Polyhedron method for early short circuit detection

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Abstract—The algorithm for detecting the short circuit current in its early stage greatly helps low voltage protection devices to make improvements in current limitation. Based on the analysis the working principle of the early short circuit detection technology, the new method of polyhedron criterion has been proposed. The short circuit current is predicted based on the relationship among the instantaneous values of current, current 1st derivative and current's 2nd derivative with respect to time as a combined criterion. And the simulation and experiment results are presented and the results validate its good performance.

Key words: current limitation, early short circuit detection; low-voltage networks;

I. INTRODUCTION

Low voltage protection device, e.g., circuit breaker, are designed to handle with the problems of the short circuit. Electrical systems (e.g. conductor lines, cables, bus bar systems) and loads (e.g. machines) are stressed electro-dynamically and thermally by short-circuit currents. The amount of stress is affected primarily by the amplitude of the short-circuit current and the time from short-circuit occurrence until switch off. In some cases, the short circuit current with the range of 10 to 150 kA (at 440 V) can be expected in low-voltage networks. Thus, it is vitally important to isolate the fault as soon as possible to minimize downtime and damage. Naturally, the concept of early short circuit detection which detects the short circuit current in its early stage can greatly facilitate the protection action of the low voltage protection device to start the current limiting as soon as possible. Therefore faster and reliable detection algorithms are needed to realize fault detection.

II. WORKING PRINCIPLE

A. Stat-of-art of early short circuit detection

To realize the early short circuit detection, locus curves criteria [1], regression method [2], modeling method [3] wavelet method [4] have been proposed by a lot of researchers. As pointed out in the overview of early short-circuit detection algorithms [5], the method of locus curve fundamental on early short circuit current detection shows high performance considering reliability, detection time and complexity.

B. Locus circurve method

There are a lot of researches regarding the application of locus curve method on early short circuit current detection. Locus curve method is based on the analysis of the

instantaneous current value and its derivative value at the same time point. The basic working principle of locus curve method is based on an ohmic-inductive equivalent circuit as shown in Fig. 1, where V_m is maximum voltage of the power source, ω is the frequency of the power source in rad, ϕ is the switching-on angle, $\cos\theta$ is the power factor which is determined by the inductance L and resistance R in the model. The formula (1) (2) below can be got according to the model.

Fig.1 Equivalent circuit

$$V_m \cos(\omega t + \phi) = Ri + Li' \quad (1)$$

$$\tan \theta = \frac{R}{\omega L}, \cos \theta = \frac{R}{\sqrt{R^2 + (\omega L)^2}}, I_p = \frac{V_m}{\sqrt{R^2 + (\omega L)^2}} \quad (2)$$

where I_p is called as the prospective current value.

Thus, the formula can be written as formula (4) with the formula (3) where I_r is called as the current threshold value,

$$I = \frac{i}{I_r}; I' = \frac{di/dt}{\omega I_r}; I'' = \frac{d^2i/dt^2}{\omega^2 I_r} \quad (3)$$

$$(I + \tan \theta \cdot I') = \frac{\sqrt{2}}{\cos \theta} \cdot \frac{I_p}{I_r} \cdot \cos(\omega t + \phi) \quad (4)$$

With the consideration of all possible power factor, switching-on angle when $I_p = I_r$, a locus curve as shown in Fig.2 can be got. Thus, any point of (I, I') which is out of the envelope definitely means that I_p is bigger I_r . By this way, the relationship whether the I_p is bigger than I_r can be determined by the measured i and its derivative value of i' .

allowable tolerance. As shown in the table 1 and table 2, the result which is satisfying the evaluation criterion will be marked in the green background, and the result which is not satisfying the criterion will be marked in the red background.

A. Simulation with simulated short circuit current

The following generated 30 short circuit currents ($I_n=250A$, time duration is 10ms) in the table 1 have been applied as the input current for the corresponding Matlab program of the polyhedron criterion, where the switching on angle is from 0° to 180° and the I_p of $5I_n$, $10I_n$, $20I_n$, $40I_n$, and $50I_n$. The detection time means the time period between the time of short circuit and the time when the algorithm detects it. And the results via cubical criterion are also simulated as reference.

Table 1 Simulation results

Simulated SC current ($I_n=250A$)	Cubical criterion method ($I_r=10I_n=2500A$) Detection time (ms)						Polyhedron criterion method ($I_r=10I_n=2500A$) Forecast time (ms)					
	0	30	60	90	120	150	0	30	60	90	120	150
Switching-on angle($^\circ$)												
1.25kA ($5I_n$)	\	\	\	\	\	\	\	\	\	\	\	\
2.5kA ($10I_n$)	\	\	\	\	\	\	\	\	\	\	\	\
5kA ($20I_n$)	\	\	\	\	\	\	2.7	1.35	1.1	1.0	1.3	4.4
10kA ($40I_n$)	4.0	2.65	1.5	1.45	7.05	5.85	1.85	0.8	0.55	0.6	0.75	3.75
12.5kA ($50I_n$)	3.5	1.9	1.2	1.1	6.4	5.0	1.7	0.75	0.55	0.55	0.65	3.7

It can be found that the better performance can be achieved via polyhedron criterion method.

B. Experiment with practical short circuit current

With a built demonstrator, the algorithms are also tested with the 9 practical short circuit currents ($I_n=400A$). And the table 2 shows the results.

Table 2 Experiment results

Measurement SC current ($I_n=400A$)	Cubical criterion method ($I_r=10I_n=4000A$) Detection time (ms)		Polyhedron criterion method ($I_r=10I_n=4000A$) Detection time (ms)	
4,0kA ($10I_n$)	\		1.60	
6,1kA ($\sim 15I_n$)	\		2.32	
8,0kA ($20I_n$)	\		1.96	
10,0kA ($25I_n$)	\		1.67	
12,1kA ($\sim 30I_n$)	3.41		1.07	
13,4kA ($33.5I_n$)	3.12		1.08	
16,0kA ($40I_n$)	2.68		0.88	
18,6kA ($46.5I_n$)	2.36		0.80	
19,7kA ($49I_n$)	2.17		0.79	

It also can be found that the polyhedron criterion method shows better performance than the cubical criterion method.

IV. CONCLUSION

Early short circuit detection method helps the protection device to take right current limitation action as soon as possible when the short circuit occurs. In this paper, a polyhedron method with high reliability is proposed based on the theoretical analysis of the short circuit model. The simulation results with the simulated short circuit currents and the experiments with the practical short circuit currents validate its realization and good performance.

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