Selected protective algorithms of modern IED

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The paper presents some aspects of the work IED protection algorithms. These functions are hidden deep in the algorithms, however, very important for the power protection automation during abnormal failure in the MV lines. These functions have not been tested yet. An example of this problem is action of the IDMT overcurrent protection when the input current changes its value after protection start-up. Another example is the work of an earth fault protection based on Y0> criteria, when Y0 signal is distorted.

The article is entirely based on the experience and measurements conducted by the author in the laboratories of the Institute of Electrical Power Engineering Poznań University of Technology.

KEYWORDS: IED, protection algorithms, IDMT overcurrent protection, admittance protection.

1. Introduction

An electric power system is a set of devices that are used for the generation, transmission and distribution of electricity. In order to ensure the proper functioning of all its components constant supervision must be carried out on them – both by humans and by a whole range of automation systems. Currently, the former is withdrawn in favor of the latter, due to not enough effective human responses to sudden events that occur in the power system. From the foregoing that the power system protection (EAZ) fulfills a very important role. It recognizes the accident and quickly take the right decision, which is, for example, the automatic exclusion the defective part.

An example of modern equipment implementing the functions of power system protection terminals are IED’s. This type of microprocessor devices have at least one digital link to a central system, perform the tasks in the use of separate fields (line, transformer, generator etc.) associated with elimination, prevention or restitution power system protection. IED's also perform the functions of electrical measurement, control switches, record the events and faults, locate the fault etc. IED’s may be equipped with a display and buttons for controlling the switch.

From IED's designed for medium voltage fields are required to complete tasks, most important of which are those, that result directly from the needs of system protection. Therefore, the most important measurement – computing algorithms refer mainly to:

- determination of basic measurement, such as currents and phase voltages and symmetrical components of current and voltage,
- calculate of other quantities, such as power, energy, admittance,
- calculation time and the starting of decision-making that affect the change in switching states,
- determining the value of logical variables [2].

All algorithms are based on the knowledge of the phenomena occurring in the power system during failures as well as the so-called engineering knowledge and experience of the authors of these procedures. There is, however, a protection group that algorithms are not fully described – most of the causes of their marginalization. These include for example IDMT overcurrent and admittance protections. The study of these two functions focused on the author in this publication.

2. IDMT overcurrent protection

IDMT current protections are the primary and backup protections of effects of phase faults or overloads in lines, transformers and motors. IDMT characteristics makes possible their selective action. An example of an IDMT overcurrent protection time – current characteristic is presented in Figure 1.

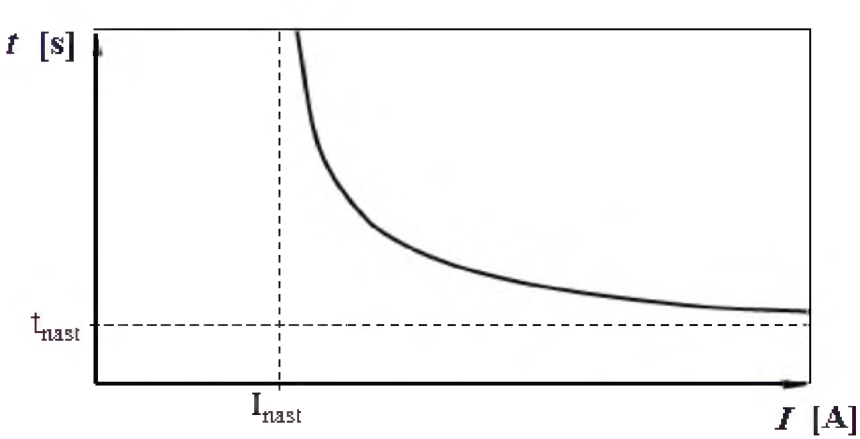

Fig. 1. Example of a time – current characteristic

Device manufacturers make a choice of several characteristics according to IEEE C37.112 and/or IEC 60255-3. Often they are also implemented the concern own dependences, can also approach your own, custom one. Role of the user in the configuration of this type of protection is low - the parameters to set are the value: t_{nast}, I_{nast} and a type of characteristic.

Operation time of this protection is calculated according to the formula:

$$t = t_{nast} \cdot \left(\frac{\beta}{\left(\frac{I}{I_{nast}} \right)^{\alpha} - 1} + L \right) \tag{1}$$

where: t_{nast} – time setting; I_{nast} – current threshold; I – the actual value of the current, α, β – constants dependent on the type of curve, L – became determined only when the characteristics belongs to the IEEE family.

The problem is to determine the current I, because in real cases, during failure, this value isn't constant. Device manufacturers cope with this issue very differently. Sometimes the problem goes unnoticed by them, and the protection works in time so that was calculated at the beginning of start-up. This is obviously a big abuse, at least because of the fact that increase in value of short-circuit current after protection start-up can cause damage to the network or, in extreme cases, the destruction of the whole MV station.

It has been made a number of tests that were intended to determine the way of the algorithm of IDMT overcurrent protection. For this purpose, a current signal was generated as shown in Figure 2.

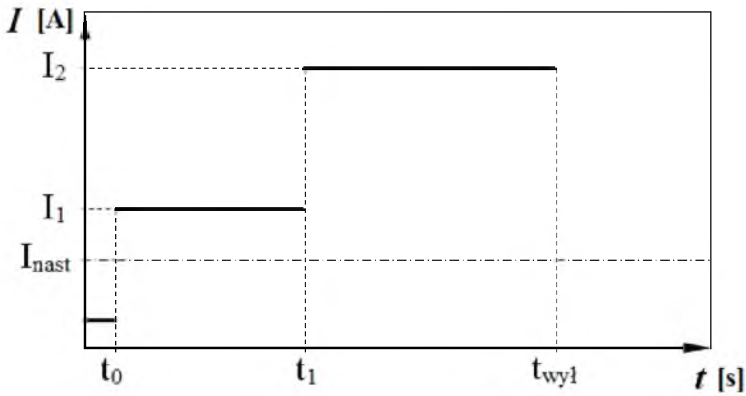

Fig. 2. Course of the current signal

Trip time of the properly configured protection were measured. This time the results were compared with analytical calculations.

There are three main methods of calculating the the selected value:

a) based on the arithmetic mean of I,
b) based on the arithmetic mean of I^2,
c) based on the geometric mean of I.

There were the devices of two leading manufacturer tested, equipped with adequate protection algorithm. Operation of the protection has been checked for three basic characteristics: IEC NI (Normal Inverse), IEC VI and IEC EI.

Sample results are presented in Table 2.1.

In Table 2.1.: I_1, I_2, t_1 – as shown in Figure 2, $t_{wyłśr}$ – the average operate time of the protection on the basis of a series of five measurements, $I_{wyłśr}$ – calculated on the base of protection characteristic, the average value of the current operate, I_{obl1} – computational current operate calculated as the arithmetic average of the current operate calculated from the arithmetic mean of the RMS current at the time, δI_1 – relative error I_{obl1} current versus $I_{wyłśr}$ current, I_{obl2} – computational current operate calculated as the arithmetic average of the current operate calculated from the arithmetic mean of the RMS squared current at the time, δI_2 – relative error I_{obl2} current versus $I_{wyłśr}$ current, I_{obl3} – computational current operate calculated as the geometric average of the current operate calculated from the geometric mean of the RMS current at the time, δI_3 – relative error I_{obl3} current versus $I_{wyłśr}$ current.

Table 2.1. Sample results of IDMT overcurrent protection tests

I_1	I_2	t_1	$t_{wyłśr}$	$I_{wyłśr}$	I_{obl1} based on average mean of I		I_{obl2} based on average mean of I^2		I_{obl3} based on geometric mean of I	
					I_{obl1}	δI_1	I_{obl2}	δI_2	I_{obl3}	δI_3
A	A	s	s	A	A	%	A	%	A	%
Device A, IEC EI										
3,5	7	0,5	2,057	6,313	6,149	2,59	6,330	0,27	5,901	6,53
3,5	7	1,5	2,817	5,419	5,136	5,22	5,424	0,11	4,836	10,76
2	7	1	2,616	5,607	5,088	9,25	5,638	0,57	4,327	22,83
2	7	5	6,376	3,660	3,079	15,88	3,702	1,17	2,621	28,39
Device B, IEC NI										
2	7	1	4,199	5,204	5,809	11,62	6,181	18,77	5,194	0,18
2	7	1,5	4,523	4,610	5,342	15,89	5,831	26,49	4,619	0,20
5	10	1	3,290	8,116	8,479	4,48	8,777	8,14	8,101	0,20
5	10	2	3,598	6,809	7,220	6,04	7,624	11,97	6,803	0,08
Device B, IEC EI										
2	7	0,5	2,163	6,209	5,845	5,85	6,213	0,06	5,215	16,01
2	7	2	3,573	4,847	4,201	13,33	4,879	0,67	3,464	28,53
2	7	3,5	4,983	4,136	3,487	15,68	4,170	0,82	2,899	29,91
5	10	1	1,586	7,228	6,850	5,23	7,261	0,46	6,456	10,68
Device B, IEC VI										
2	7	0,5	2,69	6,069	6,070	0,03	6,374	5,04	5,525	8,96
2	7	2	3,942	4,436	4,463	0,63	5,115	15,32	3,700	16,59
5	10	1	2,072	7,572	7,587	0,21	7,987	5,49	7,142	5,68
5	10	2	2,629	6,182	6,197	0,24	6,553	6,01	5,899	4,58

As can be seen, devices from different manufacturers treat in a different way the variable value of the short-circuit current at start-up, using all three of the aforementioned methods. The controversy may give rise to the application for the calculation of the geometric mean of currents. In general, this type of mean is used when no absolute but relative changes in the measured parameter are important. It is relatively difficult to transfer this information to the field of power protection. Such a method should not be used, although judging by the results of the tests (calculation according to the formula 2), provides a greater level of security for the protected device.

Calculation of current from the arithmetic mean of the square of current run by formula number 3. This approach is correctly for protection against overloads. According to Joule's law, the amount of heat generated Q is proportional to the square current I, resistance R and time t.

$$I_{obl3} = \sqrt[n]{\Pi_{i=1}^{n} I_i} = \exp\left(\frac{\ln\left(\Pi_{i=1}^{n} I_i\right)}{n}\right) = \exp\left(\frac{\Sigma_{i=1}^{n} \ln(I_i)}{n}\right) \tag{2}$$

$$I_{obl2} = \sqrt{\frac{\sum_{i=1}^{n} I_i^2}{n}} \tag{3}$$

In the above formulas: I_i - the current i-th sample, n - number of samples.

This kind of of calculating the currents can be recommended to use in new IED models. It is also worth noted that in the algorithms can often meet function of minimum response time. For large currents, in order to maintain selectivity of protection, may need to an artificial extension of the operation time. Example of a curve is shown in Figure 3.

Noteworthy feature is also called "delayed return of protection", useful especially during the occurrence of intermittent ground faults, that are difficult to detect. This function is based on maintaining the start-up provided by a set time t_r after start-up criterion failure (eg. reduced zero sequence current below the set value).

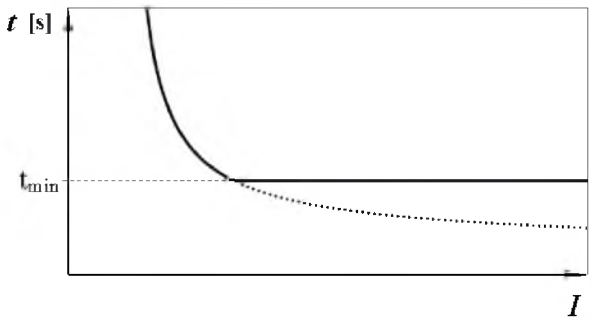

Fig. 3. Example of a time – current curve with minimal response time at t_{min}

If less than the value of criterion t_r value increased again above the set value, there will be protection tripped after a time equal to the set time, the delay will be counted from the time of the first failure. A maximum, in the case of an active function "freeze the clock", protection start-up may persist for a time expressed the relation 4.

$$t_{start-up} = t_{set} + t_r \tag{4}$$

Application of such a function, in addition to the obvious usefulness in the case of intermittent faults, it is advantageous, for example in the case of the selectivity of action of protections. This may occur when IDMT function of one terminal must be disabled in order to allow independent time-tripping of another terminal due to a selectivity of protection, especially when there are a number of relays made in different techniques, such as analog and digital.

3. Admittance protections

The detection and location of ground faults in networks with isolated neutral point and in compensated networks, characterized by low earth fault currents, are used following protection types that use:

– basic harmonics of current and voltage zero sequence and the direction of passive or active component of zero sequence current,
– the higher harmonics contained in the zero sequence current and voltage,
– external AC or DC signals [3].

In earth fault admittance protections measured or start-up value it can be the zero sequence line admittance module Y_0 or one of its components: G_0 or B_0 [1].

The aim of the laboratory measurements was to test a method for determining admittance module Y_0 by the protections implemented in IED algorithms of one of the leading manufacturers. All tests were performed with 50 Hz AC voltage. In zero sequence current was generated additional higher harmonics. This follows from the observation of waveforms in practice - deformed is mostly I_0 signal, while the zero-sequence voltage is purely sinusoidal.

Generated zero-sequence current, in the general case contains higher harmonics, and is described by the relationship:

$$i_N = a_{\%N} I_N \sin(2\pi f N \cdot t + \varphi_N) \tag{5}$$

where: $a_{\%N}I_N$ – the share of the N-th harmonic current waveform, N – harmonic number, φ_N – phase shift of the N-th harmonic of current to voltage, f – base frequency (50 Hz).

On the basis of the measurements can be confirmed that the protection operates on the basis of the calculation of zero-admittance, based on the first harmonic of zero sequence current. But have to consider the fact that the accuracy of such a procedure. Due to the nature of the ground fault in its current very often occur higher harmonics. Furthermore, the practice is known that often the amplitude of the higher frequency component is comparable to or greater than the fundamental harmonic. For this reason, taking into account the components of frequencies which are integer multiples of the fundamental frequency appear to be justified.

Such solutions have already been implemented in IED, however, these practices have been discontinued. It is recommended to return to them in the construction of new devices and to consider not only the fundamental component of the zero sequence admittance as the value or criterion at the start-up of protection.

4. Conclusion

The protection algorithms implemented in modern IED are constantly evolutions and improvements. This article focuses on two of them: IDMT overcurrent and admittance protection.

Adjudicated was how to determine the calculated current value in the case of changes of the input current at protection start-up. Is recommended to use the arithmetic mean of the squared current samples. Also worth use the protection minimum response time if the IED is provided with them.

For admittance protection it's recommended to take into account the higher harmonics in the calculation of the criterion. All of these features should be implemented in the new, modern IED's.

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