Study Intelligent Circuit Breaker with synchronous Closing Function Based on DSP

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Abstract

An intelligent circuit breaker with synchronous closing function based on DSP is presented in this paper. By which, the filtering algorithm based on Fourier algorithm is adopted in order to estimate the optimal reclosing angle so as to weaken the instantaneous current during reclosing circuit. Based on the discussion of the digital signal processing technology, the hardware circuit has been set up and the software has been programmed · And the simulation results show a good agreement with the predictions.

Keywords: digital signal processing (DSP), synchronous, circuit breaker (CB), Fourier algorithm, reclosing

1. Introduction

During making and breaking the short circuit current，the instantaneous current value is related to the initial phase angle. Because the moment of short circuit Can't be made certain。its breaking current can be impossibility to be limited. However，CB may be turn on under still Short circuit for reclosing. AS long as knowing the actual circuit parameter it is possible to minimum the instantaneous current by means Of synchronous closing.

In this paper an intelligent CB with synchronous closing function is presented. By which，the fault line can be quickly cut off，and the digital filtering algorithmis adopted in order to abstract the short Circuit current components and compute the optimal reclosing phase angle so as to weaken the instantaneous current. As the results，based on the data processing method the hardware has been set up and software has been programmed.

2. Principle Of Synchronizing Closing

2.1 Determination Criterion of Short Circuit Fault

Taking simple three—phase circuit as an example shown in Fig. 1，when the system operates in normal, the current can be expressed as

$$i = I_m \sin(\omega t + \alpha - \varphi) \qquad (1)$$

When power system takes place short circuit fault in certain site，the short circuit current can be educed as

$$i_d = i_p + i_{ap} = I_{pm} \sin(\omega t + \alpha - \varphi) + C \exp(-\frac{t}{T_a}) \qquad (2)$$

The current change rate before and after the short circuit can be educed as，respectively

$$\frac{di}{dt} = I_m \omega \cos(\omega t + \alpha - \varphi) \qquad (3)$$

$$\frac{di_d}{dt} = I_{pm} \omega \cos(\omega t + \alpha - \varphi) - \frac{C}{T_a} \exp(-\frac{t}{T_a}) \qquad (4)$$

where *N* is short circuit overload multiple . Let $I_{pm} = NI_m$ from(3) and(4)it can be seen that the current has greatly change after short circuit takes place, so in this paper the current change rate is acted as the determination criterion of short circuit fault taking place.

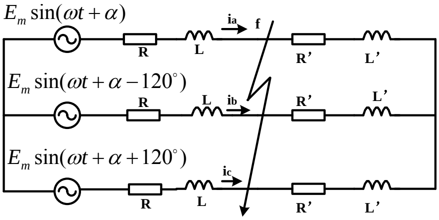

Fig 1. Three-phase R&L circuit under sinusoidal voltage excitation

2.2 The Optimal Reclosing Phase Angle

In order to simulate the closing course, taking a phase as an example shown in Fig.2

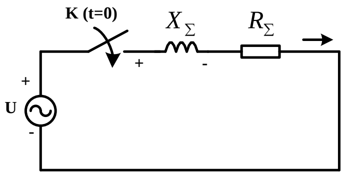

Fig 2. Single-phase R&L circuit under sinusoidal voltage excitation

When the circuit is closed, the circuit equation can be expressed as

$$R_\Sigma i + I_\Sigma \frac{di}{dt} = U_m \sin(\omega t + \varphi_u) \qquad (5)$$

Where φ_μ is the voltage initial phase angle.

Let $i = i' + i''$ and $i'' = Ae^{-t/\tau}$, $\tau = L_\Sigma / R_\Sigma i'$ is the particular solution of.

$$R_\Sigma i' + L_\Sigma \frac{di'}{dt} = U_m \sin(\omega t + \varphi_u) \qquad (6)$$

Let $i' = I_m \sin(\omega t + \theta)$,bring i' into (6), it can be educed as

$$R_\Sigma I_m \sin(\omega t + \theta) + \omega L_\Sigma I_m \cos(\omega t + \theta) = U_m \sin(\omega t + \varphi_u) \qquad (7)$$

Let $tg\varphi = \frac{\omega L_\Sigma}{R_\Sigma}$,

$|Z| = \sqrt{R_\Sigma^{\ 2} + (\omega L_\Sigma)^2}$,

it can be educed as

$$I_m[R_\Sigma \sin(\omega t + \theta) + \omega L_\Sigma \cos(\omega t + \theta)]$$
$$= I_m|Z|\left[\sin(\omega t + \theta)\frac{R_\Sigma}{|Z|} + \cos(\omega t + \theta)\frac{\omega L_\Sigma}{|Z|}\right]$$
$$= I_m|Z|[\sin(\omega t + \theta)\cos\varphi + \cos(\omega t + \theta)\sin\varphi] = I_m|Z|\sin(\omega t + \theta + \varphi) \qquad (8)$$

And then

$$I_m|Z|\sin(\omega t + \theta + \varphi) = U_m \sin(\omega t + \varphi_u) \qquad (9)$$

The underdetermined coefficients are can be obtained by (10) and i' can be calculated through (11)

$$I_m|Z| = U_m ; \theta + \varphi = \varphi_u \qquad (10)$$

$$i' = \frac{U_m}{|Z|} \sin(\omega t + \varphi_u - \varphi) \qquad (11)$$

The general solution of (5) is

$$i = \frac{U_m}{|Z|} \sin(\omega t + \varphi_u - \varphi) + Ae^{-t/\tau} \qquad (12)$$

Substituting initial condition $i(0_+) = i(0_-) = 0$ into (12), it can be educed as

$$i = I_m\left[\sin(\omega t + \varphi_u - \varphi) - \sin(\varphi_u - \varphi)e^{-t/\tau}\right]$$ (13)

where I_m is the short circuit current periodic component maximum value, $I_m = \frac{U_m}{|Z|}$; φ_μ is the voltage phase angle at the moment of short circuit taking place; φ_μ is the power factory angle, $\tan\varphi = \frac{\omega L_\Sigma}{R_\Sigma}$; is the electric source angular frequency; t is the time constant,

$$\tau = L_\Sigma / R_\Sigma.$$

From(13) it can be seen that i is composed of the periodic component and the decay component. If the circuit is closed under $\varphi_\mu = \varphi - \frac{\pi}{2}$, the current i will get the peak value and it will bring about maximum mechanical effect. . If the circuit is closed under $\varphi_\mu = \varphi$, the current i is only periodic component and the impact current is the least.

3. Block Diagram Of Hardware Principle

In order to automatically recluse the circuit at the optimum angle after CB cuts off fault, it is essential to measure breaking current and calculate the power factor angle according to the instantaneous short current. Fig.3 shows the configuration block diagram of the hardware.

The voltage and current are respectively sampled by means of the voltage transformer and Rogowski coil, which is suitable for measuring heavy current [1]. In this way, the isolation problem between measuring circuit and processing circuit is solved. The current is converted into the voltage being proportional to the measured current by the integrator. The output voltage of the integrator is an alternating one with IV amplitude value. In this paper the input of this device is strictly limited ± 1V alternating voltage.

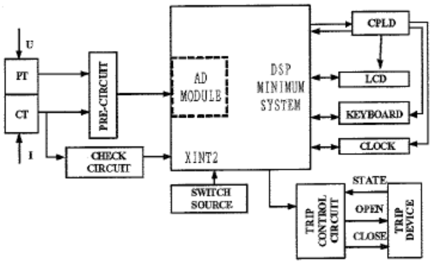

Fig.3. Intelligent circuit breaker measure and control system configuration block diagram

After A/D is enabled, A/D begins corresponding channel data transferring according to setting, and DSP reads and computes the corresponding sampling data. Taking short circuit current as an example, which contains decaying DC component, fundamental component, components of other frequencies, and noise. Thus it is needed to filter the harmonic component from the breaking current so as to calculate short circuit current fundamental component and power factor angle.

In order to make CB automatically reclose at the optimal phase angle, it is necessary to precisely calculate voltage and current phase angle at the moment of short circuit taking place. There are two kinds of filtering methods, including analog filtering and digital filtering. Because digital filtering has better feature of high precision and flexibility and is without temperature influence comparing with analog filtering, this paper adopts digital filtering to extract the fundamental current [2].

4. Digital Filtering Algorithm

The Fast Fourier Transformations (FFT) has better filtering function and fast data processing time, and can be used to filter harmonics [3，4], however it will bring error when the input signal contains decaying DC component. For analyzing FFT algorithm error, it is assumed that the current contains a decaying DC component and no more than the *h-th* harmonics, then the current can be approximated by

$$i(t) = Ae^{-at} + \sum_{i=1}^{h} I_m(i)\sin(i\omega t + \varphi_i) \qquad (14)$$

where Ae^{-at} is the decaying DC component; I_m is the peak component of the *i-th* harmonic current; f_i is the fundamental frequency; φ_i is the phase angle of the *i-th* harmonic component's.

$$I_{\mathrm{Re}}(n) = \frac{2}{T}\int_0^T i(t)\cos n\omega t dt = I_m(n)\sin\varphi_n + \frac{2}{T}\int_0^T Ae^{-at}\cos n\omega t dt \qquad (15)$$

where $I_{\mathrm{Re}}(n)$ and $I_{Im}(n)$ are respectively the real part and the imaginary part of the amplitude value of the *n-th* harmonics component.

5. Calculation Result

In order to validate the method's feasibility, take two groups actual 41kA breaking current for examples to obtain fundamental component. At different breaking time experiment data and pick-up fundamental component are respectively shown as figure in fig.4.

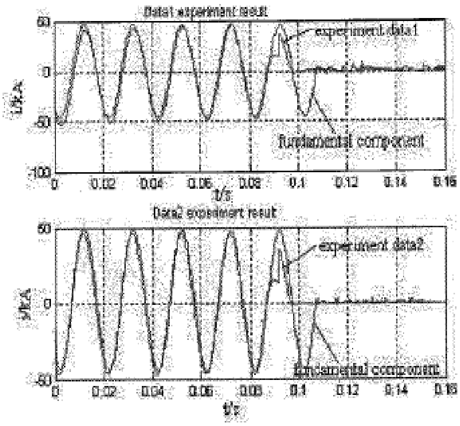

Fig.4. 41kA breaking current different breaking cases

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