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Organization of Relay Protection Against Earth Faults in a 20 KV Network in Neutral Conditions

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ABSTRACT: The implementation of the resistive neutral mode in 20 kV networks is a critical aspect of electrical power distribution systems, particularly in scenarios with high electrical load. This mode is necessary to increase the power of the distribution network and maintain its stability and reliability. One specific aspect discussed in the article is the calculation of the required minimum resistor current for the resistive neutral mode. This calculation is essential to ensure that the resistor is able to effectively mitigate the unbalance in the distribution network and prevent damage to equipment and potential power outages. Additionally, the article delves into the principle of calculating ground fault protection for 20 kV networks. Ground fault protection is crucial for ensuring the safety of the distribution network and preventing the risk of electrical shocks and fires caused by ground faults. From a scientific standpoint, the implementation of the resistive neutral mode and the calculation of ground fault protection in 20 kV networks involve complex electrical engineering principles and considerations. These aspects require a deep understanding of power systems, electrical loads, and protective measures to ensure the safe and efficient operation of the distribution network. Furthermore, the article's focus on these specific technical aspects highlights the importance of precision and accuracy in the design and operation of 20 kV networks.

KEY WORDS: 20 kV network, grounding, relay protection, resistor, active current, current limitation.

I. INTRODUCTION

Ensuring reliable power supply in the conditions of an increase in electricity consumption in the distribution electric networks in the range of 2-3% per year is possible only with a significant increase in the power of the distribution network. One of the solutions to this problem is the development of 20 kV networks. Switching to a voltage of 20 kV makes it possible to reduce the number of new cells of feeding substations, increase the economic radius of servicing electrical installations, as well as reduce the number of newly commissioned transformer substations and electrical networks. The development of a 20 kV network is typical for large areas with rapidly growing electricity consumption and extremely high electrical load density. Each transformer substation is powered by mutual redundancy of power grids [1].

As a standard solution for the protection of outgoing connections, microprocessor terminals are used that allow remote line protection, current disconnection, maximum current protection, asymmetry protection and zero sequence current protection. In order to increase the speed of relay protection and automation devices, as well as to increase the reliability of the 20 kV main distribution network for newly commissioned facilities, it is planned to install differential protection lines on connected lines as a experimental project to all outgoing lines via two independent communication channels.

If both channels are damaged at the same time, the protection devices will continue to perform the protection functions of the current stage. This approach makes it possible to ensure reliable disconnection of all types of network short circuits at maximum speed. Based on the experience of working with the protection of differential lines in a 20 kV network, a decision was made on its typical application[1,2].

II. RESISTOR PARAMETERS FOR 20 KV NETWORKS

The scheme providing for the inclusion of a resistor in the neutral winding of the low-voltage winding of 110 (220)/20 kV supply transformers of 80-160 MVA with a non-standard winding connection scheme “Y_0/Y_0” is usually used. On

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the basis of the application of resistors in 20 kV networks in Europe and USA, it is possible to note the possibility of including resistors in the neutral of a special neutral-forming device - a 20/0,4 kV transformer with the scheme "Δ/ Y_0" or a zero-sequence filter with the scheme "Z_0" without a secondary winding. When organizing low-resistance resistive neutral grounding using a neutral-forming device, a cell with a circuit breaker and relay protection terminal must be installed at each 20 kV section of the supplying substation, similar to the way it is done in 6-10 kV networks.[2]

Depending on the time of operation of the resistor under voltage and the temperature coefficient of resistance of the material from which it is made, the active current can change significantly during the existence of single-phase earth faults. Nowadays, different grades of heat-resistant stainless steel with operating temperatures up to 900 ^{0}C and electrically conductive composite materials that heat up to no more than 200 ^{0}C are used for manufacturing resistors. For the composite material due to the negative temperature coefficient of resistance is characterized by a decrease in resistance within 10% when it is heated during the nominal operating time of 10 s. Metal resistors, on the contrary, have a positive temperature coefficient of resistance, which leads to an increase in their resistance in single-phase fault modes up to two times relative to the nominal value [2].

On the one hand, this somewhat reduces the thermal effect of the grounding arc in the fault location, on the other hand, it leads to a decrease in the sensitivity coefficient of non-directional zero-sequence current protection. When selecting resistors for operation in Russian conditions, it should be taken into account that the highest permissible heating temperature of steel conductors according to the rules of the Electrical Installations Regulations is limited at the level of 300 - 400 ^{0}C [3].

In different countries of the world, resistors are used that provide an active current varying in a wide range depending on the required sensitivity of relay protection, the type of current sensors used, the tripping time of single-phase earth faults and electrical safety conditions. As an example, in 20 kV cable networks in the USA resistors with active current 200 - 1200 A are used (typical value is 400 A), in Great Britain - 600 and 1200 A, in Germany - 1500 - 2000 A, in the Netherlands - 400 A, in Spain - 300 and 500 A, in Slovenia - 150 A. The nominal operating time of resistors in the single-phase ground fault mode is determined by the technical requirements of the grid organization and ranges from 3 to 17 s [4].

However, according to IEEE 32 standard [7] resistors should be designed for repeated-short-term mode of application of operating voltage for a time not less than 10 s. This may be explained as follows. Disconnection of single-phase earth faults on the outgoing connections of the adjacent 20 kV network is reserved by the circuit breaker of the entry to the distribution point and, if the latter is not triggered, of the entry to the 20 kV section of the supplying substation. The resistor disconnection time to prevent its thermal destruction is a few seconds, which is true provided that the resistor is switched on once to the phase voltage of the network in the event of single-phase earth faults[5].

The probability that it will be necessary to disconnect several single-phase faults in a row, strictly speaking, is not zero, so in the specifications, the nominal operating time of low impedance resistors are taken at least twice the reserve. According to IEEE 142 [8], "ground fault currents in the range of I_R=100-1000 A are allowed to flow in order to provide the desired current for selective operation of relay protection against single-phase ground faults". For the 20 kV network this condition is provided at the resistor resistance in the range from 12 to 120 Ohm. to resistors for 20 kV cable networks [5], it was decided to use a resistor with nominal parameters 12 Ohm/20 kV/1000 A as a typical solution in the power system.

At preservation of the required sensitivity of protections in some cases it is possible to reduce the nominal current of the resistor to 500 A [9]. Calculations have shown that, taking into account the resistance of the grounding device of the supply substation with the highest voltage 110 - 220 kV and the resistance of the resistor in the neutral $R_N \geq$ 1 Ohm, the earth fault coefficient in all cases is equal to 1.73. Consequently, for a 20 kV network, the definition of "earth fault current" is valid, not "single-phase short-circuit current" [4, 9].

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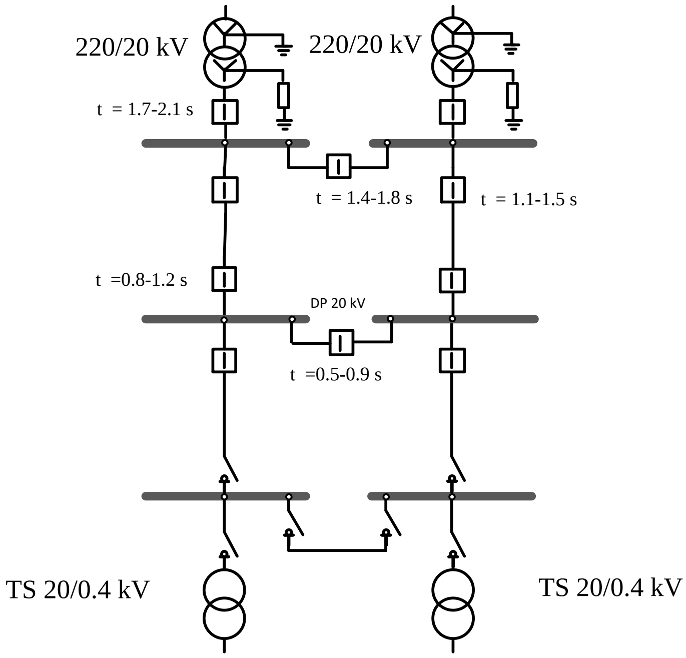

20 kV network scheme consisting of distribution centers

III. DEVICE RESISTOR PROTECTIONS

Two differential protection and zero-sequence current protection are usually used to protect the resistor in the neutral circuit of the supply transformer. 220(110)/20 kV are usually used differential protection and zero-sequence current protection. The first protection is designed to protect against damage in the resistor circuit (breakdown to earth due to burnout of elements, overlapping of supporting insulators), the second - to back up the non-disconnection of single-phase earth faults external to the resistor circuit. The current set point of the resistor protection must not exceed the minimum active current limited, among other things, by the transformer and grounding circuit resistances. Zero-sequence current protection of the resistor must be less than half of the permissible duration of single-phase earth fault current flowing through the resistor $t_{s.p.} \leq 0.5 \cdot t_{duration}$. [6,7]

Coefficient 0.5 takes into account the non-zero probability of occurrence of a second single-phase fault immediately after tripping the first one. For the circuit of Fig. 1, the resistor trip time does not exceed, as a rule, $t_{s.p.}$= 2.1 s, which is explained as follows. Disconnection failure of single-phase earth faults on outgoing connections to the distribution point in the adjacent network 20 kV (let's assume a time delay $t_{s.p.}$=0,2-0,6 s) due to failure of relay protection or circuit breaker with a selectivity step up to 0,3 s is reserved by disconnecting the input to the distribution point ($t_{s.p.}$=0,8-1,2 s) and input to the substation ($t_{s.p.}$= 1,7-2,1 s) (Fig. 1). It is necessary to perform a prohibition on the triggering of automatic backup input on the sectional circuit breaker 20 kV at the distribution point or substation to avoid switching on unrecovered single-phase earth faults [7, 9].

IV. RESISTOR CURRENT LIMITATION EVALUATION

Sensitivity of zero-sequence current protection is determined mainly by the resistor parameters in the 20 kV network. On the current in the secondary circuits of the protection, on exceeding the set point of which its operation occurs and which ultimately determines the reliability of tripping a single-phase fault, influenced by the following factors: the error of the primary sensors of zero-sequence current, the transient resistance in the place of earth fault and the total resistance of the circuit of current flow of single-phase earth faults, the time of tripping a single-phase fault, the active conductivity of the insulation relative to ground, the change in resistance of the resistor when heating in the working phase, the resistance of the resistor to the ground, the resistance of the resistor to the earth fault, the resistance of the resistor to the earth fault.[8]

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The zero sequence current transformers' average amplitude error at primary currents more than 100 A is equal to 2.5% [10]. Three transformer filters assembled according to the scheme “star” on secondary windings of accuracy class, taking into account not exceeding the nominal current of phase current transformers, the error can be taken equal to the regulated in GOST 7746-2001 value of 3% [10]. Therefore, the above factors can be neglected. That is why the active current due to the conductivity of the insulation of the 20 kV cable network to earth will not have any noticeable effect on the current in the zero-sequence loop, especially with negative errors of current transformers and zero-sequence current transformers . In selecting the parameters of the neutral-forming device, as a rule, proceed from the fact that the reduction of the resistor current in the ground fault circuit should not exceed 15%.

The calculations have shown that under this condition for connecting resistors with a current of 500 and 1000 A can be used dry transformers 20/0,4 kV with the scheme , power of 1000 and 1600 kVA respectively. What in the first case the degree of limitation of active current relative to the nominal will be 10.2%, in the second case - 12.7%. Depending on the circuit-mode requirements, the transformer capacity can be selected so that the resistor current is limited by its resistance by no more than 5 or 10%.Note that when the resistor is installed in the neutral of a 20 kV winding of a supplying power transformer with a higher voltage of 110 - 220 kV, the limitation of the active current in the neutral will be negligible[7,8].

The active-inductive resistance of the windings of such transformers in the power range 80 - 160 MVA is only 0.55- 0.28 ohms. When the single-phase fault point is electrically removed from the supplying substations to the 20 kV distribution network, the current of single-phase faults to earth may be somewhat reduced due to the effect of the resistance of the earthing device and the earthing scheme of the cable shields. The degree of this limitation depends on the number and parameters of power cable lines with such a scheme.

Calculations have shown that two-sided grounding of shields of single-core cables, provided that the entire current of the resistor through the resistance grounding device to the transformer substation, distribution center or feeding substations, corresponds to a reduction in current I_R =500-1000 A about 4 - 9% at a removal of the point of short circuit at 3.5 km. It is accepted that for distribution point and substation transformer $R \leq$ 4 Ohm or 10 Ohm [4].

Without taking into account metallic underground utilities, unilateral grounding of the screens in the calculation gives a resistor current limitation of 32 - 48%. However, several factors should be taken into account when considering this issue. Firstly, more than 80% of single-phase earth fault current flows through the well-conducting cable sheaths [5], usually connected with the main grounding circuits at the supply substations of 110-220 kV class ($R \leq 0.5$ Ohm).

Secondly, in the projects of 20 kV network construction the solution with one-sided grounding of single-core cable shields has not been used so far due to the absence of a problem with the magnitude of induced currents in copper shields of lines. Field measurements in the cable network confirmed the fact of limiting the active current by the resistance of the grounding circuit [10].

V. RESULTS

The resistances of grounding devices, as per industry protocols, comply with regulatory standards. Experimental validation was conducted using the TOL-10 current transformer with a 2000/5 ratio and 0.5s accuracy class rating. The experiment involved inducing an artificial "metallic" single-phase earth fault on the busbars of a 20 kV switchgear that is linked to a 1.2 km long line supplying power to 220/20 kV substations. The findings revealed that the recorded earth fault current was approximately 1.6% lower, representing 15 A less compared to the previously measured current on the busbars of the supplying substations[9,10]. This discrepancy may have significant implications for the protective measures and fault detection systems in the 20 kV network, highlighting the need for further investigation to understand the underlying causes and implications of this discrepancy in fault current measurements.

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Table-1. The value of the resistor current required for stable operation of the zero-sequence current protection in a 20 kV network

Design (view) of current sensor $3I_0$	Material of the active part of the resistor	The resistor is installed in the neutral of the supply power transformer	The resistor is installed in the neutral of the neutral grounding transformer.
Scheme of the “full star” three-transformer filter, rated current I_{Rmin}=318 A	composite	K_Ω=1.334 I_R=424 A	K_Ω=1.484 I_R=742 A
	metal	K_Ω=2.668 I_R=848 A	K_Ω=2.968 I_R=944 A
Zero sequence current transformer, rated current I_{Rmin}=191 A	composite	K_Ω=1.334 I_R=255 A	K_Ω=1.484 I_R=283 A
	metal	K_Ω=2.668 I_R=510 A	K_Ω=2.968 I_R=566 A

These values are obtained after analyzing digital correlate well with the calculations.
To ensure the required sensitivity of zero-sequence current protection, it is necessary, in addition to the influence of the neutral-forming transformer (the maximum limitation is assumed to be 15%) and grounding circuit (the maximum limitation is assumed to be 10%), to take into account the possibility of reducing the current of the resistor by the positive tolerance of the manufacturer on the resistance (10%) and short-term operation of the network with a voltage 10% lower than the nominal voltage (13.4% lower than the phase 12 kV), as well as - for a metal resistor - the growth of resistance up to two times when it is heated up [8,9].

Considering the above provisions, the reserve coefficient is determined as the multiplier for estimation of the resistor current with “underestimated” relative to the estimated resistance, which will ensure guaranteed operation of non-directional protection depending on the resistor material, the way of its connection to the neutral and the type of zero sequence current sensor (Table 1). The calculations do not take into account the decrease in resistance of the composite resistor in the single-phase earth fault mode for the reason of additional increase in the sensitivity coefficient of relay protection. It is evident from Table 1 that the calculated value of active current, which provides the necessary sensitivity of non-directional protections, is in the range of 260 - 950 A [9]

Smallest values of the resistor current correspond to the scheme of including the resistor in the withdrawn neutral of the 20 kV winding of the 110 - 220 kV power transformer. Regardless of the connection scheme of resistors and zero-sequence current sensors, for reliable operation of relay protection against single-phase earth faults, it is acceptable to accept $K_\Omega = 1.5$ ($I_R \geq 480$ A) provided that composite resistors $K_\Omega = 3$ ($I_R \geq 950$ A) - metal resistors. Advantage of the first variant is the reduction of thermal impact on the equipment, as well as touch and step voltages proportional to the short-circuit current.

Second variant corresponds to the established practice of operation and is typical from the point of view of calculation of zero-sequence current protection settings and unification of their setting. The two variants are valid and make sense first of all in relation to the value of the current and not to the design of the resistor. These features should be taken into account when selecting the parameters of resistive neutral grounding at independent, geographically separated substations of 110 - 220 kV, which in some modes supply the same sections of the 20 kV network [10].

VI. CONCLUSIONS

The process of accommodating the growing demand from electric power consumers necessitates a corresponding increase in the capacity of distribution networks. In environments characterized by high-density electrical loads, transitioning to the 20 kV voltage class serves as a viable solution to address this challenge. Selective protection against earth faults within the 20 kV cable network of the Moscow power system has been established in the form of non-directional zero-sequence current protection with the action to disconnect the affected line.

To ensure the requisite sensitivity of the protection, a low-impedance resistor with an active current of up to 1000 A is included in the neutral of the system. The selection of resistor parameters and the calculation of protection settings must account for crucial factors, including the total resistance of the current-carrying circuit of the zero-sequence current

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protection, the response time to a single-phase fault, and the variation in resistance of the resistor as it heats up during operational conditions.

In the context of 20 kV networks, various designs of resistors have been developed using both metal alloys and composite materials. The application of composite resistors, which adhere to domestic standards regarding the permissible temperature of current-carrying components, enables a substantial reduction of the nominal active current in the 20 kV network by half in relation to the stipulated value of 1000A. This advancement significantly enhances electrical safety conditions and mitigates the thermal impact on equipment in the event of single-phase earth fault modes, all while preserving the requisite sensitivity of the protection system.

The scientific and engineering considerations involved in optimizing the protection and resistor designs for 20 kV networks demonstrate the critical interplay between electrical safety, fault detection, and equipment performance, underscoring the sophisticated nature of modern power distribution systems and the importance of advanced technological solutions in addressing these complex challenges.

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