Selective complex single-phase earth fault protection for distribution medium-voltage networks

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Abstract—**This article deals with selective protection against single-phase earth faults at 6 – 10 kV electrical networks. Different kinds of earth faults, factors influencing the implementation of protection, various principles of protection implementation, are described. Requirements and structure of complex protection applicable to networks with any neutral grounding mode and providing separation of various kinds of earth faults are given in this text.**

Keywords-6 – 10 kV distribution electrical cable networks; neutral grounding mode; single-phase earth faults; selective earth faults protection

I. INTRODUCTION

In Russia the main part of the electricity is distributed to consumers of urban and industrial power supply through the medium-voltage electrical networks (6-10kV). The area of 20 kV cable networks application is also expanding. Single-phase earth faults (SPEF) dominate at these networks (their general number is 75-90% of all electrical damages) and frequently cause faults accompanied by significant economic damage. As a rule, SPEF protection acts on a signal. Its tripping action is provided only for the generators, motors and lines, which tripping is dictated by the electrical safety requirements.

Performance effectiveness of medium voltage distribution networks, and electric reliability of consumers significantly depend on technical perfection (excellence) (selectivity and stability functioning) of SPEF protection devices. Scarce technical perfection reduces the reliability of power supply.

Variety of neutral grounding modes at electrical medium voltage networks is one of the key factors, which makes achieving of universal effective solution in SPEF protection implementation rather difficult. In Russia, medium voltage network (6-10kV) can be ungrounded systems, resonant grounding with arc-suppression reactor (ASR) or high-resistance grounding systems. Neutral grounding mode determines the principles of SPEF protection implementation and the character of the electromagnetic transients that occurs during the fault.

Another important factor is the difference in SPEF, typical for cable networks operating with the afore-referenced neutral grounding modes. There are sustainable SPEF (SSPEF), arc intermittent fault (AIF), arc unsteady fault (AUF), self-extinguishing fault (SEF). The most dangerous kind of SPEF is AIF, which cause significant overvoltage, covering the entire power grid, and an increase of current RMS value at the fault location. AIF is the main source of double and multiple earth faults, causing disconnection of two or more feeders, as well as serious motor damages, fire in cable tunnels, etc. Therefore, in the 80s, some Russian experts offered protection for any type of connection (lines, electric motors) with acting on trip in case of AIF, and if the faults are less dangerous - SSPEF and AUF - on a signal [1].

AIF and SSPEF usually precede SEF, that's why their selective fixation can be used for diagnostics and improvement of medium voltage cable networks insulation protective treatment effectiveness [2, 3]. It is known [3, 4] that about 50% of feeders disconnection can be prevented by selective fixation of SEF and collected information using for cable networks (6-10kV) diagnostics. Effectiveness of SEF information using for diagnostics increases with fault location determination (zone-within the accuracy of the network's part, which can be isolated for maintenance tests).

Considering the above-stated, complex solution to the problem of SPEF protection at medium voltage cable networks must meet the following basic requirements:

- Complex protection has to be applicable to electrical medium voltage networks with any neutral grounding mode.
- Complex protection has to identify all kinds of SPEF, especially the most dangerous - AIF and allow possibility of separate protection action on trip or a signal, depending on the damage risk degree.
- Complex protection has to provide SEF fixation.
- Complex protection has to provide a continuity of operation for the whole time interval of SPEF existence, in case of sustainable faults, to search the fault feeder (area) by switching method.
- Complex protection has to provide, if it's possible, remote fault location determination, including the SEF.

Complex solution based on these requirements is possible only for combined protection, using different methods of fault feeder determination and SPEF kind identifying at networks with any neutral grounding mode. Only protections based on the use of different components of steady - state SPEF zero-sequence current (e.g. operating frequency components, higher harmonics components, superimposed currents) have continuity of operation. However, this type of protection does not always provide SEF fixation, selectivity and operation stability in case of AIF. As usual, only protections based on the use of transient electrical values can provide selective fixation of SEF, selectivity and operation stability in case of AIF, AUF.

Such function of a digital complex protection, providing AIF clear identification, allows fast identification of the most dangerous fault type for the network and protected feeder, and technical excellence increase of widely used protections, based on different components of the steady state SPEF current, due to their automatic lock or settings changing during the existence of AIF.

Thus, the SPEF complex protection is not just a mechanical combination of several independent protections, based on various methods, in "one device", but interaction between functions that brings into action various methods of protection implementation, in order to maximize the efficiency of their operation. Complex protection creation is possible only on a microprocessor element basis.

II. ARC INTERMITTENT FAULTS AND ARC UNSTEADY FAULTS

Arc unsteady fault is the main kind of SPEF at cable networks (6-10kV) which is characterized by intermittent current form with a predominance of free transient components [1, 5 – 8]. Amplitude of these components reaches values up to hundreds and even thousands of amperes and depends on total capacitive current $I_{c\Sigma}$, distance of fault location from power source busbar, faulty phase voltage at the moment of insulation failure, and electrical network line parameters. All arc SPEF can be divided into 2 species:

a) *Arc intermittent fault.*

b) *Arc unsteady fault.*

Arc unsteady SPEF isn't accompanied by significant overvoltage during repeated ignitions of the grounding arc, like in case of AIF. Studies, carried out with simulation models of isolated cable networks, showed that the overvoltage value during repeated ignitions of the arc mainly depends on the time interval between repeated insulation breakdowns (Fig. 1). Analysis showed that when these time intervals are less than 0,08-0,1 s the overvoltage reach dangerous values (unfaulted phase-to-ground voltages degree is over than 2,7 - 2,8 times). In that case RMS fault currents value, as a rule, is less than total capacitive current $I_{c\Sigma}$. Taking this into account, in complex protection, the value of the time intervals between repeated insulation breakdowns is proposed to use as a distinction criterion between dangerous AIF and relatively safe for a network AUF.

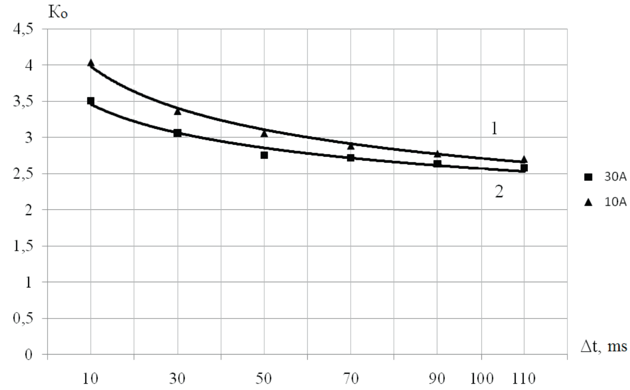

Figure 1. The overvoltage ratio K_O dependence from the time intervals between repeated insulation breakdowns Δt in case of AIF: 1 – 6 kV network, $I_{c\Sigma}$ = 10 A, 2 – 6 kV network, $I_{c\Sigma}$ = 30 A

III. AIF DETECTING METHODS

The results of the arc intermittent faults and arc unsteady faults researches, carried out with simulation models of 6-10 kV cable networks in the modeling system Matlab, showed that AIF detecting can be based not only on direct measuring of the time intervals between repeated ignition of the grounding arc but also on simpler methods, which are based on higher harmonics components measuring in the spectrum of the zero-sequence currents and voltages. They are:

A. *Measuring the higher harmonics overall rate of the zero-sequence voltage $3U_0$.*

B. *Measuring the higher harmonics overall rate of the protected feeder zero-sequence current $3I_0$.*

During normal operation total harmonic distortion THD value have to be under 8%. Exceeding this level indicates AIF. Calculations show that if the THD=8% and individual HH components value reaches maximum permissible level, the overall level of the HH in SSPEF current will not exceed $0,65I_{c\Sigma}$ (or $0,65I_{Ci}$, where I_{Ci} is capacitive feeder current), but in case of AIF it will exceed $0,65I_{c\Sigma}$.

Proposed methods can be used as a part of SPEF complex protection, as well as separate protection fault detectors locking or changing the settings, if protection doesn't provide selectivity and stability of operation in case of AIF.

IV. MEDIUM VOLTAGE CABLE NETWORKS SPEF COMPLEX PROTECTION BLOCK DIAGRAM

The simplest zero-sequence current protection (ZSCP) and directional zero-sequence current protection (DZSCP) got wide application at 6 - 10 kV electrical power networks with isolated neutral in Russia and over countries [9]. They are also used at high-resistance grounding systems. The main ZSCP disadvantages are limiting of its application, depending on the magnitude of capacitive feeder current ($I_{ci*}= I_{ci}/I_{c\Sigma} \leq$ ~0,15–0,2) and possibility of operation failures in case of AIF, which is also critical to DZSCP.

SPEF protection based on measurement of higher harmonics overall rate (HHZSCP) in protected feeder zero-sequence current $3I_0$ got wide application at resonant grounding by ASR electrical power networks 6 - 10 kV in Russia. HHZSCP main disadvantages are limiting of its application, depending on the magnitude of capacitive feeder current (I_{ci*}≤0,05–0,1) – the same as for ZSCP, and inability to detect AIF. Devices responsive to higher harmonics (HHDZSCP) direction allow obtaining more efficient solution for SSPEF protections at resonant grounding with ASR systems.

AIF clear definition by complex protection allows technical excellence increase of protections above due to their automatic lock or settings changing in case of AIF.

Proposed complex protection overall structure, including ZSCP, DZSCP, HHZSCP and HHDZSCP, is shown in Fig. 2. The main protection in the structure is that which distinguishes AIF. It is designed as directional protection with continuity of operation (DCOP), based on the use of transients electrical quantities.

V. Principles of DCOP implementation

One possible way of directional protection with continuity of operation embodiment is based on definition of zero-sequence power mean value sign for the whole time interval, when transient current $i_0(t)$ exists. At the same time voltage derivative du_0/dt is used as a polarizing value. It provides protection proper operation in case of possible distortions between voltage $u_0(t)$ and current $i_0(t)$ initial signs ratio, which is possible because of the network neutral displacement.

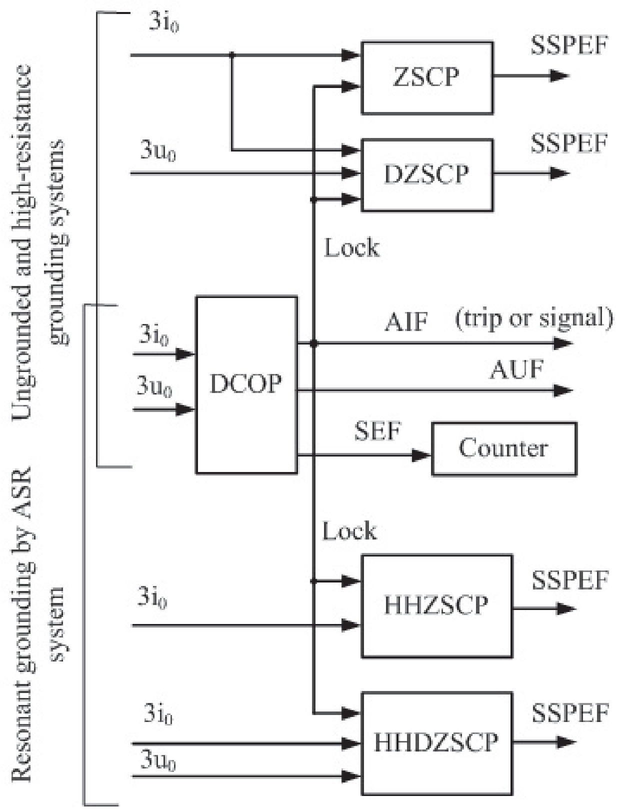

Figure 2. Complex protection functional logic diagram

Continuity monitoring of transient zero-sequence power mean value in case of the SPEF can be implemented on the basis of algorithm described by the ratio

$$J = \int_0^{t_o} i_0(t)\cdot(du_0(t)/dt)dt, \qquad (1)$$

where t_o - SPEF transients observation time.

Thus, in networks with any neutral grounding mode it seems possible to implement complex protection against all types of earth faults combining previously known principles of protection implementation, well-proven itself in identifying sustainable SPEF with principles providing precise fixing and separation of various kinds of unsteady faults. This protection provides continuity of operation under both transient and steady-state conditions of SPEF and can separately acts on a signal in case of relatively safe AUF and on trip in case of AIF. Viewed principles of protection implementation are realized within the limits of joint effort with the protection devices manufacturer («EKRA» RPE Ltd). Technical specification for experimental development is currently created, preproduction prototype and experimental sample are also developing.

Conclusions

- Basic requirements for complex protection against single-phase earth faults, including the requirement of AIF identification, that allows improving of widely used protections efficiency as well as power supply reliability, were stated.
- Studies, carried out with simulation models of isolated cable networks, showed that the risk degree of different kinds of SPEF depends on time interval between repeated arc ignitions. It was proposed to perform protection acting on trip in case of AIF, which time intervals between repeated arc ignitions are about 0,01 – 0,02 s.
- The structure of complex protection, applicable to networks with any neutral grounding mode, combining previously known principles of SPEF protection implementation and directional protection based on transient values, which provides separation of various kinds of SPEF based on measurement of time intervals between repeated insulation failures was proposed.

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