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Research on the Performance of the Controlled Arc Suppression Reactors in Electric Distribution Networks 6–35 kV

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Abstract

The paper presents the experimental results of performance evaluation of two types of Arc Suppression Reactors (ASRs): traditional (plunger-type) and Magnetically Controlled (MC-type). The aperiodic component in reactor current is observed and its influence on reactors response speed is analyzed. It is shown that the delay in complete capacitive earth-fault current compensation is determined mostly by aperiodic component and not by forcing of magnetic excitation of MC-type ASRs. From this point of view ASRs of both type show similar performance and the criterion for their correct comparison is still has to be discovered.

Keywords: Arc Suppression, Capacitive Current Compensation, Distribution Network, Petersen Coil, Single-Phase Earth Fault

1. Introduction

In Russian Federation and in many other countries the neutral points of electric distribution networks 6–35 kV are isolated or grounded through resistor or arc suppression coil (ASR), the latter compensates the capacitive current of the single-phase fault[1]. The ASR is also called the Petersen coil after the name of W. Petersen, who was the first to propose this principle of compensation[2]. The single-phase arcing fault capacitive currents compensation is used if the currents are greater than the values specified in the standards (single-phase arcs with currents above these values are stable and can bring a lot of damage to the network). In Russian Federation, according to[3,4], these currents are 10–30 A depending on the rated voltage of a network. Installation of the ASR gives many benefits to the network, the most important are:

– Ability to continue power supply during the single-phase fault[5];

– Increased probability of the arc self-extinguishing which leads to the reduced probabilities of fire and single-phase arcing fault transition into two- or three-phase fault[6];

– Low speed of the voltage recovery on the faulty phase after the arc extinction, which decreases the frequency of intermittent arcing faults[7];

– Low over voltages in the case of the accurate tuning of the ASR[8].

After many years of operational experience, it is now evident that the ASRs should be continuously controlled and the control should be stepless and automatic[9]. Among automatically tuned ASRs in Russian Federation the two types of reactors are being used: Mechanically regulated by means of a plunger[10] and magnetically controlled[11]. Other designs are proposed[12,13]. Plunger-type reactors are being tuned before single-phase fault, MC-type reactors – immediately after ground fault occurs[14], that is the main difference between them.

The preliminary tuning of ASR[15] has a drawback of creating the resonance conditions in the zero-sequence contour of the network. The neutral displacement in the network with ASR can be estimated by the following formula[16]:

$$U_N = U_0 \frac{1}{\sqrt{\vartheta^2 + \delta^2}} = U_{ph} \frac{m-1}{m+2} \frac{1}{\sqrt{\vartheta^2 + \delta^2}}, \qquad (1)$$

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Where U_0 – the neutral displacement without ASR installed in the network; U_{ph} – phase voltage; m – the degree of the capacitance unbalance in the network; $\delta = \frac{I_R}{I_C}$ – the damping factor of the network; $\vartheta = \frac{I_C - I_L}{I_C}$ – the degree of ASR detuning; I_L – the inductive component of ASR current; I_R, I_C – the active and capacitive components of the single-phase fault current.

The damping factor of the network is usually 0.05–0.1 and it can be seen from (1) that in the case of ideal ASR tuning ([vartheta] = 0) the reactor increases the neutral displacement by the factor of 1/[delta] = 10–20, which can lead to unacceptable values of U_N. MC-type reactors are not tuned to resonance in normal operating mode of the network, so they do not establish resonance conditions. But these reactors have to rapidly change their inductance after single-phase fault in order to create conditions for arc extinction as fast as possible. If the response of the MC-type reactor is fast enough, its application is preferable. To compare the response speed of ASRs of different types it was decided to carry out an experiment, which is discussed in this paper.

2. Materials and Methods

A good review of experimental techniques for providing measurements and registrations of single-phase faults is given in[17]. Our experimental setup is presented in Figure 1. The supply voltage is 0.4 kV stepped-up by power transformer 630 KVA to 6 kV. The rigid busbar 6 kV is made of copper conductors of 4x40 mm cross section. The Neutral Coupler (*NC*) is connected to the network terminals *A*, *B* and *C* and its neutral terminal *N* serves for the connection of ASR. The ASR neutral terminal is connected to the grounding grid with the same conductor 4x40 mm. The distributed network capacitance is modeled by the set of lumped capacitors, which provide single-phase fault current up to 90 A. Voltages required to operation of control system of the ASR are measured by inductive Voltage Transformer (VT). The digital oscilloscope registers signals from Capacitive-Resistive Dividers (CRD) and Current Transformers (CT). Single-phase fault is imitated by switching of one pole of vacuum circuit breaker directly to grounding grid (metallic fault) or through arcing horns (arcing fault)[18].

Two different ASRs were subjected to testing and corresponding measurements: 300 kVA plunger-type ASR with manual tuning and 300 kVA Magnetically Controlled ASR with automatic tuning. In all experiments the time instant of the single-phase fault was a random variable, measured in terms of voltage phase angle at the instant of fault (hereafter fault angle FA, in degrees).

3. Results

The measurements have been provided at three different levels of single-phase fault current $I_{f,RMS}$ (30, 45 and 60 A, RMS-values). For each ASR and value of I_f ten single-phase faults have been accomplished. As an example in the Figure 2 the measured traces of fault current I_f and reactor current I_r for close values of FA for both reactors are shown. In both cases the aperiodic component in current and high harmonics content are clearly seen. The aperiodic component seems to draw out the current compensation to a great length of approximately 50 periods of power frequency. The overall picture of the process is identical for reactors of both type. Another important point is that there is no zero-crossing of I_f during the first 2 periods of power frequency – in the case of arcing fault it could lead to delayed extinction of the arc.

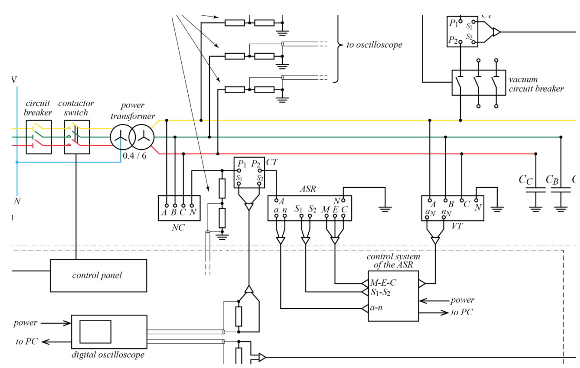
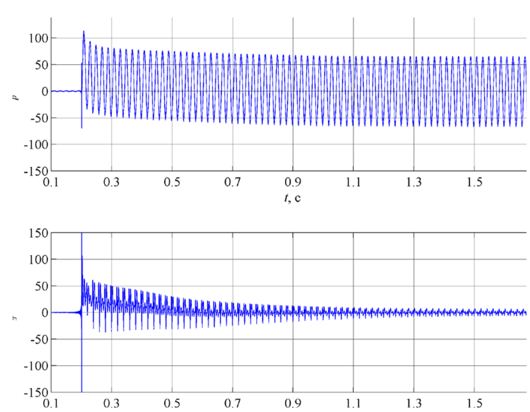
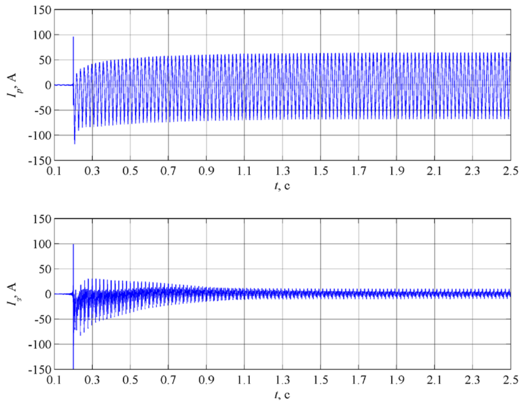


Figure 1. Experimental setup.



(a)



(b)

Figure 2. Single-phase fault and reactor currents ($I_{f,RMS}$ = 45 A) a – Plunger-type ASR, FA = 46°; b – MC-type ASR, FA = 45°.

As a measure of ASR response speed estimation we use the value of time $t_{20\%}$ required for residual current to reach the 20% level of fault current, i.e. to reach the reduction of fault current RMS-value by the factor of 5. The details of this parameter calculation from measured data are presented in[19]. After handling of the measurement results it was found that $t_{20\%}$ has a large statistical dispersion, as can be seen from Table 1.

Table 1. Estimated response time of plunger-type and MC-type ASRs

$I_{f,RMS}$, A	ASR type	$t_{20\%}$ range, ms	$\overline{t}_{20\%}$, ms
60	Plunger	27–364	218
	Magnetically controlled	124–425	344
45	Plunger	28–563	333
	Magnetically controlled	79–701	525
30	Plunger	30–842	328
	Magnetically controlled	31–1045	621

4. Discussion

The slow response speed of both ASRs is explained by the occurrence of aperiodic component in reactor current. Theoretical analysis[1–21] shows that this component is influenced by the time instant at which the single-phase fault occurs[19]. For the ASR with linear inductance L the inductive current $i(t)$ is:

$$i(t) = i(0) + \frac{1}{L}\int_0^t u(t)\,dt \quad , \qquad (2)$$

Where $u(t)$ – voltage at reactor terminals, initial current value is usually $i(0) = 0$.

If voltage $u(t)$ is sinusoidal,

$$i(t) = \frac{1}{L}\int_0^t U_m \sin(\omega t + \mathrm{FA})\,dt = \frac{U_m}{\omega L}\left[\cos \mathrm{FA} - \cos(\omega t + \mathrm{FA})\right] \quad . \qquad (3)$$

It is seen from (3) that if FA ≠ 90° the constant term $\frac{U_m}{\omega L}\cos \mathrm{FA}$ is present in the reactor current. Considering losses in the network this term decays exponentially, which gives aperiodic current component.

Registrations of intermittent arcing faults also show aperiodic components in arc current. If they occur, the arc self-extinction has a delay of 1–2 periods of power frequency. During the time of arc burning the considerable energy is released in the place of arcing fault. This fact leads to the idea of using the mean value of released power in the arc as a criterion for comparing the performance of ASRs of different types, which is the subject for further investigations.

5. Conclusion

- The aperiodic component in the reactor current leads to significant reduction of effectiveness of capacitive current compensation by ASRs of both considered types. Experimentally obtained mean values of time required for residual current to reach the 20% level of fault current are of the order of several hundred milliseconds.
- Aperiodic component in reactor current leads to delays of arc extinction and increased levels of mean energy, dissipated in the arc channel. Further investigations are required to develop the method of comparing ASRs of different type, mean value of power released in arc channel could become a good quantitative criterion.

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