.3 ∟43°
S.St.-1, **L-2** (L-3)	$S_{l2}=S_{l1}$	1.5 ∟30°	**0.6 ∟84°**	**-0.4 ∟37°**	**-0.2 ∟43°**
	$S_{l2}=0.5S_{l1}$	2.2 ∟30°	**1.3 ∟84°**	**-0.7 ∟37°**	**-0.3 ∟43°**
S.St.-2, **L-2** (L-1)	$S_{l2}=S_{l1}$	-1.5 ∟31°	**0.4 ∟82°**	**0.4 ∟37°**	**0.1 ∟44°**
	$S_{l2}=0.5S_{l1}$	-2.2 ∟31°	**0.8 ∟82°**	**0.7 ∟36°**	**0.2 ∟44°**
S.St.-2, L-3	$S_{l2}=S_{l1}$	11.4 ∟30°	0.3 ∟-101°	-0.3 ∟33°	0.1 ∟44°
	$S_{l2}=0.5S_{l1}$	7.2 ∟30°	0.6 ∟-101°	-0.5 ∟33°	0.2 ∟44°

As the same time, if the neutral of the transformer at S.St.-1 or S.St.-2 is disconnected from the earth, then the application of zero sequence values for selective disconnection of the damaged line is impossible. The above-mentioned characteristic requires taking into account of this factor while choosing substations with transformers neutrals, disconnected from the earth.

Conclusions

Values, directions and relations of power, zero sequence, conventional powers of zero and reverse sequences in longitudinal asymmetry modes are analyzed.

For protection against open-phase modes of supply lines with one-way direction of power transmission the directed protection of conventional power of zero sequence (current of zero sequence) is suggested to be used, the given protection operates on the fact of detection of this power (current) argument in preset sectors of complex plane.

For supply lines with two-way direction of power transfer the uniformity of location of vectors $\underline{S}_{10}$ of controlled line and $\underline{S}_{10\,\mathrm{T}}$ of S.St. transformer is suggested as the criterion of wire break of one phase of circular grid line.

REFERENCES

1. Правила улаштування електроустановок. – Харків : Вид-во «Форт», 2011. – 736 с.

2. Вагнер К. Ф. Метод симметричных составляющих / К. Ф. Вагнер, Р. Д. Эванс. – ОНТИ НКТП СССР, 1936. – 407 с.

3. Нагай В. И. Релейная защита ответвительных подстанций электрических сетей / Нагай В. И. – М. : Энергоатомиздат, 2002. – 312 с.

Burbelo Mykhailo – Dr. Sc. (Eng.), Professor with the Department of Electrical Engineering Systems of Energy Supply and Energy Management.
Vinnytsia National Technical University.

Melnytchyk Sergiy – Engineer, South-West Electric Energy System of State Enterprise NEC «Ukrenergo».
South-West Electric Energy System of State Enterprise of «NEC «Ukrenergo».

Emelianov Olexiy – Student, Institute of Electrical Power Engineering and Electromechanics.
Vinnytsia National Technical University.