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Multiplicity of Overvoltages during Arc Single Phase Earth Faults in 35 kV Electrical Grids

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Abstract

The arc overvoltages during the single phase to earth faults in electrical distribution grids of 6-35 kV are the object of the research in this paper. The development of 35 kV distribution electrical grids is accompanied by the construction of new overhead and cable power lines. It causes a change of the capacitive earth fault current in the grids and also affects the multiplicity of overvoltages in electrical distribution grids during the single phase to earth faults. The paper shows the research results of overvoltages during arc single phase to earth faults in 35 kV electrical grid with the different grounding modes of a grid neutral (an isolated neutral, a grounded neutral through an arc-quenching reactor, a grounded neutral through a resistor). The calculations were performed on the digital models of the investigation power grids. According to the research results, a mathematical model has been created, which allows obtaining the maximum expected multiplicity of overvoltages in 35 kV electrical grids during the single phase to earth faults. This allows making decisions about the optimal measures for the protection of an electrical equipment insulation taking into account expected values of overvoltages as early as at the stage of pre-design works for the development of such electrical grids.

Keywords: electrical grid; arc overvoltage; isolated neutral; single phase to earth fault; mathematical model.

1. Introduction

In Ukraine, the medium voltage electrical grids of 6-35 kV operate normally on a radial principle, although in most cases they have closed connection or two-way power supply. The 6-35 kV electrical grids consist of the overhead and cable power lines. There are the grids with only overhead or cable power lines and also the power grids with both overhead and cable lines.

The electrical grids are developing – the new overhead and cable power lines are being built. Together with the transmission power lines, which have the uninsulated wires and cables with oil-paper insulation, the new designs of power lines are appearing with the self-supporting insulated wires and cables with cross-linked polyethylene insulation. The development of electrical grids causes an increase in a total length of the power lines and an increase of the capacitive earth fault current in the network, which also affects the level of overvoltages.

The 6-35 kV electrical grids, according to “Rules for arrangement of electrical installations” (RAEI) (Ukr. – PUE) [1], can operate with the below grounding modes of a grid neutral: with an isolated neutral; with a grounded neutral through an arc-quenching reactor in case of exceeding the normative values of capacitive earth fault currents or with a grounded neutral through a resistor; and also, with a neutral grounded simultaneously through an arc-quenching reactor and a resistor. If the 6-35 kV electrical grids are equipped with the devices for a selective

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protection against a single phase to earth fault, which turn off the damaged connection, it is possible not to carry out the compensation of a capacitive earth fault current.

The arc single phase to earth faults occur in the 6-35 kV electrical grids . If the single phase to earth fault is accompanied by an intermittent nature of arc combustion, then there are overvoltages, the level of which can be dangerous for the insulation of electrical equipment. The arc overvoltages accelerate the aging of electrical equipment insulation and often lead to the damage of weakened points in the insulation in the electrical grid. It reduces the reliability of electricity supply to the consumers. This is especially true for the cables with cross-linked polyethylene insulation. For such cables, the level of arc overvoltages in the electrical distribution grids is undesirable as it leads to the deterioration of their condition – the defects occur in the cable insulation and in the end, it will cause a damage of a cable.

During the consideration a project of electrical grid development, at the pre-design stage it is expedient to be able to quickly and qualitatively assess the expected level of arc overvoltages during the single phase to earth fault in the electrical grid, without having to spend time and resources on the study of the transients.

2. Research aim and objectives

The arc overvoltages during the single phase to earth faults in 6-35 kV electrical distribution grids are the object of the research in this paper.

The development of 35 kV electrical distribution grids is accompanied by the construction of new overhead and cable power lines and it leads to a change of the capacitive earth fault current in the network. This change of the current affects the multiplicity of overvoltages in electrical distribution grids during the single phase to earth faults. Therefore, the goal of a research is to create the mathematical models that will allow forming the dependences of the expected multiplicities of overvoltages in 35 kV electrical grids during the single phase to earth faults on the value of capacitive earth fault current at the different grounding modes of a neutral. This will allow making decisions about the optimal measures for the protection of an electrical equipment insulation (especially for the cable power lines) against overvoltages taking into account expected their values already at the stage of pre-design works for the electrical grid development.

To achieve this goal, it is necessary to solve the following tasks:

- According to the research results of the arc overvoltages in 35 kV electrical grids, it is necessary to define the nature of changes in overvoltage multiplicities depending on the values of capacitive earth fault currents, the nature of the grounding arc combustion and the grounding mode of a grid neutral;
- Create a mathematical model for an assessment the possible maximum multiplicity of arc overvoltages.

3. Analysis of the recent studies and publications

The results of a theoretical and experimental investigation, a digital simulation of the operation modes in 6-35 kV electrical distribution grids during the single phase to earth faults are given in [2]–[10]. These articles describe the processes of an occurrence and existence of the arc overvoltages during such faults in electrical distribution grids, and also the probable multiplicities of these overvoltages are given. The occurrence and development of overvoltages during the arc single phase to earth faults in the power grid are described by the three theories: Petersen's theory; Peters's and Slepian's theory; Beliakov's and Dzhuvarla's theory [2]–[4]. The results of an experimental research [2] indicate that under certain conditions of electrical grid operation, each of these theories is confirmed.

A digital simulation of transient processes gave a new qualitative impetus for the research into arc overvoltages during the single phase to earth fault in 6-35 kV electrical distribution grids, namely: an investigation of the process of an occurrence and development of overvoltages, a research into expected overvoltage values, an investigation of the influence of a neutral mode on the overvoltage values [5]–[10]. This takes into account: the features of a simulation of arc single phase to earth faults in the network; an adequacy of a simulation of electrical grid elements (the power transformers, voltage transformers, the busbars, overhead and cable power lines, the arc-quenching reactors). The obtained results of a computer research confirmed and supplemented the available theories of the occurrence and development of overvoltages. In particular, their possible multiplicities in the electrical grids, the influence of grid parameters and methods of neutral grounding on the overvoltage values were investigated [9]–[10].

4. Presentation of the main material

The investigation of overvoltages during the arc single phase to earth faults was performed for the 35 kV electrical grid, the scheme of which is shown in Fig.1. For these purposes the digital complex “REC” [11] was used to study the multiplicity of arc overvoltages.

The digital scheme of 35 kV electrical grid in a three-phase design (Fig.1) was created by using the digital models of electrical grid elements: the models of a power supply, the power transformers, distribution busbars, voltage transformers (type ZNOM-35), overhead and cable power lines. These elements of electrical grid were represented by their parameters, which were calculated according to their type and construction. In order to obtain an adequate characteristic of a transient process and an overvoltage level, the digital scheme of electrical grid simulation includes the active resistances of current conductors taking into account their surface effect, the phase capacitance and phase-to-phase capacitance, the electrical conductivities and parameters of voltage transformers [5]–[8].

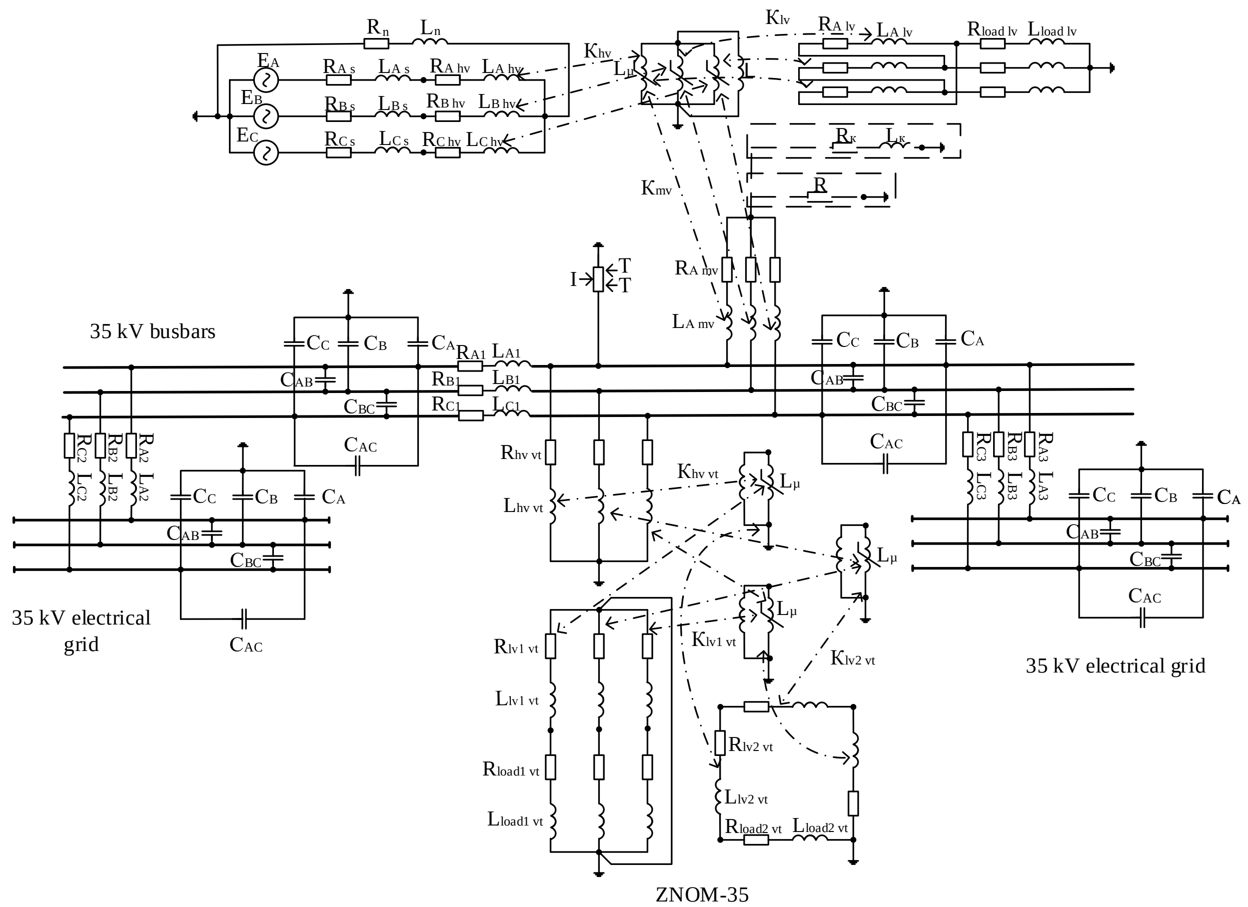

Fig.1. A digital model of 35 kV electrical grid for the research of arc overvoltages.

The analysis of known theories of the occurrence and existence of overvoltages during the single phase to earth faults in electrical grids: Petersen’s theory, Peters’s and Slepian’s theory, Beliakov’s and Dzhuvarla’s theory – showed that Petersen’s theory gives the highest theoretical values of overvoltages, which exceed the value of $4{\cdot}U_{phase\ m.}$ [3]. This is confirmed by the results of a computer simulation of arc single phase to earth faults in the electrical grid of 35 kV with an isolated neutral, which are given in [8],[10].

The investigation of arc transient processes was performed for the different types of grounding arc combustion for the following neutral modes in simulated 35 kV electrical grid: an isolated neutral, a grounded neutral through an arc-quenching reactor, a grounded neutral through a resistor.

The results of digital simulation of overvoltages during the arc single phase to earth fault in 35 kV electrical network with an isolated neutral according to the main theories of overvoltage existence are given in Table 1. The multiplicities of overvoltages are calculated relative to the maximum operating voltage of 35 kV electrical grid. An increase of the capacitive earth fault current leads to an increase of the overvoltage multiplicity in the network. Therefore, for the capacitive earth fault currents I_{C0} that are greater than 32 A, the maximum multiplicity of overvoltages K_U may exceed the value of 6 according to a Petersen's theory.

Table 1. Multiplicities of arc overvoltages depending on the change of capacitive earth fault currents in the electrical grid with an isolated neutral.

I_{C0}, A	1.25	2.5	6.3	12.7	19.0	25.5	32.1	38.4
K_U, p.u. *Petersen's theory*	2.71	3.2	3.87	4.67	5.09	5.54	6.01	6.63
K_U, p.u. *Peters's and Slepian's theory*	2.04	2.1	2.48	2.76	2.82	2.94	3.28	3.29
K_U, p.u. *Beliakov's and Dzhuvarla's theory*	2.0	2.02	2.05	2.13	2.17	2.21	2.24	2.27

The analysis of research results of overvoltage multiplicities during the arc fault in 35 kV electrical grid with an isolated neutral showed that an increase of the overvoltage value is insignificant during the increase of capacitive earth fault current according to both theories: Beliakov's and Dzhuvarla's theory and Peters's and Slepian's theory (Fig.2). The maximum multiplicity of overvoltages K_U in the 35 kV electrical grid with a capacitive earth fault current I_{C0} of 40 A according to the Beliakov's and Dzhuvarla's theory it was equal to 3.3, and according to the Peters's and Slepian's theory it was equal to 2.3.

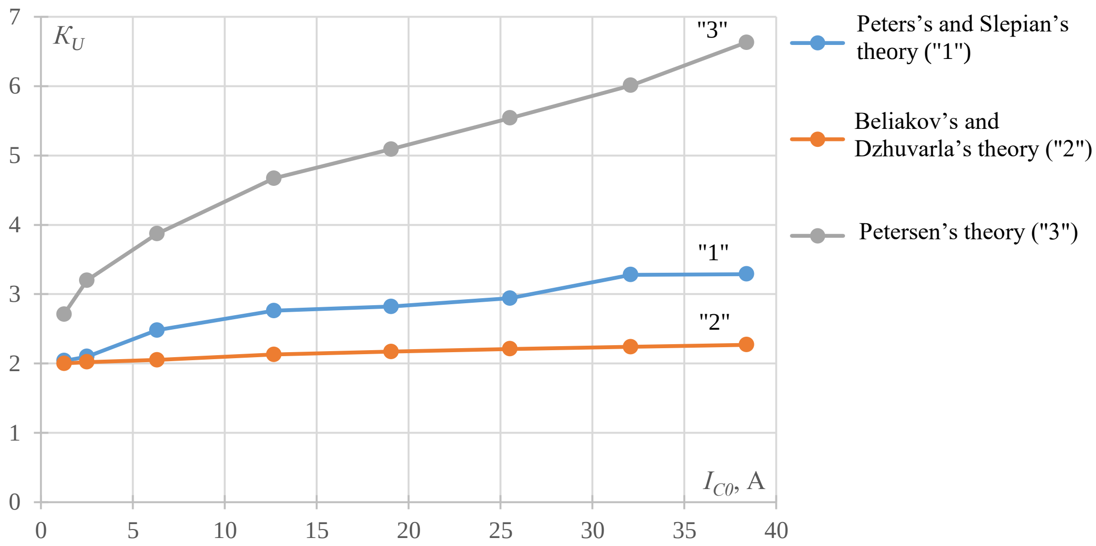

Fig.2. Dependences of a change of overvoltage multiplicities in the 35 kV electrical grid on the value of a capacitive earth fault current.

According to the Petersen's theory, the multiplicity of overvoltages changes from 2.7 to 6.63 during the single phase to earth fault when the capacitive earth fault current changes from 1.25 A to 38.4 A in the electrical grid of 35 kV. The level of overvoltages according to the Petersen's theory is many times higher than overvoltages according to both the Beliakov's and Dzhuvarla's theory and Peters's and Slepian's theory. When the value of capacitive earth fault current is 10 A, the overvoltage in the 35 kV electrical grid is equal to $4.4{\cdot}U_{phase\ m.}$ according to the Petersen's theory, and according to the Beliakov's and Dzhuvarla's theory the overvoltage is equal to $2.1{\cdot}U_{phase\ m.}$, according to the Peters's and Slepian's theory the overvoltage is equal to $2.7{\cdot}U_{phase\ m.}$.

The nature of a change of overvoltage multiplicities depending on the value of a capacitive earth fault current in the 35 kV electrical grids according to the Petersen's theory should be taken into account during the development of these electrical networks. The expected maximum value of overvoltage in the new electrical grid (which is obtained by the simple calculations) will allow optimizing the measures to ensure a reliable insulation of electrical equipment already at the design stage.

According to the research results of overvoltage multiplicities during the arc single phase to earth fault in 35 kV electrical grid with an isolated neutral, a mathematical model has been created, which allows assessing the maximum multiplicity K_U of arc overvoltages depending on the value of a capacitive earth fault current I_{C0} in this electrical grid

$$K_U = -0.0014 \cdot I_{C0}^2 + 0.1508 \cdot I_{C0} + 2.7806 . \quad (1)$$

In the 35 kV electrical network with a grounded neutral through the arc-quenching reactor, in the case of a resonant configuration, the value of overvoltages during the arc earth fault will not exceed $2.2 \cdot U_{phase\ m.}$ with capacitive earth fault current from 1 A to 40 A. In the case of decompensation within ±20 %, the value of overvoltages increases significantly. So, it is recommended to focus on the maximum overvoltage multiplicities already at the design stage of electrical grid development. These multiplicities are calculated by using a mathematical model of the electrical grid with an isolated neutral.

The grounding of a neutral through a resistor in the 35 kV electrical grid allows limiting the overvoltages to the maximum multiplicity of 3.2 during the arc single phase to earth fault when a capacitive earth fault current changes up to 40 A (during the calculation, the resistors with a resistance from 500 Ohms to 5000 Ohms were considered; these resistors were connected to a neutral). The multiplicity of overvoltages depends on the value of a resistance of a grounding resistor in the neutral of the electrical grid. Thus, the multiplicity K_U is equal to 2.4 when a capacitive earth fault current is equal to 40 A and a resistor has a resistance of 500 Ohms; and the multiplicity K_U is equal to 3.2 when a resistor has a resistance of 5000 Ohms.

The obtained results of the research for the combined neutral grounding modes (simultaneously through a high-resistance resistor and an arc-quenching reactor) confirm that the maximum expected multiplicities of overvoltages will not exceed the value of 2.2 in the 35 kV electrical grid, regardless of a characteristic of the grounding arc combustion and a value of the capacitive earth fault current.

5. Conclusion

1. According to the research results, a mathematical model has been offered to calculate the maximum level of overvoltages in the 35 kV electrical grid with an isolated neutral. This model should be used at the stage of pre-design works, which are related to the electrical grid development and a construction of new overhead and cable transmission lines.

2. During the designing of a development of 35 kV electrical distribution grid with a grounded neutral through an arc-quenching reactor, it is necessary to focus on the expected maximum overvoltage multiplicities of the same level as for the electrical grid with an isolated neutral.

3. The grounding of electrical neutral through a high-resistance resistor allows limiting the overvoltages to a maximum multiplicity of 3.2 during the arc single phase to earth fault in the electrical grid.

4. The mode of a combined grounding of the electrical neutral is the most effective in terms of a limitation of the arc overvoltages, because the maximum expected overvoltage multiplicities will not exceed the value of 2.2.

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Кратність перенапруг під час дугових однофазних замикань на землю в електричних мережах 35 кВ

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Анотація

Об'єктом дослідження є дугові перенапруги під час однофазних замикань на землю в розподільних електричних мережах 6-35 кВ. Розвиток розподільних електричних мереж 35 кВ пов'язаний з будівництвом нових повітряних і кабельних ліній і призводить до зміни ємнісного струму замикання на землю мережі, що впливає на кратність перенапруг в розподільних електричних мережах під час однофазних замикань на землю. Наведено результати дослідження перенапруг за допомогою цифрового моделювання під час дугових однофазних замикань на землю в електричній мережі 35 кВ за різних режимів роботи нейтралі: ізольованій, заземленій через дугогасний реактор, заземленій через резистор. За результатами досліджень розроблено математичну модель, яка дає змогу одержувати максимальні очікувані кратності перенапруг в електричних мережах 35 кВ під час однофазних замикань на землю. Це дає змогу уже на етапі передпроектних робіт розвитку таких електромереж приймати рішення стосовно оптимальних заходів, спрямованих на захист ізоляції електроустаткування з врахуванням очікуваних величин перенапруг.

Ключові слова: електрична мережа; дугова перенапруга; ізольована нейтраль; однофазне замикання на землю; математична модель.