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THE EXPECTED REDUCTION OF ENERGY NOT SUPPLIED TO CONSUMERS AFTER INSTALLATION THE IDENTIFIERS OF SINGLE-PHASE-TO-EARTH FAULT IN POWER NETWORKS WITH ISOLATED NEUTRAL

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Summary. Statistical researches of failures in medium voltage electrical power networks, which are constructed as overhead power lines with ACSR wire, show that most failures are due to single-phase-to-earth faults, which under certain conditions can transit into interphase faults. To reduce the energy not supplied to consumers proposed to install the special device in the power network. The name of this device is the identifier of single-phase-to-earth fault. It is shown that if the device is installed on supports of the overhead line of the power network, this can reduce the expected energy not supplied to consumers (EENS) by up to 32%. Moreover, the shorter the time it takes to locate the single-phase-to-earth fault in the power network, the greater will be the reduction in the EENS.

Key words: identifier of single-phase-to-earth fault, reliability indicators, EENS indicator, electrical power networks of medium voltage.

INTRODUCTION

Medium voltage power networks (in the post-Soviet countries this is 6-10 kV) is the longest and much branched, as a result less reliable. Most of these networks are made as overhead lines with ACSR wire and supply of electrical energy to consumers in areas with low electrical load density (in rural areas). In such networks it is used the isolated neutral mode to ensure the uninterrupted operation in the event of a single-phase-to-earth fault. However, during such faults, in the network the voltage asymmetry is created across the pin insulation, namely, the voltage in the damaged phase tends to zero, but in the other two phases it increases to a linear value. This increases the possibility of an interphase short circuit through the earth, which leads to power outage for consumers until fault is fixed.

ANALYSIS OF RESEARCHES AND PUBLICATIONS

In the articles (Buinyi et al., 2014; Farajollahi et al., 2019; Roos et al., 2018)to reduce the expected energy not supplied (EENS indicator), it is proposed to section the electrical network with switching devices, which allows to reduce the time of the search for the damaged section. In the article (Bezruchko et al., 2019) it was proposed to use special devices that allows you to determine the location of fault place with accuracy to the overhead line support, which will significantly improve the reliability of power supply. The name of this device is the identifier of single-phase-to-earth fault (ISPEF).

THE PURPOSE OF THE RESEARCH

The purpose of the article is to explain how presence of the ISPEFs on supports of the overhead line influences on the value of the reliability indicators. For it is necessary to create a mathematical model and make research.

THE RESULTS OF RESEARCH

The power supply reliability in existing medium voltage power network can be evaluate with used energy not supplied indicator (ENS). But in forecasting, it is used a multi-purpose indicator – the expected energy not supplied (EENS) (Buinyi et al., 2016). This indicator can be calculated:

$$EENS = P \cdot \theta = P \cdot (\omega_0 \cdot \tau + \gamma \cdot \nu_0 \cdot \eta) \cdot l_\Sigma \quad (1)$$

where: P – average power of disconnected consumers; θ – the duration of the restoration of supply to consumers with steady faults per year; ω_0 – linear total intensity of steady failures; τ – average duration emergency power cutoff or forced outage hours; ν_0 – linear frequency of planned power cutoff; η – average duration of network service during planned power cutoff; γ – coefficient taking into account smaller aftermath from planned compared to emergency power cutoff; l_Σ – total length of power overhead line in the network.

From the formula (1) it is seen that the reduction of energy not supplied can be achieved by reducing:

- the failure intensity ω_0;
- the duration emergency power cutoff τ.

Measures aimed at reducing the failure intensity ω_0 are measures that can only be applied when building new or reconstructing existing distribution power networks. Therefore these measures require large investment.

But measures aimed at reducing the duration emergency power cutoff τ, as a rule, are measures that reduce ENS due to small investments in existing medium voltage power networks.

The method proposed by the authors (Bezruchko et al., 2019) for found place of single-phase-to-earth fault in existing medium voltage distribution power networks makes it possible to detect these faults in a relatively short period of time and, as a result, reduce the reliability of a transition of the single-phase-to-earth fault into interphase fault (Tkach et al., 2019). That is, the energy not supplied to customers only if interphase fault take a place.

Based on the foregoing, the linear total intensity of steady failures ω_0 can be divided to components:

$$\omega_0 = \omega_0^{(2,3)} + \omega_0^{(1+1)}, \quad (2)$$

where: $\omega_0^{(2,3)}$ – linear total intensity of steady failures caused by two- and three-phase faults in the electrical network; $\omega_0^{(1+1)}$ – linear total intensity of steady failures caused fault in the electrical power network, which are formed after the transition of the single-phase-to-earth fault to interphase faults.

The device proposed in (Bezruchko et al., 2018) have influence on decreasing only value of $\omega_0^{(1+1)}$. This is due to the fact that with a decrease in the overall single-phase-to-earth fault clearance time, the probability of the transition of the single-phase fault into interphase fault is reduced.

In respect that formula (1) takes the form

$$EENS = P \cdot \theta =$$
$$= P \cdot (\omega_0^{(2,3)} \cdot \tau + \omega_0^{(1+1)} \cdot \tau + \gamma \cdot \nu_0 \cdot \eta) \cdot l_\Sigma =$$
$$= P \cdot (\theta^{(2,3)} + \theta^{(1+1)} + \theta_{\text{planned}}), \quad (3)$$

where: $\theta^{(2,3)}$ – the duration of the restoration of supply to consumers after emergency power cutoff caused by two- and three-phase faults in the electrical power network per year; $\theta^{(1+1)}$ – the duration of the restoration of supply to consumers after emergency power cutoff which are formed after the transition of the single-phase-to-earth fault into interphase faults; θ_{planned} – the duration of the restoration of supply to consumers after planned power cutoff.

Formula (3) is the objective function that needs to be analyzed.

Based on (3), it can be written that in the absence of ISPEF in the power network, the duration of restoration of power supply to consumers can be calculated by the formula:

$$\theta = \theta^{(2,3)} + \theta^{(1+1)} + \theta_{\text{planned}}, \quad (4)$$

and if ISPEF available in the power network, it can be calculated using the formula:

$$\theta_{\text{ISPEF}} = \theta^{(2,3)} + q \cdot \theta^{(1+1)} + \theta_{\text{planned}}, \quad (5)$$

where: q – the probability of a single-phase into interphase fault, in the case of a ISPEFs in the power network and emergency power cutoff.

Statistical research (Tkach et al., 2019) of failures in existing 6-10 kV distribution power networks of show that the value is a function of time t, $q = f(t)$. In case the ISPEFs is installed in the distribution networks, the time t includes both the duration of determining the location of the fault and the duration of the emergency crew moving to the location of fault and fixed it. It is clear that

$$q(0) = 0,\ q(\infty) = 1.$$

The value of q depends on the isolation state of the power network, namely:

- the level of pollution and aging;
- air humidity;
- the possibility of coincidence of the fault with precipitation and other.

Taking into account the above phenomena is a difficult task, requiring reliable statistical data not only on the state of electrical grid facilities, but also on natural and climatic factors. In a case of the absence of reliable statistical information, an expert method can be used.

Based on long-term researching of power failures at JSC «Chernigovoblenergo», it was established that the transition of single-phase into interphase faults can occur in two ways:

1) up to a certain critical time $t_{\text{cr.t.}}$ the probability of the transition of the single-phase into interphase fault linearly q increases with time;

2) up to a certain critical time $t_{\text{cr.t.}}$ the probability of the transition of the single-phase into interphase fault increases insignificantly $q \to 0$, and then sharply increases $q \to 0$.

It is proposed to describe the two above ways by the distribution laws depicted in Fig. 1.

In the first case, when by certain critical time the probability of the transition of a single-phase into interphase fault increases linearly with time, the mathematical reflection of the distribution law will look like:

$$q = f(t) = \begin{cases} \dfrac{t}{t_{\text{cr.t.}}}, & t < t_{\text{cr.t.}}; \\ 1, & t \geq t_{\text{cr.t.}}, \end{cases} \qquad (6)$$

but the other case, when the probability of the transition of the single-phase into interphase fault increases insignificantly, and after that time its increases abruptly:

$$q = f(t) = \begin{cases} 0, & t < t_{\text{cr.t.}}; \\ 1, & t \geq t_{\text{cr.t.}}. \end{cases} \qquad (7)$$

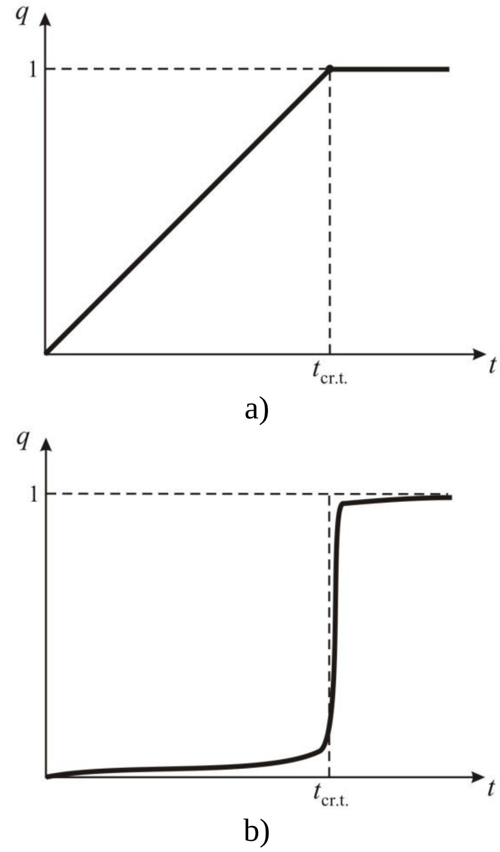


Figure 1. Proposed laws of transition probability distribution single-phase into interphase fault

That is, in the case of using the ISPEFs in the medium voltage distribution power networks, the duration of the restoration of supply to consumers θ can be reduced by:

$$\delta\theta = \theta - \theta_{\text{ISPEF}} = \theta^{(1+1)} \cdot (1-q), \qquad (8)$$

but energy not supplied can be reduced by:

$$\delta EENS = P \cdot \delta\theta = P \cdot \theta^{(1+1)} \cdot (1-q). \qquad (9)$$

Using formulas (6), (8) and (9), we can obtain the dependences of a decrease in the duration of restoration of power supply:

- for the first case

$$\delta\theta = \begin{cases} \theta^{(1+1)} \cdot \left(1 - \dfrac{t}{t_{\text{cr.t.}}}\right), & t < t_{\text{cr.t.}}; \\ 0, & t \geq t_{\text{cr.t.}}, \end{cases} \qquad (10)$$

- for the second case

$$\delta\theta = \begin{cases} \theta^{(1+1)}, & t < t_{\text{cr.t.}}; \\ 0, & t \geq t_{\text{cr.t.}}, \end{cases} \qquad (11)$$

and the expected energy not supplied to customers:

- for the first case

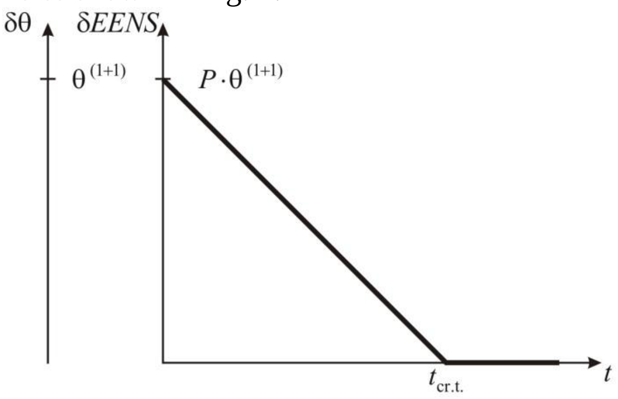
$$\delta EENS=\begin{cases}P\cdot\theta^{(1+1)}\cdot\left(1-\dfrac{t}{t_{\text{cr.t.}}}\right), & t<t_{\text{cr.t.}};\\ 0, & t\geq t_{\text{cr.t.}},\end{cases} \quad (12)$$

- for the second case

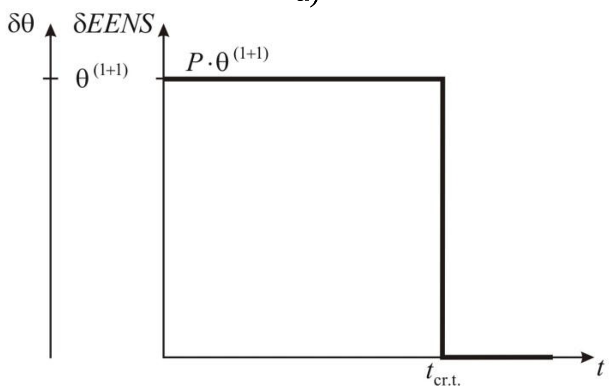
$$\delta EENS=\begin{cases}P\cdot\theta^{(1+1)}, & t<t_{\text{cr.t.}};\\ 0, & t\geq t_{\text{cr.t.}},\end{cases} \quad (13)$$

for the two proposed types of probability distribution of the transition of a single-phase into interphase fault if there are ISPEFs in the network.

The graphical display of such dependencies shown in Fig. 2.



a)



b)

Figure. 2. Decrease in the duration of restoration of power supply to consumers and the energy not supplied from time in case of introduction of the ISPEFs: a) for the first type of distribution; b) for the second type of distribution

As a rule, at the stage of introducing any means of increasing reliability, which also includes the device proposed by the authors, everybody are interested not in absolute but in relative values of the parameters. Therefore, dependencies were obtained that made it possible to calculate the relative value of reducing of the duration of the restoration of power supply to consumers $\delta\theta_{\%}$ and reducing the energy not supplied to customers $\delta EENS_{\%}$:

$$\delta EENS_{\%}=\delta\theta_{\%}=$$
$$=\frac{\theta^{(1+1)}\cdot(1-q)}{\theta^{(2,3)}+\theta^{(1+1)}+\theta_{\text{planned}}}\cdot 100\%=$$
$$=\frac{\omega_0^{(1+1)}\cdot\tau\cdot(1-q)}{\omega_0^{(2,3)}\cdot\tau+\omega_0^{(1+1)}\cdot\tau+\gamma\cdot\nu_0\cdot\eta}\cdot 100\%\,. \quad (14)$$

Since from statistical research it is known that single-phase-to-earth faults are α% of all faults in the power network, then

$$\begin{cases}\omega_0^{(1+1)}=\dfrac{\alpha}{100}\cdot\omega_0\,;\\ \omega_0^{(2,3)}=\left(1-\dfrac{\alpha}{100}\right)\cdot\omega_0\,.\end{cases} \quad (15)$$

Using (15) and (14):

$$\delta\theta_{\%}=\frac{\frac{\alpha}{100}\cdot\omega_0\cdot\tau\cdot(1-q)}{\left(1-\frac{\alpha}{100}\right)\cdot\omega_0\cdot\tau+\frac{\alpha}{100}\cdot\omega_0\cdot\tau+\gamma\cdot\nu_0\cdot\eta}\cdot 100\%$$

$$\delta EENS_{\%}=\delta\theta_{\%}=\frac{\frac{\alpha}{100}\cdot\omega_0\cdot\tau\cdot(1-q)}{\omega_0\cdot\tau+\gamma\cdot\nu_0\cdot\eta}\cdot 100\%\,. \quad (16)$$

The statistics show that $\gamma\cdot\nu_0\cdot\eta/\omega_0\cdot\tau\approx 0{,}25$, therefore

$$\delta EENS_{\%}=\delta\theta_{\%}\approx 0{,}8\cdot\alpha\cdot(1-q)\,. \quad (17)$$

It is known from (Tkach et al., 2019) that $\alpha=40\,\%$, so the relative value of reducing of the duration of the restoration of power supply to consumers $\delta\theta_{\%}$ and reducing the energy not supplied $\delta EENS_{\%}$ will be equal to:

- for the first kind of probability distribution of single-phase transition into interphase fault

$$\delta EENS_{\%}=\delta\theta_{\%}\approx\begin{cases}32\cdot\left(1-\dfrac{t}{t_{\text{cr.t.}}}\right), & t<t_{\text{cr.t.}};\\ 0, & t\geq t_{\text{cr.t.}},\end{cases} \quad (18)$$

- for the second type of probability distribution of single-phase transition into interphase fault

$$\delta EENS_{\%} = \delta\theta_{\%} \approx \begin{cases} 32, & t < t_{\text{cr.t.}}; \\ 0, & t \geq t_{\text{cr.t.}}. \end{cases} \quad (19)$$

From the above and formulas (18) and (19) it is evident that in the case of installation of the devices proposed by the authors in the electrical power network, the duration of the restoration of power supply to consumers $\delta\theta_{\%}$ and reducing the energy not supplied $\delta EENS_{\%}$ will be reduced by up to 32%.

CONCLUSIONS

1. Formulas based on probability theory are obtained that allow one to evaluate the effect of ISPEFs in power networks with isolated neutral on the EENS. They take into account two different possible ways of transferring a single-phase into interphase faults, which are obtained from long-term research of power networks at JSC «Chernigovoblenergo».

2. An analysis of the obtained formulas based on the accepted statistics on failures made it possible to establish that in the case of integration into the electrical power network of the ISPEF, one should expect a decrease in the EENS by up to 32%. Moreover, the shorter the time to determine the fault location, the greater will be the reduction in the EENS.

REFERENCES

Buinyi R.O., Dikhtiaruk I.V., & Zorin V.V. (2014). The automatic sectionalization of the distributing networks with high voltage of 6–10 kV with application the disconnectors of new generation. *Technical Electrodynamics,* 3/6, 70-75 [in Ukrainian].

Farajollahi M., Fotuhi-Firuzabad M., & Safdarian A. (2019) Sectionalizing Switch Placement in Distribution Networks Considering Switch Failure. *IEEE Transactions on Smart Grid,* 10, 1080-1082. doi: 10.1109/TSG.2018.2867199.

Zidan A., Khairalla M., Abdrabou A.M., Khalifa T., Shaban K., Abdrabou A., Shatshat R.E., & Gaouda A. M., (2016) Fault Detection Isolation and Service Restoration in Distribution Systems: State-of-theArt and Future Trends", *IEEE Transactions on Smart Grid*, 99, 1-16. doi: 10.1109/TSG.2016.2517620.

Bezruchko V., Buinyi R., Strogii A., & Tkach V. (2019) Integration of New Single-Phase-to-Ground Faults Detection Devices into Existing SmartGrid Systems. *IEEE 6th International Conference on Energy Smart Systems, ESS 2019,* 84-87. doi: 10.1109/ESS.2019.8764237.

Buinyi R., Zorin V.V., Tislenko V.V. (2014) How to take into account the distribution of load in distribution lines 10kv for optimal allocation of switches. *Electrification and automation of agriculture.* [in Ukrainian].

Tkach, V., Bezruchko, V., & Buinyi, R. (2019). The effect of single-phase-to-ground faults on the operational reliability indicators of overhead lines 6-10 kV PJSC «Chernigivoblenrego». *Bulletin of NTU "KhPI"*, 1, 120-126. [in Ukrainian]. doi:10.20998/2413-4295.2019.01.14

Bezruchko V.M., Buinyi R.O., Strogii A.Y., Tkach V.I. (2018). Application of GSM technology for identification of phase-to-ground faults in electric networks with isolated neutral and pin-type isolation. *Technical Electrodynamics,* 5/6, 96-99 [in Ukrainian]. doi: 10.15407/techned2018.05.096