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A New Method of Early Short Circuit Detection

Feng Du[1], Weigang Chen[1], Yue Zhuo[1], Michael Anheuser[2]

[1]Siemens Ltd. China, Shanghai, China
[2]Siemens AG, Amberg, Germany
Email: feng.du@siemens.com

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Abstract

To reduce the pressure on contacts and circuit breaker and realize the zone selective interlocking (ZSI) function above the instantaneous protection threshold (e.g., >10In), the short circuit current needs to be early detected. The state-of–art of early short circuit detection (ESCD) method is reviewed. Based on the equivalent model of the short circuit, a new method based on the current and its integration is proposed. The prospective current value can be detected in the early stage of the short circuit. According to the evaluation result, the short circuit current can be early forecasted with the proposed method.

Keywords

Early Short Circuit Detection; Zone Selective Interlocking; Instantaneous Protection

1. Introduction

As known, 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, contacts) 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. What's more, realization of the zone selectivity interlocking (ZSI) function above the instantaneous protection threshold (e.g., >10In) is required. 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.

At short circuit (SC) current, the prospective current value or peak value will be bigger than normal case. The early detection of the peak value is proposed as the evaluation criterion for forecasting short circuit current in this paper. In the second section, the working principle is analysed. In the third section, the evaluation results are presented. Finally, the conclusion is summarized in the final part.

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2. Working Principle

2.1. Stat-of-Art of Early Short Circuit Detection

To realize the early short circuit detection, the state-of-art can be classified into three types. The first kind of ESCD is called as locus curves criteria. The locus curve of (i, i’) is proposed in [1]. However, the initial current should be zero which is not always same as the practical condition. The improved locus methods of (i, i’) are also motioned in [2] [3]. However, there is no concrete definition of the locus curve. The method of the extrapolated Locus-Curves based on (i,i’) is proposed in [4], which has the clear definition of locus curve. However, it has the high dependence on the practical power factor. And the Cubical criterion based on (i, i’, i’’) is proposed to improve the time performance in [5] [6]. However, the relatively high hardware complexity is necessary. The second kind of method is the regression method, which aims to calculate the prospective peak current value before it reaches. The Estimation of the current peak based on the sequence of (i,i’) is mentioned in [7]. And the eestimation of the current peak based on the sequence of i is proposed in [8], which is only suitable for the sinusoidal wave at given frequency. The other methods include the methods based on the Complex Impedances or Powers [9], or Short-Time Admittance Spectrum Analysis [10], or Neural Networks [11], or the Locus-Curves in Combination with Morphology-Wavelet-Filtering [12]. They have a strong dependence on the practical networks.

What’s more, all the above methods involving the operation of i’or i’’ are often sensitive to the high frequency noise and harmonic interference.

In this paper, the regression method based on the sequence of (i, ∫idt) is proposed to solve the mentioned drawbacks.

2.2. Regression Method Based on the (i, ∫idt)

The typical electric network can be equivalent to a circuit as in **Figure 1**, which comprises at least one voltage source connected to at least one resistive load R and one inductive load *L*, where V_m is maximum voltage of the power source, w is the frequency of the power source in rad, φ is the switching-on angle, cosθ is the power factor which is determined by the inductance L and resistance R in the model. The Formulas (1) and (2) below can be got according to the model.

$$V_m \cos(wt+\varphi) = Ri + Li' \tag{1}$$

$$\tan\theta = \frac{R}{wL}, \tag{2}$$

$$\cos\theta = \frac{R}{\sqrt{R^2 + (wL)^2}} \tag{3}$$

$$I_{peak} = \frac{V_m}{\sqrt{R^2 + (wL)^2}} \tag{4}$$

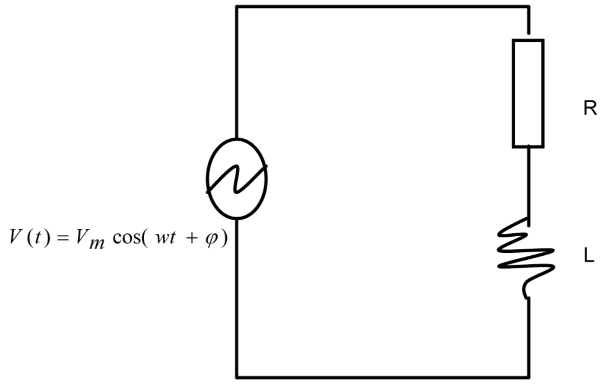

Figure 1. Equivalent circuit.

where I_{peak} is called as the short circuit current peak value. With the integration operation on the Formula (1), the Formula (5) can be got,

$$\int_0^t V_m \cos(wt+\theta)dt = R\cdot\int_0^t i(t)dt + L\cdot\left(i(t)-i(0)\right) \quad (5)$$

And Formula (2)-(5) can be converted to the Formula (6) by dividing the whole impedance, $\exists I(t)=\int i(t)dt$

$$I(t)-I(0) = -tg\varphi / w\cdot(i(t)-i(0)) + \frac{I_{peak}}{w}\frac{\sin(wt)\cos\theta}{\cos\varphi} + \frac{I_{peak}}{w}\frac{(\cos(wt)-1)\sin\theta}{\cos\varphi} \quad (6)$$

Further, the Formula (7) can be got by defining the Formulas (8)-(11).

$$R(t) = -tg\varphi\cdot A(t) + \frac{I_{peak}\cdot\cos\theta}{\cos\varphi}\cdot B(t) + \frac{I_{peak}\cdot\sin\theta}{\cos\varphi}\cdot C(t) \quad (7)$$

$$R(t) = I(t)-I(0) \quad (8)$$

$$A(t) = \frac{i(t)-i(0)}{w} \quad (9)$$

$$B(t) = \frac{\sin(wt)}{w} \quad (10)$$

$$C(t) = \frac{\cos(wt)-1}{w} \quad (11)$$

With the definition of the (12), (13), (14), the Formula (7) can be rewritten as Formula (15).

$$\gamma = tg\varphi \quad (12)$$

$$P = \frac{I_{peak}\cdot\cos\theta}{\cos\varphi} \quad (13)$$

$$Q = \frac{I_{peak}\cdot\sin\theta}{\cos\varphi} \quad (14)$$

$$R(t) = -\gamma\cdot A(t) + P\cdot B(t) + Q\cdot C(t) \quad (15)$$

Or in the matrix formation,

$$\left[R(t)\right] = [\gamma, P, Q]\cdot[A(t), B(t), C(t)]' \quad (16)$$

It can be found that the (12)-(14) can be solved as parameter estimation method in mathematics. For example, with three points of (i, ∫idt),

$$\left[R(1), R(2), R(3)\right] = [\gamma, P, Q]\cdot\begin{bmatrix} A(1), A(2), A(3) \\ B(1), B(2), B(3) \\ C(1), C(2), C(3) \end{bmatrix}$$

To get a more reliable parameter estimation, the regression method is suggested.

And the Formula (17) can be calculated to solve the peak value of the short circuit current.

$$I_{peak} = \sqrt{\frac{P^2+Q^2}{1+\gamma^2}} \quad (17)$$

Further, the power factor can also be calculated according to Formula (12) when (15) or (16) is solved.

2.3. Realization

According to the above analysis, the proposed algorithm is realized in the following steps, which can be shown in the **Figure 2**.

a measuring the values of the instantaneous current flowing in the load and calculating the integral of said current;
b performing N successive samplings of the values of the instantaneous current;
c estimating the short circuit current peak value in the sampling period according to the sampled current values and the integral values; and,
d generating a short-circuit detection signal when the values of a peak current exceed an assigned threshold level.

3. Evaluation

In order to validate the proposed method, both the simulated short circuit current and the practical tested short circuit current are taken as the input of the algorithm.

3.1. Evaluation Based on Simulated Short Circuit Current

As shown in the **Figure 3**, there are 13 simulated short circuit current (prospective current is 52 kA) with different switching-on angles from 0˚ to 180˚ with a step of 15˚.

The ESCD only makes sense if it can forecast the short circuit current in the initial stage. Thus, the closer to 52 kA in the initial stage, the better performance of the prediction algorithm is. The average of first four calculation values is taken as the forecast result. With different regression points N = 5, N = 12, N = 16, the detection time is 80 µs, 150 µs, 190 µs respectively as shown in **Figure 4**.

The statistical results according to Forecast Error (FE, is defined in Formula (18)) is shown in **Table 1**.

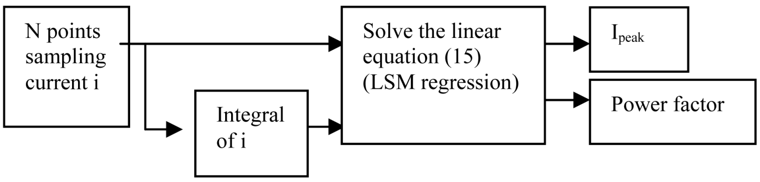

Figure 2. Realization structure.

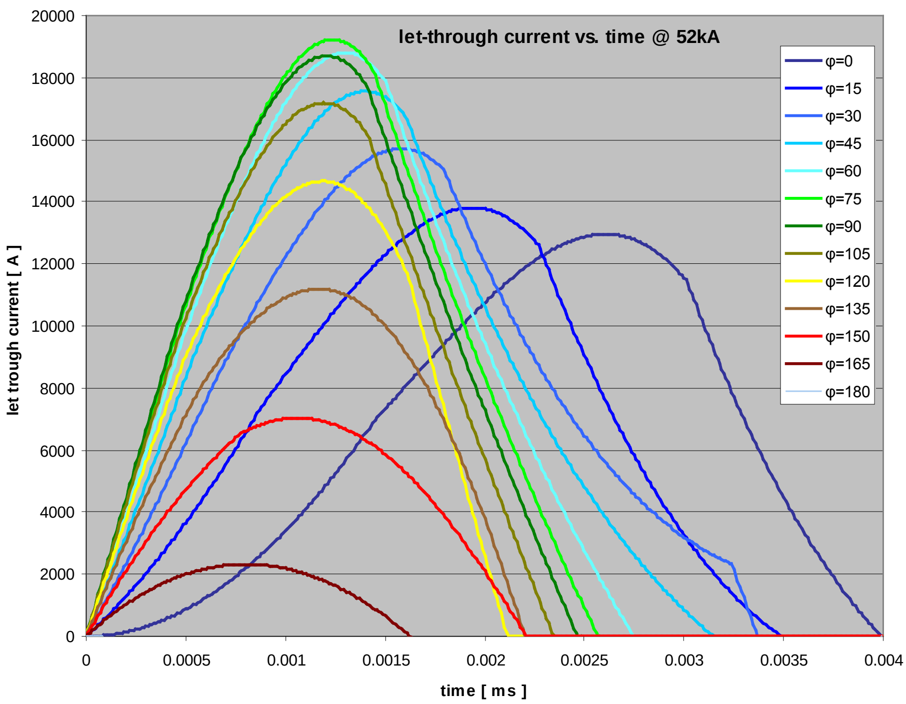

Figure 3. 13 Simulated short circuit current.

$$\text{FE(Forecast error)} = \frac{\left| I_{forecast\_prospective} - 52kA \right|}{52kA} \cdot 100\% \quad (18)$$

3.2. Evaluation Based on Practical Short Circuit Current

There are 11 practical short circuit current data with the prospective values of 153 KA (3 currents with a sampling frequenc of 50 kHz), 105 KA(1 current with a sampling frequenc of 50 kHz), 52 KA (3 currents with a sampling frequenc of 50 kHz), 24.9 KA (3 currents with a sampling frequenc of 50 kHz) and 52 KA (1 currents with a sampling frequenc of 200 kHz) which have been the input of the proposed algorithm.

The **Figure 5** of the one current with 153 KA and **Figure 6** of the 52 KA show the ealuation results as examples. The green line is the forecasted prospective value and the blue line is the orignal current. Per to the results, all the fault currents can be early detected within 200 us.

It can be found that the faulted prosepective value can be forecasted in the early stage of the short circuit, which is very helpful to realize the ZSI function, especially for high short circuit.

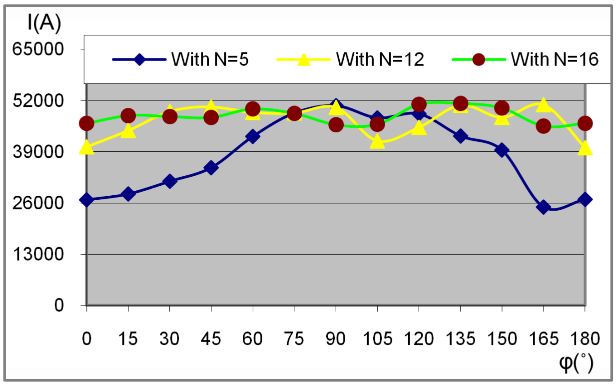

Figure 4. Results of the detected prospective current values.

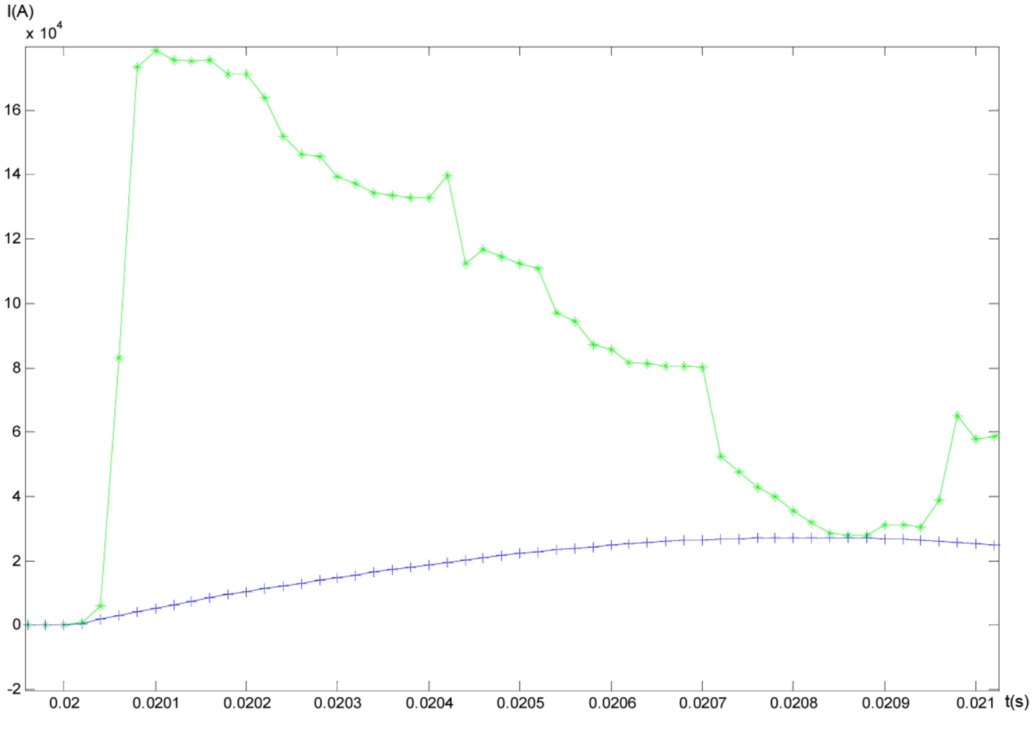

Figure 5. Results of 153 KA with fs = 50 kHz.

Table 1. Statistical forecast error with different regression points.

Points	FE ≤ 15%	15% < FE ≤ 26%	FE > 26%
N = 16	13	0	0
N = 12	10	3	0
N = 5	4	3	6

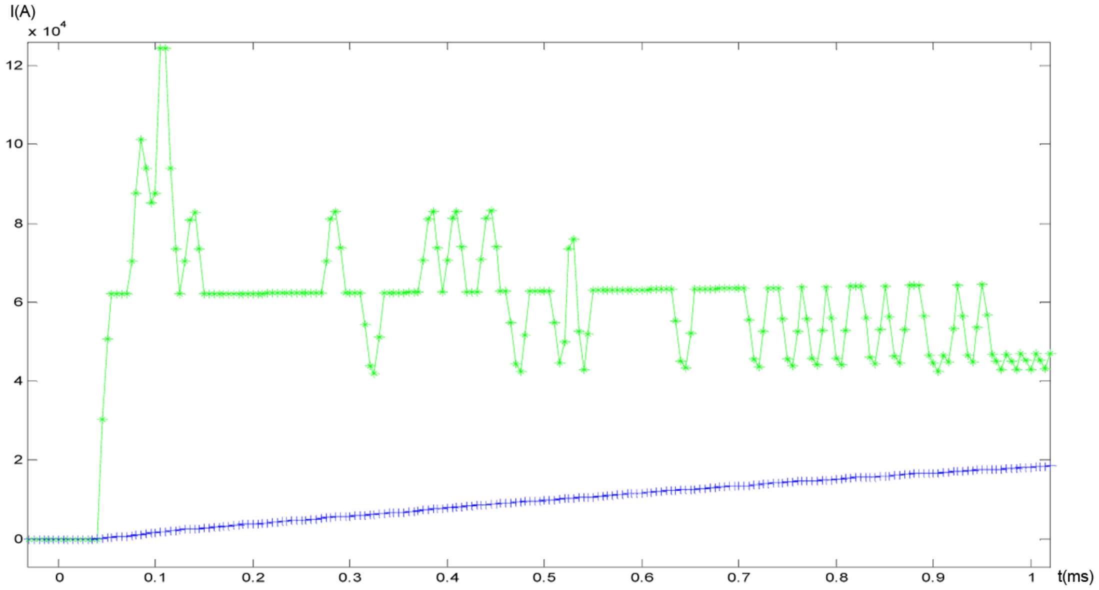

Figure 6. Results of 52 KA with fs = 200 kHz.

4. Conclusion

In this paper, an early short circuit detection method based on regression method is proposed. And some evaluation results based on simulated short circuit current and practical short circuit current are provided. The time performance of the early detection is suitable for the ZSI function in power distribution system.

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