An Innovative Method to Achieve Minimum Tripping Current Conformity for Type A RCCBs

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Abstract: This paper presents an innovative method to decrease the discreteness of minimum tripping current for type A residual current operated circuit breakers (RCCBs). Different but continuous time intervals’ detection method is proposed to identify the residual current’s type and judge whether its root mean square (RMS) value has exceeded the rated value in one cycle. That is, after the timer is started, 0-3ms $\pm 135^\circ$ leakage current is detected, 3-7ms $\pm 90^\circ$ is detected, 7-12ms $\pm 0^\circ$ is detected, 3-7ms and 12-16ms type AC is detected. What’s more, the method is fabricated in a mixed-signal 0.5\textmu m CMOS process, and test results show that the type A RCCB’s tripping current variation is decreased to 2.8mA, which greatly improves the chip’s reliability and anti-interference ability.

Keywords: type A RCCBs, the discreteness of the minimum tripping current, reliability

Classification: Integrated circuits

References

1 Introduction

With the extensive application of frequency converters, switching apparatus and energy efficient equipment in our daily living and production, non-sinusoidal leakage current is polluting our grid and causing problems in the electric network. Nowadays, type A RCCBs are most commonly used in the power supply mains to protect personal and property safety from the non-sinusoidal residual current. According to China’s national standard GB16917.1-2003, type A residual currents contain AC and seven pulsating DC types, whose delay angles are ±0°, ±90°, ±135° and 0° stacking 6mA smooth DC respectively, as shown in Fig. 1. Table I shows the tripping current range for residual AC and pulsating direct currents, whose upper limit is 1.4I_Δn for rated residual current I_Δn > 10mA or 2I_Δn for I_Δn < 10mA [1]. It’s important to note that the tripping current value is root mean square (RMS) value.

![Wave shape of type A pulsating DC and type AC leakage current](image)

**Table I.** Tripping current range of type A RCCB (I_Δn is the rated residual current)

<table>
<thead>
<tr>
<th>Delay angle α</th>
<th>The range of tripping current</th>
</tr>
</thead>
<tbody>
<tr>
<td>+0°</td>
<td>0.35I_Δn or 1.4I_Δn or 2I_Δn</td>
</tr>
<tr>
<td>±90°</td>
<td>0.25I_Δn or 1.4I_Δn or 2I_Δn</td>
</tr>
<tr>
<td>±135°</td>
<td>0.11I_Δn or 1.4I_Δn or 2I_Δn</td>
</tr>
<tr>
<td>0° stacking 6mA smooth DC</td>
<td>1.4I_Δn+6mA or 2I_Δn+6mA</td>
</tr>
<tr>
<td>AC residual current</td>
<td>0.5I_Δn or I_Δn</td>
</tr>
</tbody>
</table>

![Table I](image)

The wide range of tripping current reduces type A RCCBs’ reliability, for they can trip at any current value in the range, thus nuisance tripping is more likely to take place. Most of the manufacturers of RCCBs would like to reduce the discreteness of the tripping current, and hope to produce type A RCCBs with conform leakage current value.

Some researches have used micro control unit (MCU) to realize the main route leakage protection [2][3]. Full-wave Fourier algorithm is selected to...
finish the residual current signal’s sampling, analyzing characteristics and making some change according to MCU’s sample processing synchronization error. Although excellent performances in intelligence, multi-functions and reliability have been achieved, complex Fourier analysis and the whole system’s high cost hinder its widespread usage.

What’s more, in [4][5], the developed construction of residual current devices (RCDs) contains simple discrete components such as electromechanical relay with a permanent magnet. If the residual current transformed by the current transformer reaches a predetermined level, its magnetic flux is high enough to reduce the magnetic flux of the permanent magnet to the level in which the spring is able to pull out the moving armature of the electromechanical relay to open the main circuit. Although small tripping current variation has achieved, the absence of filtering circuits and other auxiliary circuits such as overvoltage protection decreases the chip’s reliability in face of non-sinusoidal currents.

A type A RCCB with simple peripheral circuits is implemented in [6]. Because of the wave distortion brought about by the current transformer’s secondary coil, which will be introduced in section 4, it is not proper to detect the pulsating DC leakage currents only in positive or negative half cycle. The final test results shows that the tripping thresholds only satisfy the national standards. Thus the detection method is unsuitable for type A RCCBs. Therefor, it is of vital importance to develop an innovative and optimized detection method for type A RCCBs’ chip with better peripheral filtering and protective circuitry.

According to IEC publication 60479-1 [7], when a current higher than 30mA passes through a part of a human body, there is serious danger for people if the current is not interrupted in a very short time. Thus an RCD suitable for protection against direct contact has to have its trip threshold set at 30mA for AC current.

In this paper, an innovative method is proposed for type A RCCBs to achieve rated operating residual current $I_{\Delta n}=30mA$. The method can recognize the residual current’s type accurately in different but continuous time intervals. After the timer is started, 0-3ms ±135° leakage current is detected, 3-7ms ±90° is detected, 7-12ms ±0° is detected, 3-7ms and 12-16ms type AC is detected. With signal processing circuits integrated into a single ASIC chip, which is realized in a mixed-signal 0.5μm CMOS process in CSMC, the type A RCCB’s tripping current variation is decreased to 2.8mA. What’s more, the type A RCCB has a complete filtering and protective circuitry, which greatly improves the chip’s reliability and anti-interference ability. In addition, the type A RCCB’s peripheral circuits gets simplified and conform to the RCCBs’ dimensions and specifications, which greatly contributes to the chip’s commercialization.

After an introduction of type A RCCBs in section 1, system architecture of type A RCCBs’ application circuit is recommended in section 2. In section 3, realization of the type A RCCB is shown. Then in section 4, the proposed innovative method is discussed in detail. Section 5 presents test
results to verify the innovative algorithm’s effectiveness. Finally, conclusions are summarized in section 6.

2 System architecture of type A RCCBs’ application circuit

Fig. 2 illustrates the recommended system architecture of application circuit for the type A RCCBs, whose main parts consist of a residual current detection section, a voltage regulation section, a controller IC type A RCCB, an overvoltage protection section and a execution section containing silicon controlled rectifier (SCR) and inductor L. The voltage regulation section provides a stable 5V power supply from 50Hz AC power mains. The residual current detection part can sense the unbalanced current between phase line and neutral line. When residual current is detected, the type A RCCB sends out pulses to trigger the SCR to conduct. As a result, the on-state SCR, inductor L and the rectifier bridge form a low resistance circuit loop, and the current flowing through inductor L increases sharply. Thus the inductor exerts enough magnetic force to trip and cut off the faulty circuit. In addition, the piezoresistor VDR is employed for absorbing the surge current caused by lightning strikes, etc.

![Fig. 2. The application circuit of type A RCCBs](image)

3 Realization of the type A RCCB

Main structure of the type A RCCB is shown in Fig. 3. It is a typical mixed-signal designed IC, including both analog and digital parts. The analog part is the auxiliary circuit and primarily responsible for signal amplification and comparison, and it mainly includes reference voltage generation circuit, chopper amplifier circuit (common mode voltage is 2.4V), hysteresis comparators, power-on reset circuit and temperature-compensated ring oscillator. In view of the different voltage amplitude that different kinds of residual current of the same RMS value induce through the secondary coil of a current transformer, every type A residual current corresponds to a hysteresis comparator and a tripping current comparison level generated by the
reference voltage generator. The digital part is the core processing circuit and mainly for realizing the innovative algorithm for type A leakage current identification. The digital section chiefly incorporates disturbance filtering circuit, type A leakage current detection module which realizes the innovative method, output buffer circuit and overvoltage protection circuit.

![Fig. 3. Main structure of the IC](image)

### 4 The proposed innovative method

For type A RCCBs, the most important and difficult issue is to identify the residual current’s type and to judge whether its RMS value has reached the minimum tripping current precisely and promptly. This section will introduce the proposed innovative method to achieve minimum tripping current conformity in detail.

Because the electric-power grids carry 50Hz alternating current, the residual current’s frequency also is 50Hz. Fig. 4-Fig. 7 illustrate the type A residual currents’ process procedure in one cycle 20ms. (I) represents the initial residual leakage current. The current transformer senses the residual current and generates leakage signal in its secondary coil. (II) is the amplified leakage signal by the chopper amplifier, which is used for the following signal processing. (III) is the trigger timer impulse generated by (II) as it is compared with the trigger timer voltage level 2.5V(for the positive delay angles) or 2.3V(for the negative delay angles). (IV) is the leakage current impulse generated by (II) as it is compared with the corresponding tripping comparison voltage. When (IV) turns up, it indicates that the residual current is equal or larger than the minimum tripping value. The timer triggered by (III) is to calculate the time point when (IV) turns up, and the leakage current’s type is judged by the time interval the time point falls in. If (IV) comes out, the type A RCCB outputs (V) to trigger SCR to cut off the faulty circuit.

Through an in-depth study of the response voltage (II), the authors find out that the leakage current impulse (IV) comes out within different time interval from the time when the timer is activated by (III). If there were
leakage current, the ±135° type impulse, shown in Fig. 4, would appear within 3ms from the timer is activated, the ±90° type impulse, shown in Fig. 5, between 3ms and 7ms, and the ±0° type, shown in Fig. 6, between 7ms and 12ms. As for the AC type, in order to avoid its interference in other types’ judgments, the authors use the wave crest and trough detection method, that is, after the timer is started, if the leakage impulses turned up not only between 3ms and 7ms but also between 13ms and 16ms, as shown in Fig. 7 (a), the AC type leakage would be detected. With regard to the 0° stacking 6mA smooth DC type, tests indicate that its response is similar to that of 0° type, so the detection approach is same to 0°, as shown in Fig. 7 (b). After 16ms, all the digital parts get reset to prepare for the next cycle’s detection.

Table II summarizes the identification time intervals for all residual current types. It’s notable that the time intervals are different but continuous. Hence, even though the residual currents are not the standard residual waves, this type A RCCB can still protect personal safety from electric shock effectively. Another key point is that the residual current’s type can be easily distinguished according to the duty cycle of chip’s output pulse, which really helps the designers to evaluate the chip’s functions. For ±135° residual current, the trigger SCR pulse turns up at about 2.5ms after the timer is triggered in one cycle, so the duty is approximately (16-2.5)/20=13.5/20. For ±90° residual current, the trigger SCR pulse turns up at about 5ms after the timer is triggered in one cycle, so the duty is approximately (16-5)/20=11/20. For ±0° residual current, the trigger SCR pulse turns up at about 10ms after the timer is triggered in one cycle, so the duty is approximately (16-10)/20=6/20. For AC residual current, the trigger SCR pulse turns up at about 15ms after the timer is triggered in one cycle, so the duty is approximately (16-15)/20=1/20.

<table>
<thead>
<tr>
<th>Type A leakage current type</th>
<th>±135°</th>
<th>±90°</th>
<th>±0°</th>
<th>ac</th>
<th>0° stacking 6mA smooth DC</th>
</tr>
</thead>
<tbody>
<tr>
<td>identification time interval</td>
<td>0-3ms</td>
<td>3-7ms</td>
<td>7-12ms</td>
<td>3-7ms and 12-16ms</td>
<td>7-12ms</td>
</tr>
</tbody>
</table>

5 Test result

This type A RCCB is fabricated in a mixed-signal 0.5µm CMOS process in CSMC. The chip micrograph is shown in Fig. 8, and the chip size is 1.037×0.686mm². The total input current is 480µA from a 5V supply. Of all the 15 pins, only 6 are indispensable, and the others are all testing pins.

A dedicated type A RCCB test equipment IDB–3, which can provide type AC and type A pulsating DC residual currents, is employed to test the type A RCCB’s performance. The test circuit is shown in section 2 Fig. 2. The rated current the power supply can provide to load is 6A. The type
Fig. 4. ±135° residual currents’ process (a)+135° (b)−135°, (I) residual current (II) amplified leakage current (III) trigger timer pulse (IV) leakage current pulse (V) trigger SCR pulse.

A RCCB detects unbalanced current (residual current) between phase line and neutral line of the power supply mains. If residual current’s RMS value exceeds 30mA, the type A RCCB would activate the SCR, whose gate trigger
current is no more than 200μA, to cut off the faulty circuit. Fig. 9–Fig. 12 present the type A leakage current signals and their corresponding tripping outputs, in which the upper wave is leakage current signal amplified by the
chopper amplifier and the lower wave is type A RCCB’s output signal to cut off the dangerous circuitry when an electric shock occurs. The output signal’s duty cycle reflects the each residual current’s characteristics, and we can easily identify the residual current’s type.

![The type A RCCB’s micrograph](image)

**Fig. 8.** The type A RCCB’s micrograph

![Residual currents’ test results](image)

**Fig. 9.** ±135° residual currents’ test results (a)+135° (b)−135°

Table III shows the test result of Type A RCCBs’ minimum tripping current value, which ranges from 28.9mA to 31.7mA and has 2.8mA variation in all type A residual currents. Table IV gives out the comparison of this type A RCCB to recent publications, which signifies the excellent performance of this chip.

6 Conclusion

This paper presents an innovative method to achieve the minimum tripping current conformity for type A RCCBs. The type A RCCB can identify the residual current’s type and judge whether its root mean square (RMS) value has exceeded the rated value in different but continuous time intervals in one cycle. After the timer is started, ±135° leakage current is detected during 0-3ms, ±90° during 3-7ms, ±0° during 7-12ms, and type AC during 3-7ms
Fig. 10. ±90° residual currents’ test results (a)+90° (b)−90°

Fig. 11. ±0° residual currents’ test results (a)+0° (b)−0°

Fig. 12. AC and 0°+6mA residual currents’ test results (a)ac (b)0°+6mA

and 12-16ms. Test result of reducing the minimum tripping current variation to as low as 2.8mA verifies the effectiveness of this method, which enhances type A RCCBs’ anti-interference ability and ensures the continuity service of electric equipment. The type A RCCB, fabricated in a 0.5μm CMOS process, occupies 0.711mm² chip area and consumes only 480μA current from 5V voltage supply. In conclusion, the low cost, excellent performance
Table III. Test result of A-type RCCB’s minimum tripping current

<table>
<thead>
<tr>
<th>NO.</th>
<th>AC</th>
<th>+0°</th>
<th>-0°</th>
<th>+90°</th>
<th>-90°</th>
<th>+135°</th>
<th>-135°</th>
<th>0°+6mA</th>
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<tbody>
<tr>
<td>1</td>
<td>30.4</td>
<td>30.6</td>
<td>28.9</td>
<td>31.2</td>
<td>29.7</td>
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<td>31.5</td>
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Table IV. Performance comparison

<table>
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<tr>
<th>Ref. implementation</th>
<th>[6]/2012</th>
<th>[2]/2010</th>
<th>[5]/2008</th>
<th>This Work*</th>
</tr>
</thead>
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<tr>
<td>minimum tripping current variation</td>
<td>ASIC</td>
<td>MCU</td>
<td>discrete devices</td>
<td>ASIC</td>
</tr>
<tr>
<td>21.5mA</td>
<td>4.4mA</td>
<td>4mA</td>
<td>2.8mA</td>
<td></td>
</tr>
</tbody>
</table>

and high reliability make the type A RCCB more competitive in the market application.