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CONCEPTUAL TECHNIQUE MEDIUM VOLTAGE NETWORKS PROTECTION AGAINST GROUND FAULT STRATEGY AND PRACTICE

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Abstract- In article conceptual technique medium voltage networks protection against ground fault are considered. The following questions are considered: correct account of imbalance current, account (metering) of capacity current, choice of neutral grounding mode, algorithm of relay protection operate, calculation relay protection operate settings, estimation of the relay protection by The Least Resistance strategy.

Keywords: Capacity Current, Estimation of Sensitivity, Ground Fault, Imbalance Current, Medium Voltage, Neutral Mode, Operate Settings, Overvoltages, Relay Protection, Transient Resistance.

I. INTRODUCTION

Recently, unfortunately the modern condition of medium voltage networks protection against ground fault don't satisfy the requirements of exploitation reliability and accident prevention of networks, and also, selectivity, noise stability, sensitivity and relay protection and automation speeding-up.

Most electric power engineers must regularly deal with design and operational problems with protection complex against ground fault following result in non selective operate of relay protection. A significant number of these problems are related to incorrect calculation of imbalance current. A good understanding of these subjects and appropriate engineering software tools is critical to every power utility that is concerned with the safety and reliability of its system and responsibility towards the safety of technical staff.

As researches shows, most simple in adjustment and operation, and at the same time, most reliable and selective protection against single-phase ground faults, are the current protections, based on measurement of parameters of ground fault stationary mode.

To solve a problem of calculation operate settings of protection against ground fault it allowing to calculate correctly complex algorithm imbalance currents and to estimate sensitivity of protection is offered. Conceptual technique medium voltage networks protection against ground fault the following. Let's consider step-by-step offered complex algorithm.

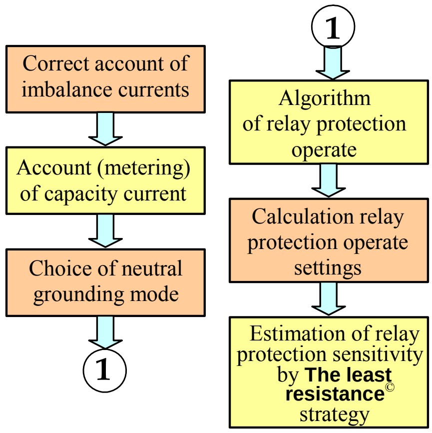

Figure 1. Conceptual technique medium voltage networks protection against ground

II. CORRECT ACCOUNT OF IMBALANCE CURRENTS

Researches, conducted in substations of Tumenenergo Electrical Networks was marked, that is experimentally measured the imbalance currents considerably higher from calculated by the classic strategy [1]. In all cases they were considerably less than calculated.

In an attempt to tune away from considerable on the value of imbalance currents, results in necessity or to decrease the value of a resistors resistance when non direction protection is used, or to use a current direction protection. Take note that at considerable distinction of lines extension, connected to one substation, even when usage the direction protection not always it is possible to construct selective protection when value of the resistors resistance (upper limit).

$$R_N \le 1/3\omega C_{PH}\left(1+2\eta\right) \qquad (1)$$

where $\eta=\left(C_{BC}/C_{PH}\right)$, C_{BC} is intercircuit capacity and C_{PH} is phase capacity [3,4]. As the decrease demanded (for limitation of overvoltages) resistors value is accompanied by increase of the ground fault current, the problem of necessity of the more correct account of imbalance currents still remains open.

In Tables 1-3, the values of obtained imbalance currents to cite data as a result of last experimental results in Tumenenergo Electrical Networks in current circuits of overhead lines 35 kV are shown (for three typical power plant). For community and comparison with experimental results, the meterings were conducted in networks of current transformers (mode: TPWO/TB) with accuracy rating 0.5 and 10R. TPWO is current transformer oil-filled with porcelain insulation with link type wirings; TB is bushing current transformer; 0.5 - Absolute ratio error 5%; 10R - Absolute ratio error 10%.

Table 1. Power Plant A

Feed	Ia, Ah	Ib, Ah	Ic, Ah	I_{IMB}, mAh	K_{TA}	Mode	Accuracy rating
1	0.47	0.3	0.43	65	600/5	TB	10R
2	0.2	0.12	0.15	50	600/5	TB	10R
3	2.3	2.3	2.3	9	600/5	TB	10R
4	2.3	2.3	2.3	15	600/5	TB	10R
5	0.9	0.9	0.9	3.4	1500/5	TB	10R
6	0.9	0.9	0.9	4	1500/5	TB	10R

Table 2. Power Plant B

Feeder	Ia, Ah	Ib, Ah	Ic, Ah	I_{IMB}, mAh	K_{TA}	Mode	Accuracy rating
1	0.42	0.43	0.43	0.2	600/5	TPWO	10R
2	0.44	0.46	0.44	0.3	600/5	TPWO	10R

Table 3. Power plant C

Feeder	Ia, Ah	Ib, Ah	Ic, Ah	I_{IMB}, mAh	K_{TA}	Mode	Accuracy rating
1	0.9	0.9	0.95	0.3	600/5	TPWO	0.5
2	1.9	1.9	1.9	0.3	600/5	TPWO	0.5

Unfortunately, it is impossible to make of Tables 1-3 unique conclusions about any dependence of imbalance current from operating current. For example, for feeders 5 and 6 (Table 1) at identical operating currents, current transformers mode and accuracy rating, the measured imbalance currents differ from each other. And for feeders 1 and 2 (Table 3) the identical imbalance currents were measured with operating currents differs from other twice.

Results of measurements of imbalance currents in transformers current circuits with an accuracy rating 0.5 and their comparison to calculated data allows to draw a conclusion that the absolute value of these currents with other things being equal approximately on the order are lower, than give measurements with the current transformers of accuracy rating 10R.

In Table 4-6 the values of imbalance currents calculated by the strategy [1] are shown. As initial operating conditions those were accepted, at which one the measurements were conducted.

Table 4. Power Plant A

Operating Current, Ah	I_{IMB}, mAh /Ah Measure	I_{IMB}, Ah Calc.	K_{TA}	Mode	Accuracy rating
0.4 (48)	65 (7.8)	≈0*	600/5	TB	10R
0.16(18.84)	50 (6)	≈0*	600/5	TB	10R
2.3 (276)	9 (1.08)	2.413	600/5	TB	10R
2.3 (276)	15 (1.8)	2.413	600/5	TB	10R
0.9 (270)	3.4(1.02)	2.433	1500/5	TB	10R
0.9 (270)	4 (1.2)	2.433	1500/5	TB	10R

* It is impossible to define $H=H_{max}-H_{min}$ (Figure 2, [1]), because of small values of induction for a maximum burden

Table 5. Power Plant B

Operating Current, Ah	I_{IMB}, mAh /Ah Measure	I_{IMB}, Ah Calc.	K_{TA}	Mode	Accuracy rating
0.425(51)	0.2(0.024)	≈0*	600/5	TPWO	0.5
0.45 (54)	0.3(0.036)	≈0*	600/5	TPWO	0.5

* It is impossible to define $H=H_{max}-H_{min}$ (Figure 2, [1]), because of small values of induction for a maximum burden

Table 6. Power Plant C

Operating Current, Ah	I_{IMB}, mAh /Ah Measure	I_{IMB}, Ah Calc.	K_{TA}	Mode	Accuracy rating
0.95 (114)	0.3(0.036)	0.974	600/5	TPWO	0.5
1.9 (228)	0.3(0.036)	1.806	600/5	TPWO	0.5

As shown from Tables 4-6 all calculated values of imbalance currents were received much more than measured values. According to the classic strategy [1], the maximum possible value of imbalance current of series transformers caused by a discrepancy of magnetization [B-H] curves and a non identical chemical treatment of steel is defined.

Substantially, the probability of origin of the maximum imbalance current is trifling. Therefore, if for calculation of operate settings of protection against ground fault to take into account values of imbalance currents, calculated on the strategy [1], will is inevitable be received operate setting too high. Thereof the protection will not be enough (and probably and in general) is sensitive to ground fault currents.

In order to calculate the operate settings of current protection against ground fault it is expedient as a basic data to use really measured imbalance currents. For example, maximum imbalance current recorded in the log of electrical networks, for all time of networks operation. It will allow avoiding nonfunctioning of the protection against ground fault and prevents a development ground fault in more serious damages. (Approximately it is possible to decrease the imbalance current calculated by the strategy [1] by 30%). For a decrease of imbalance currents the installation the current transformers with accuracy rating 0.5 is recommended. On those objects, where it expediently and economically feasible, the adjustment of inserted cables for a decreased of imbalance currents can be applied.

III. ACCOUNT OF CAPACITY CURRENT

Typical scheme of medium voltage network is submitted in Figure 2. Currents of zero sequence in installation sites of the relay will be defined as:

$$3\overline{I}_{01D} = j\omega l_D[\overline{U}_{N1}C_1 + C_{BC}] - \overline{U}_{N2}C_{BC} + \\ + \overline{E}_A C_{11} + \overline{E}_B C_{22} + \overline{E}_C C_{33} + \overline{I}_{GF} \tag{2}$$

$$3\overline{I}_{01UD\Sigma} = (3\overline{I}_{01D} - \overline{I}_{GF})(l_\Sigma - l_D)/l_D \tag{3}$$

$$3\overline{I}_{02\Sigma} = j\omega l_\Sigma[\overline{U}_{N1}C_{BC} - \overline{U}_{N2}(C_1 + C_{BC}) - \\ - \overline{E}_A C_{11} - \overline{E}_B C_{22} - \overline{E}_C C_{33}] \tag{4}$$

where $\underline{I}_{01D}$ is current in damaged line (section I); $\underline{I}_{01UD}$ is current in undamaged line (section I); $\underline{I}_{02\Sigma}$ is current in undamaged line (section II); $\underline{I}_{GF}$ is ground fault current;

$C_1 = C_{11} + C_{22} + C_{33}$; l_D is length of the damaged line; l_Σ is total length of section lines;

$C_{BC} = C_{14} + C_{15} + C_{16} + C_{24} + C_{25} + C_{26} + C_{34} + C_{35} + C_{36}$;

C_{ii} is phase capacity of wire i to the ground; C_{ij} is intercircuit capacity between wires i and j.

Voltage on neutral $\underline{U}_{N1}$ and $\underline{U}_{N2}$ are defined as follows:

$$\bar{U}_{N1} = \frac{-\bar{E}_A g_N (Y_\Sigma + g_N + Y_{BC}) - \bar{I}_S (Y_\Sigma + g_N + 2Y_{BC})}{g_N (Y_\Sigma + g_N + Y_{BC}) + (Y_\Sigma + g_N)(Y_{BC} + Y_\Sigma + g_N) + Y_{BC}(Y_\Sigma + g_N)} \quad (5)$$

$$\bar{U}_{N2} = \frac{U_{N1} Y_{BC} - \bar{I}_S}{Y_{BC} + Y_\Sigma + g_N} \quad (6)$$

where;

$Y_\Sigma = j\omega l_\Sigma \left(C_1 + C_{BC} \right)$; $g_N = 1/R_N$;

$\bar{I}_S = j\omega l_\Sigma (\bar{E}_A C_{11} + \bar{E}_B C_{22} + \bar{E}_C C_{33})$; $Y_{BC} = j\omega l_\Sigma C_{BC}$;

$g_N = 1/R_{GF}$; R_{GF} and R_N are transient resistance at the ground fault point and resistance of the resistor in a neutral of each power transformer.

To receive the most exact calculation results of capacity currents to measure capacities of phases to the ground, capacities between circuits, and also lengths of lines it is necessary.

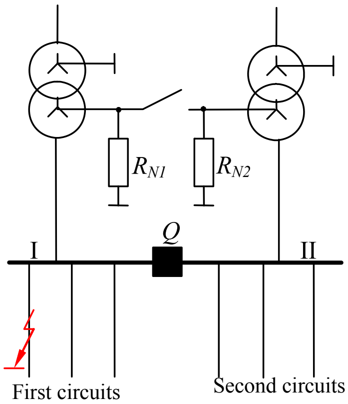

Figure 2. Typical medium voltage network

IV. CHOICE OF NEUTRAL GROUNDING MODE

Principles of grounding of a neutral of medium voltage networks are formulated in the Table 7. A series of designs and protection circuits for resistive grounding of the neutral application is developed. The researches confirming the efficiency of resistive grounding and to lay down requirements to values of resistors resistance and their energy features in papers [3, 4] are formulated. On application of the resistive grounding of the neutral values of resistance it is necessary to solve three main problems:

1. To full eliminate ferroresonant phenomena and reduce values of arc overvoltages to the level guaranteed a ground fault closing localisation.
2. To design the engineering factors to construct a selective and reliable protection against ground fault to find a damaged feeder based on the active current occurrence in damaged feeder.
3. To determine the permissible time of resistor operate in the ground fault mode.

Table 7. Principles of Neutral Grounding

Ground fault current	Terms of choice resistor's resistance	Alternative to resistive grounding of the neutral
I<5 Ah	$R_N = \frac{U}{4I_{ground\ fault}}$ – defined by creation of an active current of ground fault for selective revealing the damaged feeder	---
5<I<50 Ah	**Upper limit**: R_N=1/3ωC_{PH}(1+2η) **Lower limit**: - *For air networks*: thus current non-directional protection selectively worked; - *For cable networks and networks of a generator voltages*: thus at failure protection against a short circuit current (phase-to-phase) did not operate	Arc suppression coil
I>50 Ah	Resistive grounding of the neutral can be applied, if ground fault current will not exceed a short circuit current (phase-to-phase).	Arc suppression coil

V. CHOICE OF ALGORITHM OF RELAY PROTECTION OPERATE

As already it was spoken earlier, most simple in adjustment and operation, and at the same time, most reliable and selective protection against ground faults, are the current protection, based on measurement of parameters of ground fault stationary mode.

In most cases necessary sensitivity to be achieved on the basis of the current is not direction protection. However when necessary to increase of sensitivity or when it is impossible to achieve sensitivity on the basis of the current non direction protection current the direction protection it is necessary to apply.

Method of selection the values of resistance and energy features of resistors in medium voltage networks, including such factors, as: purpose of the network (for example, distributive network, and house network or generator voltage), design (air or cable), overvoltages, algorithms of relay protection organisation, and also the theoretical and practical conclusions are shown in paper [3].

The nomenclature range of resistors values for medium voltage networks of a various design and purpose in the Table 8 are shown.

Table 8. Nomenclature Range of Resistors Values

Classification	Nomenclature range, Ohm
Air networks	100, 500, 1000, 2000, 5000, 10000, 20000
Cable networks	100, 500, 1000, 2000, 5000, 10000
Networks of generator voltage	500, 1000, 2000

Thus an energy features range is 0.5-100 kWt and 1-300 kJ (time of action of stand-by relay protection against ground fault ≈3 sec).

Low resistance grounding refers to a system in which the neutral is grounded through a small resistance that increases ground fault current magnitudes. Low resistance grounding normally increases the ground fault currents to approximately 100-600 Ah. The amount of current necessary for selective relaying determines the value of resistance to be used.

When the necessary conditions for switching-off of the damaged connection with ground fault is take place: in the presence of starve equipment and selective relay protection the given connection in this case should be immediately switched-off. When realisation of such operation mode of the network the values of resistors resistance to choose by a condition current creation, sufficient for reliable work of relay protection and does not depend on a capacity current of network. The required values of resistor resistance for this disconnected resistors case laid in the follow range:

$100 \le R_N \le 500$ Ohm

Unfortunately, in the majority of medium voltage networks, there are no conditions for immediate switching-off the damaged connection. In this case time of operate of the resistor in the ground fault mode is determined by brief space of time during the technical staff can to determine a point of damage and to remove it, or to create the temporary circuit of power supply without switching-off of the consumers.

High resistance grounding refers to a system in which the neutral is grounded through a predominantly resistive impedance whose resistance is selected to allow a ground fault current through the resistor equal to or slightly more than the capacitive charging current of the system.

Really the application and effective exploitation of resistive grounding of the neutral – for increase the level of reliability and accident prevention, the time of ground fault existence is necessary to minimize. Otherwise we increase a ground fault current, the minimum at $\sqrt{2}$ time (in comparison with a mode of insulated neutral) and if the damaged element is not switched-off, the accident prevention of such network is reduced. And main – one of advantages of resistive grounding of the neutral – possibility of creation the simple and effective relay protection against the ground fault based on the principle of occurrence of an active current in damaged feeder is not used. The resistor is regular connected to neutral of network and operates in the ground fault mode till to clear a fault. In a Figure 3 the dependence of values of resistance for neutral grounding from time of his operation in the ground fault mode is shown. It is necessary whenever possible to reduce time of ground fault existence in the considered networks, that will allow will increase their reliability and accident prevention.

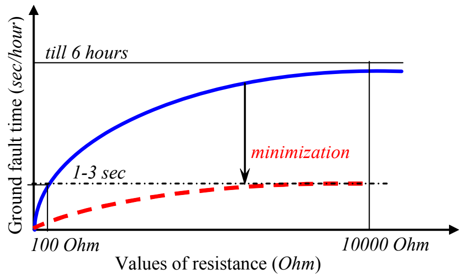

Figure 3. Dependence of values of resistance from time operate in the ground fault mode

VI. CALCULATION RELAY PROTECTION OPERATE SETTINGS

Operating currents to determine circuit as the sum of currents on each of one circuit (two-circuit) lines separately in a normal operate mode.

Therefore, the lower limit of a resistors resistance is expedient for choosing so that current direction and non direction protection selectively operated:

$$I_{OS\ N-D} = K_{SF}\left(I_C + I_{IMB}\right)$$
$$I_{OS\ D} = K_{SF} \cdot I_{IMB} \qquad (7)$$
$$R_{NL} = f(I_{IMB},\ I_C)$$

where $I_{OS\ N-D}$ is operate settings of current non direction protection against ground fault; $I_{OS\ D}$ is operate settings of current direction protection against ground fault; K_{SF} is safety factor including reliability index and reset ratio in protection of the relay; I_C is stationary capacity current of ground fault defined by feeder capacity; I_{IMB} is stationary initial imbalance current defined by maximum operating current and R_{NL} is lower limit of a resistance of the resistor.

VII. THE LEAST RESISTANCE STRATEGY

Sensitivity of protection against ground fault in not standard sensitivity factor (the relation of a current of the zero sequence through the current transformer in the damaged line to the operate current of protection), but size of transient resistance in the point of ground fault at which protection still can «feel» ground fault.

Strategy of estimation sensitivity based on the minimal transient resistance rating when relay protection is still reacting on the ground-fault mode – The Least Resistance strategy [4].

The major question – for use of size of transitive resistance as an estimation of sensitivity it is necessary to know that value of this size that is minimal, R_{GFmin}.

The proposed strategy of an estimation sensitivity of protection against ground fault is considered as constituent part of complex of measures on resistive grounding of the neutral and consists in the following:

1. To define size R_{GFmin}:

1.1. To be set by size of transient resistance, R_{GFmin} at which protection still reacts on ground fault;

1.2. At a known level of devices operation of the signal system reacting to occurrence of a voltage of zero sequence to determine limiting value of transient resistance in the point of ground fault, R_{GFmin}. For basic in concrete region the substation to which the most extended network is accepted.

2. Proceeding from the maximal working current to calculate the imbalance current.

3. To calculate operate settings of direction and non direction protection (lines 1 and 2, Figure 3).

4. To plot dependence of a current in the damaged line from transient resistance in the point of ground fault – $3I_{0GF}=f(R_{GFmin})$ – a curve 3, Figure 3.

5. By the schedule to define real transient resistance to which the direction and non direction protection ($I_{0S\ D}$ and $I_{0S\ ND}$) is reacts.

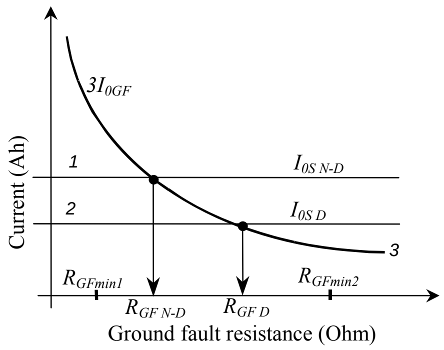

Figure 4. Sensitivity estimation of protection against ground fault

6. Having compared desirable transient resistance in the point of ground fault – R_{GFmin} (item 1) with the real, received graphic way to draw a conclusion on in the point of ground fault – R_{GFmin} sensitivity.

The sensitivity factor of protection:

$$f_S = \frac{R_{GF\ D/N-D}}{R_{GF\min}} \quad (8)$$

where $R_{GF\ D/N-D}$ is transient resistance at which the direction and non direction protection sets on the concrete substation in considered region are reacts. If $1 \le f_S \le 1.1$ then protection meets necessary requirements. Such sensitivity factor provides the minimal increase of ground fault current.

It is necessary to note, that $f_S >> 1$ size of transient resistance at which relay protection will disconnect the damaged feeder, it will be totally unjustified more than R_{GFmin}. It, in turn, results in increase of ground fault current (in case of resistive grounding of the neutral) and to deterioration of accident prevention level.

For the networks located in the other climatic area, characterized by the own ground resistance, and as consequence, other transient resistance, the sensitivity estimation of protection against ground fault is made similarly (features of other climatic area will be taken automatically). Applying this strategy is possible to carry out the qualitative analysis of different variants of protection, and to choose most acceptable, from the technical and economic point of view.

VIII. CONCLUSIONS

1. The modern condition of medium voltage networks protection against ground fault don't satisfy the requirements of exploitation reliability, accident prevention of networks, selectivity, sensitivity and relay protection speeding-up.
2. The imbalance currents, calculated by classic strategy, usually, on the order exceed actual (measured) imbalance currents. Therefore the imbalance currents should be determined or by maximum imbalance current recorded in the log, or by actual operating current of practicable object.
3. It is necessary and expediently to introduce the resistive grounding of the neutral to apply in industry of electrical networks; to log all advantages and potentialities of resistive grounding of the neutral for medium voltage networks in the normative documents.
4. When the presence of starve equipment and selective relay protection the damaged connection should be immediately switched-off. When on a condition of maintenance of uninterrupted power supply the long existence of ground fault in the network is required (to clear a fault objectively is supposed the sometime), the technical staff should begin search of a ground fault point immediately and to clear a fault in the shortest time.
5. To evaluate sensitivity of current protection against ground fault it is necessary, with the help of The Least Resistance strategy.

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BIOGRAPHY

Alexey V. Wishtibeev was born in Novosibirsk, Russia, 1974. In 1997 has received a Master of Science degree of «Technical Equipment and Technology» on a specialty «Power Industry» in Novosibirsk State Technical University, Russia. In 2000 has received the Thesis on a theme «Research of efficiency of resistive grounding of the neutral in electric networks 6-35 kV a various design and purpose». He is the Senior lecturer and Associate Professor in Power station faculty of Novosibirsk State Technical University. From 2002 to 2004 he was the scientific secretary of Conference «Overvoltages restriction and modes of neutral grounding of networks 6-35 kV». Since 2005 he is the member of the Advisory and Scientific Committee of the World Scientific and Engineering Academy and Society (WSEAS). Since 2007 he is the head of Power Network Development Department in Siberian Power Engineering Centre. Since 2009 he is the member of Scientific Committee of International Conference on “Technical and Physical Problems of Power Engineering”. He is the author more than 70 papers in the proceedings. His special fields of scientific interests are modes of neutral grounding of medium voltage networks, arc overvoltages, ferroresonant phenomena, relay protection against ground fault, electromagnetic compatibility of power technical complexes, transient modeling, and power network development.