THE PROBLEMS TESTING DIGITAL RATE-OF-CHANGE IN FREQUENCY RELAYS

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The frequency of alternating current in electric power networks is the paramount parameter of the operating mode of a network. Even small frequency deviations can bring about serious malfunctions in the networks and demands for urgent corrective action. In many cases, a parameter for an emergency mode in a network is not just the absolute value of frequency, rather it includes the frequency's change in time.

Such a parameter as Rate-of-Change of Frequency (ROCOF) is today the principal parameter that is monitored by numerous specialized digital relays (the ANSI code for relays of this type is 81RL), which are available on the market (for example, UFD34, MRF2, G59, PPR10, LMR-122D, FCN950, KCG593, MFR 3, MFR 11, LS 4, VAMP 210, SPCF 1D15, 256-ROCL and many other types).

There are two cases in which ROCOF relay protection is used in the core:

1. For automatic load shedding, that is, for switching-off part of the loading upon detection of sweeping changes of frequency. It is necessary to note that in the emergency mode in a high-voltage power network, changes of frequency can be distinctive in different sections of a network depending on the power of the separate substations which are available in this network. In addition to sweeping decreases of frequency in a branch network, there are overflows of power between the energy sources powering this network, accompanied by frequency fluctuations in the network as a whole. Thus, the absolute value of the downgraded frequency is not constant and therefore cannot serve as the criterion for pickup adjustment of the frequency relay, switching-off a part of the loading. A much more reliable criterion for load shedding is the ROCOF function which is used as an additional criterion upon detection of the decrease of an absolute value of frequency below the set level.

2. The case of an instantaneous interdiction of repeated connection of the generator to a power network if it has been already disconnected, even for a short-term (isolated from a network). In the latter case, this protection is referred to as "loss of mains", or "loss of grid", or "islanding protection". A high-voltage circuit breaker tripping and the separation of a section of a network with the generator (that is, the formation of an isolated "island") from the main network (that is "loss of mains") leads to an infringement in the balance of power in the isolated section of the network creating oscillations, accompanied by frequency fluctuations. Very quickly, however, the frequency can return to normal under the action of an automatic voltage excitation controller in the generator or if the load of the generator is insignificant. However, the situation remains potentially dangerous, as the frequency of the generator can change at any moment during the change of its load; thus the automatic reclosing of the circuit breaker will lead once more to the emergency mode of operation. For this reason, ordinary frequency relays are not applied in this situation. The ROCOF relays are capable of detecting the frequency fluctuations of fractions of a second at once after the circuit breaker trip, stopping the automatic reclosing.

The set point ROCOF for the protective relays is calculated according to concrete parameters of a network, the generator, loads and can be essentially different for various networks. For example, in

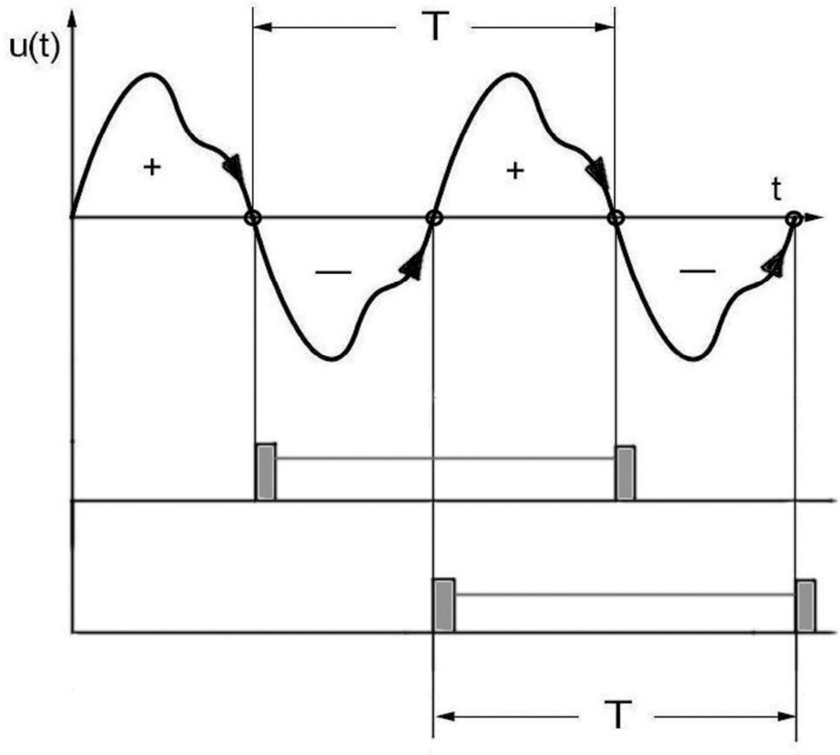

Fig.1. Principle for measurement frequency of the distorted periodical signal.

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Frequency Relays

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networks of Great Britain this set point is a constant - 0.125 Hz/sec, but in nearby Northern Ireland ranges between 0.45 - 0.50 Hz/sec. In it is shown that a wrong choice of the set point of the relay for this parameter results in false pickups, or insufficient sensitivity. This imposes certain requirements as to the accuracy of the protective relay.

The algorithm of frequency measurement in digital protective relays is related to the allocation of transition points of a sine wave through the zero value that allows eliminating the effect of sinusoid distortion on the accuracy of the frequency measurement, Fig. 1.

The sinusoid signal, as a rule, is first converted to a square wave and filtered, and then short pulses are formed in transition points of a sine wave through the zero value. Intervals between these pulses are filled with the high-frequency pulses produced by a highly stable quartz resonator with a fixed oscillation frequency (usually 100 kHz). The pulses counter, with a very high degree of accuracy, counts the number of these pulses which within the interval determined by the transitions through zero value of the sinusoid (that is from period T of an input signal). The error in measurement of frequency by the modern digital relays with this algorithm does not exceed as a rule: ± 0.01 to 0.005 Hz.

The algorithm of measurement of the rate-of-change of frequency (ROCOF) is different. We shall observe the operation of this algorithm of such a relay in an example of automatic load shedding, Fig. 2.

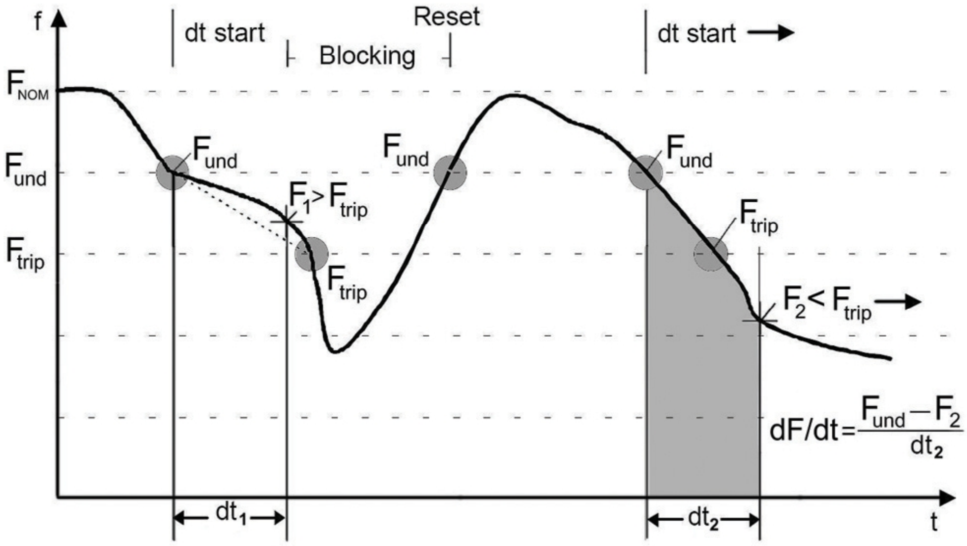

Fig. 2. Principle of functioning of the ROCOF relay for load shedding.

FNOM – rated network frequency; Fund – lower frequency; Ftrip – critical value of the frequency to starting ROCOF function; dt start – time interval for which relay remains in an active mode after the lower frequency (Fund) detecting; Blocking – deactivation relay at expiration determined time interval (dt1) even if frequency remains lower; Reset – returning the relay to initial position at increasing frequency up and more than Fund value; F2 – lowest value of critical frequency in the time interval dt2 for which ROCOF value is calculated.

As shown on Fig. 2, the ROCOF function is started in the relay only if the value of the controlled frequency drops below the critical level Ftrip. If this drop does not occur, the relay will deactivate after a specified time interval (dt1) even if the frequency remains downgraded. The ROCOF function is put into effect only when the frequency in a network drops below the critical level Ftrip. Therefore, the frequency is measured at two points: Fund and F2 with a time interval dt2 between these two measurements. If the value dF/dt for these measurements is more than the set point, the relay is activated, disconnects a part of the load and reestablishes the power balance in the network.

A more complex algorithm, which is realized via auxiliary elements (Table 1), also determines a higher error of the relay in the ROCOF mode in distinction to the usual function of just monitoring the frequency. Whether we are talking about this algorithm or the one previously discussed, one thing is quite certain: accuracy is required when testing such a crucial protective relay as the ROCOF. Testing such relays is only possible in the presence of a special simulator that implements the ROCOF function. With the progress made in the field of microprocessor protective relays, many companies today make simulators for testing these relays. These simulators are even supplied with the capability of simulating the ROCOF function.

However, when testing the very precise FCN950 relay type in the ROCOF mode, an interesting fact is revealed: the relay behaved differently, depending on what type of simulator was used; thus the maximum error in the threshold of the relay pickups exceeded 10%. This is absolutely inadmissible, in our opin-

Table1. Parameters of some common types of the frequency protective relays

Type	Manufacturer	Error of pickup	
		On Frequency, Hz	ROCOF (df/dt), Hz/sec
module SPCF 1D15 to relay SPAF 340C	—	0.01	0.15
FCN 950	ABB	0.005	0.05
MRF2	Woodward SEG	0.03	0.1

ion. The analysis of the technical specifications of the simulators of the various types manufactured by the leading companies of the world: EPOCH-III (Multi-Amp), ORTS (Relay Engineering Service), F-2250 and F-6150 (DOBLE), PTE-300-V (EuroSMC), DVS3 mk2 (T&R Test Equipment), CMC256 (Omron), T-1000 and DRST-6 (ISA), PTR233/133 (Francelog Electronique), FREJA 300 (Programma), MPRT (Megger), etc., has shown that there is no mention in the specifications of the accuracy in the mode of ROCOF generation for any of these devices.

All manufacturers determine only the precision in the mode of continuous frequency generation. But as we have seen in Table 1, for protective relay the error in the ROCOF mode is approximately one exponent higher than in an operating mode monitoring an absolute value of frequency.

It is obvious that the same should be expected from the simulators which are implementing the ROCOF function simulation. The accuracy of the reproduction of an absolute value of frequency, declared by manufacturers, does not mean the same accuracy of ROCOF reproduction. What is this accuracy? And how are we to calibrate the simulator used for testing such crucial devices as the protective relays?

To solve this problem, we have developed the following simple technique: The output signal generated by the simulator in the ROCOF mode (with parameters close to the set point of the protective relay) is recorded with high resolution by means of a digital recorder in the memory recording mode (we used a multichannel Hioki-8842 digital recorder).

Further, the plotted sinusoidal signal was recorded by means of cursors on a time axis, a fixed time interval T (between 0.5 to 1 sec) and by means of the cursors the period for two single sinusoids was measured: beginning (at t1) and ending (at t2) in the fixed time interval, Fig. 3.

The frequencies of the beginning (f1 = 1/t1) and the ending (f2 = 1/t2) sinusoids within the time interval can be calculated. And from this it is possible to calculate the ROCOF = (f1 - f2)/T.

The digital recorders (manufactured by Hioki, Yokogawa) with high-resolution capabilities in a memory recording mode, can determine the time intervals of the low-frequency (45 - 60 Hz) signals with accuracies of parts of a millisecond.

This technique was used for calibration simulators types F-2253 (Doble) and T-1000 (ISA) in function of ROCOF simulation. The results of the calibration are presented in a Table 2.

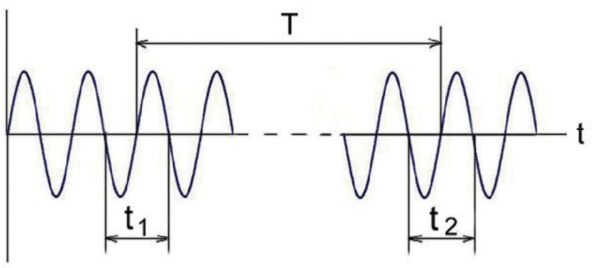

Fig. 3. Suggested method for precise ROCOF measurement

Table 2. Result of calibration of simulators in ROCOF mode according to suggested method

ROCOF, Hz/sec			
Simulator's Set Point	Value Measured and Calculated by Suggested Method	Error	
		Hz/sec	%
Simulator F-2253 type			
0.4	0.395	0.005	-1.37
Simulator T-1000 type			
0.4	0.449	0.049	+12.15

Using the technique, it is possible not only to make periodic calibrations of the simulators of any type in a mode of ROCOF generation, but also to check the usability of concrete simulators for the testing of relays. For example, from the results presented above, it is possible to consider that simulator í-1000 is not suitable for testing the relay type FCN950, but it can be applied for testing the relay type SPAF 340C.

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