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Research Article

Advanced Fast Large Current Electronic Breaker Using Integration of Surge Current Suppression and Current Divider Sensing Methods

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Electronic breakers or fuses are most widely used tools to protect the electric-driven facilities from overload or short circuit. However, they may suffer from two major drawbacks: (1) it normally takes more than 0.1 s to react, resulting in facilities not sufficiently protected, and (2) a higher rating size of breakers or fuses is demanded than expected due to lack of a surge current suppression mechanism. To overcome these problems, this paper proposes a fast large current electronic breaker based on the integration of current divider sensing and surge suppressing methods. The load surge current can be effectively suppressed by series negative temperature coefficient (NTC) thermistors. The load current is then divided into a small portion and converted to a voltage signal for amplification and comparison with the predefined threshold value, i.e., the maximum load tolerance current. AC power will be disconnected immediately by the switching circuit once the load current exceeds the tolerance value. The disconnection of power supply will continue for a period of time set by the timer. The experimental results verify that the proposed electronic breaker can provide a large load current protection up to 20 A under effective surge suppression within 10 ms.

1. Introduction

The growth of world economics has driven an increasing demand for industrial equipments and home appliances. For this reason, the protection for such facilities has attracted more attention in recent years. Without proper protection devices, these facilities may be burned out immediately when the overload happens. The power system may be sequentially affected more seriously beyond expectation. For example, a short-circuit fault current can abruptly rise more than 20 times the maximum nominal value, probably resulting in the most destructive event in the power distribution systems [1–3]. If the protection devices can work properly, in a better situation, it may just cause loss of service, transient undervoltage or overvoltages, and loss of synchronization. In the worst situation with no sufficient protection, an extreme surge of power may penetrate the equipments and sequentially cause serious explosion or fire.

The fuse is well known as a simple and cheap device used to interrupt fault currents instantly [4, 5]. However, it has two major disadvantages: (1) it is a single-use device so that it is unrecoverable and (2) its reaction time may take more than 50 ms that is insufficiently fast to protect some facilities. Nowadays, the electronic breaker (EB) is the most widely used device for overload protection in industry [6–9]. Therefore, IEEE Standard announced IEEE Recommended Practice for Applying Low-Voltage Circuit Breakers Used in Industrial and Commercial Power Systems since 2007 [7]. Further, IEEE Std C37.119-2005 was revised to IEEE Std C37.119-2016: IEEE Guide for Breaker Failure Protection of Power Circuit Breakers in 2016 [6]. The EB can return to work after being reset, but it has some disadvantages like limited lifetime and long reaction time [10, 11]. A fault current limiter (FCL) may provide an alternative option. Several advantages to the electrical power protection have been achieved [12, 13]. If the event of a fault current occurs, the impedance of the FCL can rapidly increase and thus limit the fault current rising. It is therefore used to prevent transformer damage and also mitigate voltage dips on the medium-voltage bus. However, FCLs need more complex circuit design using semiconductor, inductive devices, nonlinear elements, and superconductor technologies [14–17]. Recently, a fast electronic overcurrent protection circuit using current-adjustable sensing method was reported [18]. The power supply can be cut off taking less than 10 ms whenever the overload or short circuit is detected. Unfortunately, this method is only suitable for applications in small-size loads like 3 A due to direct use of current sensor.

2. Design of the Proposed Circuit

The proposed fast large current electronic breaker is shown in Figure 1. It mainly contains six parts: (A) soft-start, (B) current divider, (C) sensing circuit, (D) comparator, (E) timer, and (F) switching circuit, where the system block is shown in Figure 1(a). The operation procedure of the proposed control strategy shown in Figure 1(b) is described as follows: (1) suppress the surge current using soft-start circuit; (2) use full bridge rectifier to obtain DC current and divide the current using shunt microresistors; (3) sense the divided current using a Hall effect sensor and amplify the output voltage; (4) compare the output voltage with the reference value, i.e., the maximum tolerance load current (I_{max}); (5) the timer will generate a pulse signal to control the switching circuit; and (6) turn off the triac with the switching circuit if the current exceeds I_{max}. Note that the triac remains on when the current is working below I_{max} under a normal situation.

The function of delay time timer(m) is defined as [18]

$$\text{timer}(m) = \begin{cases} 1, & \text{others}, \\ 0, & \text{continue for } m \text{ seconds}, \end{cases} \tag{1}$$

where m denotes time that is set by the timer in advance.

The switching signal $y(x)$ is used to control the triac, being defined as

$$y(x) = \begin{cases} 1, & x < I_{max}, \\ 0 + \text{timer}(m), & x \geq I_{max}, \end{cases} \tag{2}$$

where x denotes the load current.

As shown above, $y(x) = 0$ will continue for m seconds when $x \geq I_{max}$, and it will return to 1 after m seconds.

2.1. Soft-Start. The soft-start circuit is shown in Figure 2. Initially, the power supply connected to the load goes through NTC (10 Ω), where the relay (24 V) is situated at N.O. status. Accordingly, the surge current can be effectively suppressed, and its maximum current will be limited by 10 Ω at the beginning. The relay will be switched to "on" status whenever the voltage of the capacitor (300 μF) is charged to 24 V via the 2 KΩ resistor.

2.2. Current Divider. Based on the current divider principle, the load current is divided using 2 shunt microresistors (1 mΩ) shown in Figure 3. The output is connected to the current sensor (Figure 4; for details, see next stage) so that the range of current measurement can be amplified 3 times from the original size of the current sensor, where the internal resistance of the current sensor is about 1 mΩ. In other words, the load current can be reduced to one-third of the original one to be sensed in this case.

2.3. Sensing Circuit. The current sensing circuit shown in Figure 4 is designed to detect the divided sensing current (I_{in}) using Hall effect-based linear current sensor (ACS712), where the input is connected to the output of Figure 3. The output voltage (V_{out}) from the sensor is proportional to the amount of input current (I_{in}), and it is amplified 13 times via the amplifier using HA17358. Note that the relation between the input current (I_{in}) and output voltage (V_{out}) is $I_{in} = (V_{out} - 2.5\text{V})/66\,\text{mV}$ according to the sensor specification.

2.4. Comparator. The comparator circuit shown in Figure 5 is used to detect if the load current exceeds the predefined value I_{max} that is converted to Vref (reference value). Once the input signal converted from the sensing current goes beyond the Vref of the comparator, the output signal will change to a high voltage from a low voltage (0 V) for triggering the timer at the next stage.

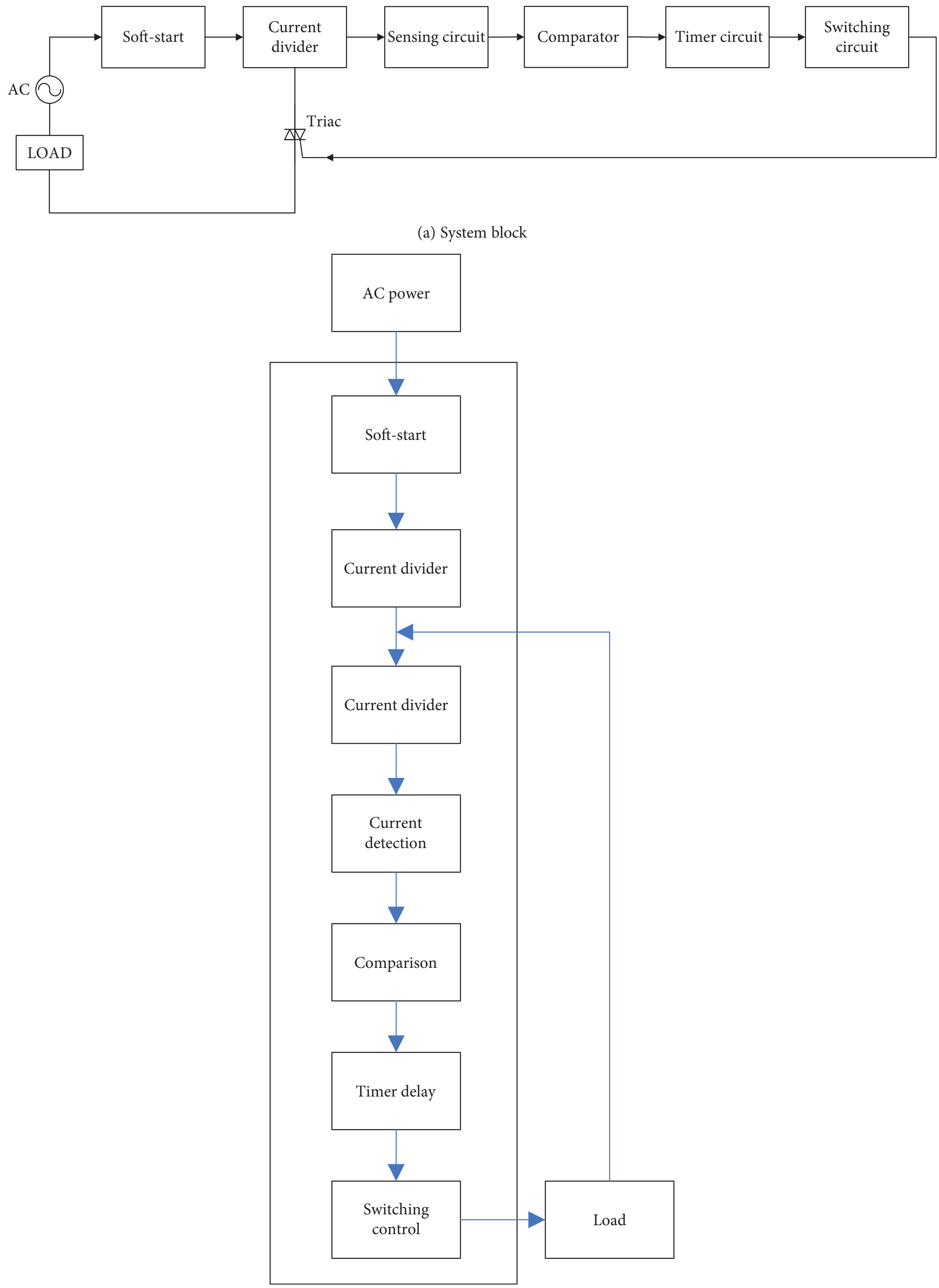
2.5. Timer. The timer circuit is shown in Figure 6, where the input signal is received from the output of the comparator, and the output signal is connected to the switching circuit. Once the load current exceeds the predefined value, a pulse signal will be generated by the timer (NE555) to interrupt the AC power supply. The pulse duration time, i.e., delay time, is set as $T = 1.1^{*}R^{*}C = 1.1^{*}5\,\text{M}^{*}1\,\mu\text{F} = 5.5\,\text{s}$.

2.6. Switching Circuit. The switching circuit is shown in Figure 7. In a normal situation, the load can keep working with the AC power, where the triac remains on. In an overcurrent case or short circuit, the triac will be turned off immediately by the switching signal (pulse signal) that is produced from the timer, and the AC supply is thus disconnected. Note that the triac (BAT41) is connected with optoisolator triac driver (MOC3020).

3. Experimental Results

3.1. Setup of Test Platform. The test platform shown in Figure 8 was set up to carry out the performance of the proposed model. The tested loads include light bulbs and motor controlled by SW1 and SW2, respectively. The push button switch (SW3) is used for short-circuit test. Fuse and current meter are also included in the platform for safety and current indication, respectively.

3.2. Linear Load. To verify the effectiveness of the proposed model, both linear load and nonlinear loads were tested and described as follows.



(a) System block

(b) Control flowchart

Figure 1: Structure of the proposed electronic breaker.

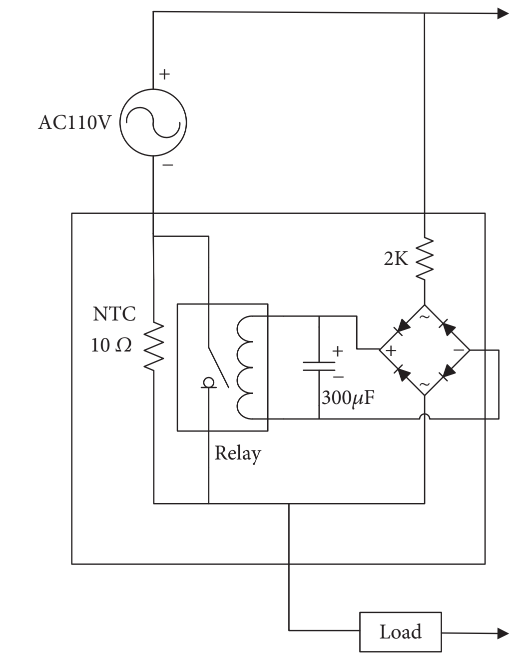


Figure 2: Soft-start circuit.

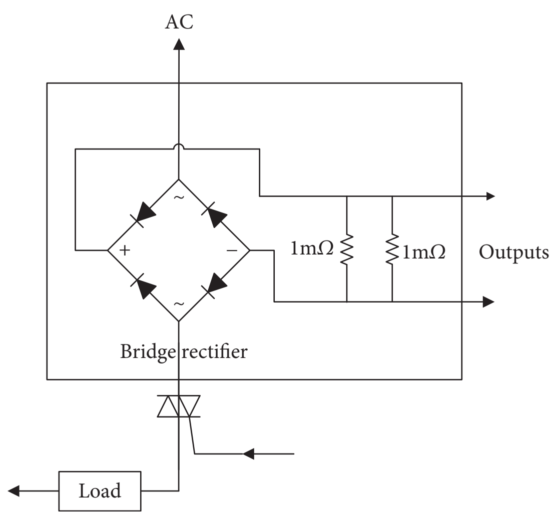


Figure 3: Current divider circuit.

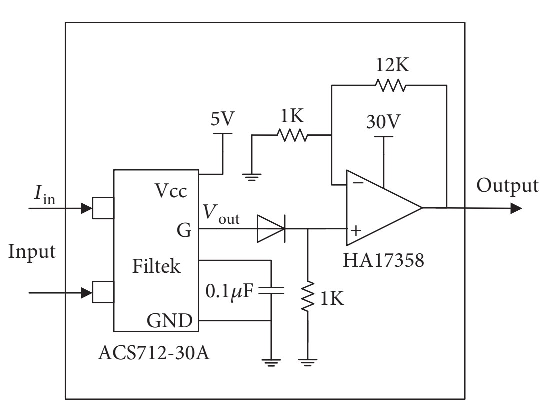


Figure 4: Sensing circuit.

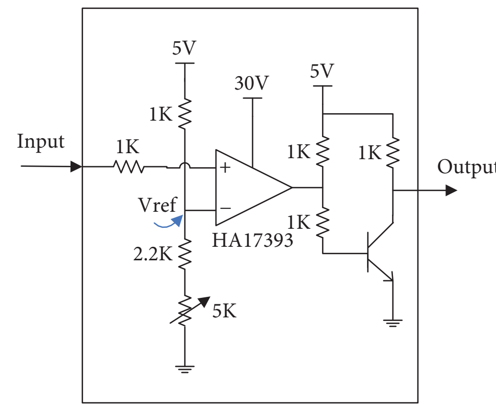


Figure 5: Comparator circuit.

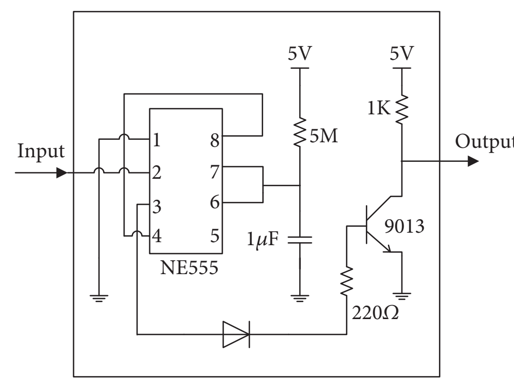


Figure 6: Timer circuit.

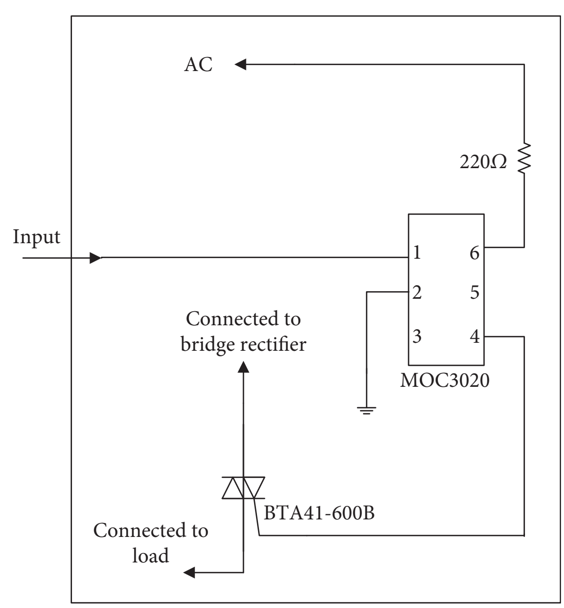
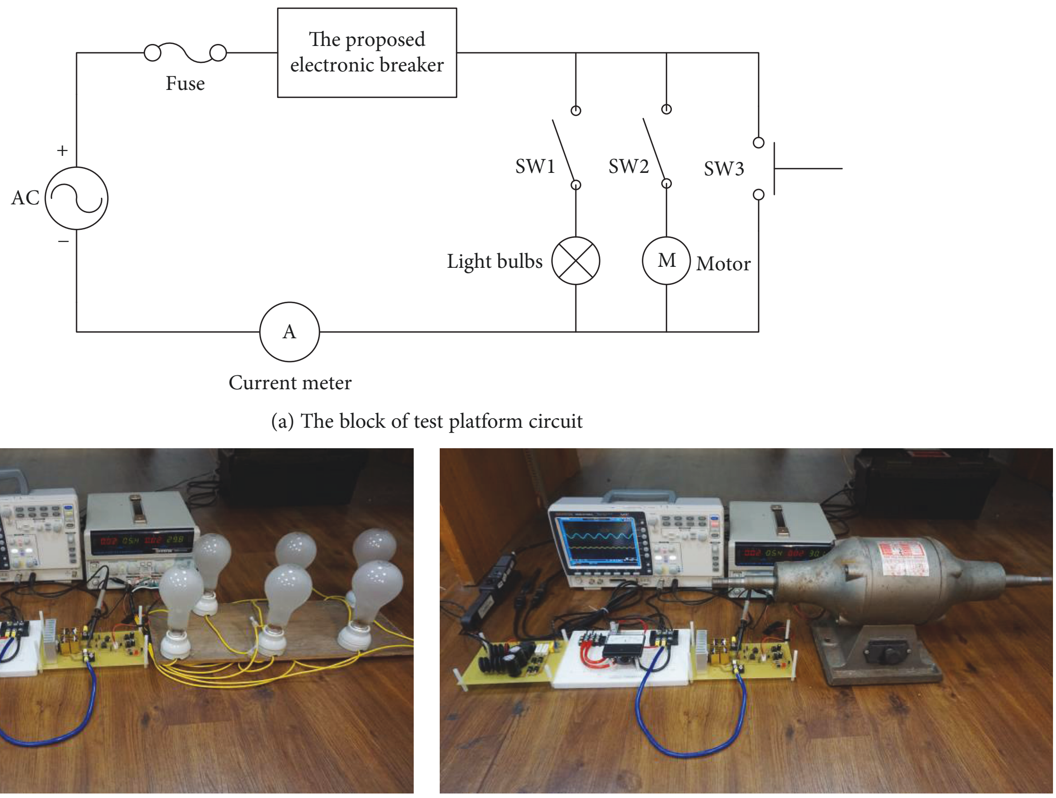


Figure 7: Switching circuit.

Case 1. 750 W load using three 250 W light bulbs.

The 750 W load with three 250 W light bulbs consuming 8.8 A (peak value) was used for a linear load test. The divided



(a) The block of test platform circuit

(b) Real test system using light bulbs

(c) Real test system using AC motor

Figure 8: Profile of test platform.

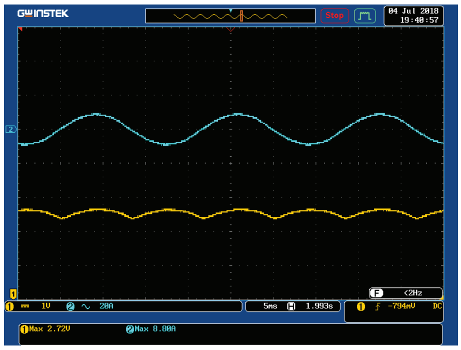
sensing current, load current without soft-start, load current with soft-start, and short-circuit current are shown in Figures 8(a)–8(d), respectively. In Figure 9(a), the load current (AC) is 8.8 A (blue line), and the divided sensed current (DC/yellow line) is only 3.6 A. In Figure 9(b), the load surge current without soft-start rises up to 36.0 A. On the other hand, the maximum surge load current with soft-start is effectively suppressed to 10.4 A, shown in Figure 9(c). Figure 9(d) indicates that the short-circuit current is cut off within less than 6 ms, where the maximum current is restricted within 36.0 A. Note that the soft-start period of time is about 1.1 s in this case.

Case 2. 1500 W load using six 250 W light bulbs.

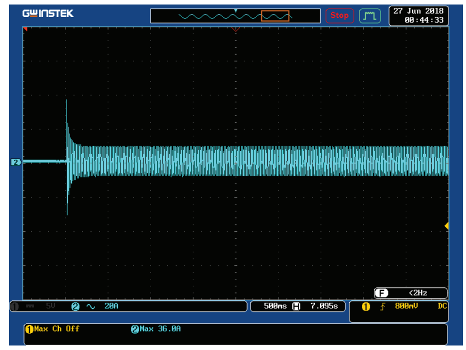
The 1500 W load using six 250 W light bulbs consuming 16 A (peak value) was used for a linear load test. The divided sensing current, load current without soft-start, load current with soft-start, and short-circuit current are shown in Figures 9(a)–9(d), respectively. In Figure 10(a), the load current (AC) is 16 A (blue line), and the sensed current (DC/yellow line) is only 7.2 A. In Figure 10(b), the load surge current without soft-start is 37.6 A. With soft-start, the maximum surge load current is effectively suppressed to 20 A, shown in Figure 10(c). In Figure 10(d), it reveals that the short-circuit current is cut off within 4 ms, and the maximum current is limited within 36 A. Note that the soft-start period of time is about 1.8 s in this case.

3.3. Nonlinear Load Using AC Motor. The 3/4 hp AC motor consuming 10 A (peak value) is used as a nonlinear load test. The divided current, load current without soft-start, load current with soft-start, and short-circuit current are shown in Figures 10(a)–10(d), respectively. In Figure 11(a), the load current (AC) is 8.8 A (blue line), and the sensed current (DC/yellow line) is only 3.6 A. In Figure 11(b), the load surge current without soft-start is 33.6 A. With soft-start, the maximum surge load current is effectively suppressed to 16 A, shown in Figure 11(c). In Figure 11(d), it indicates that the short-circuit current is cut off within 8 ms, and the maxima current is only 36.4 A. Note that the soft-start period of time is about 2.4 s in this case.

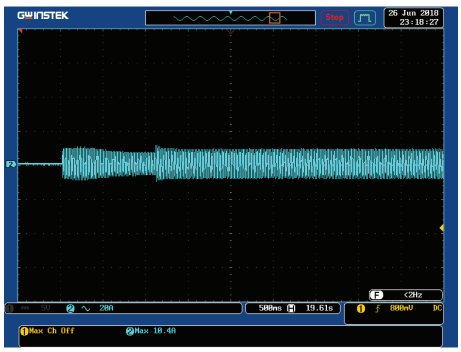
3.4. Comparison with Existing Devices. Table 1 concludes the comparison between the commercial products, previous method, and the proposed model from the view of size, construction, cost, and reaction time. It can be seen that the commercial products like fuse and traditional breaker are better in size (protection current range) but may suffer from slow action time. The fast electronic breaker can significantly reduce the reaction time less than 10 ms [18]. It, however, can only protect a small-size load such as 3 A. The proposed model is superior to the above products or previous method, not only in reaction time (<10 ms) but also in sufficiently protecting the electrical facilities from overload or short circuit for a large-size load up to 20 A.



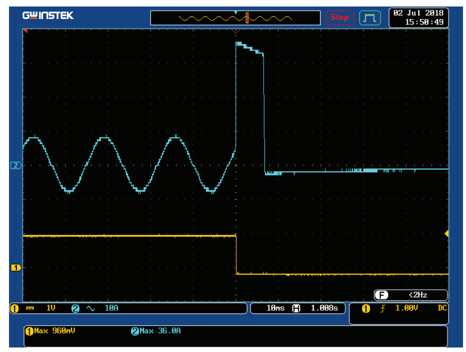
(a) Divided sensing current (blue line: load current, yellow line: sensed current)



(b) Load current without soft-start

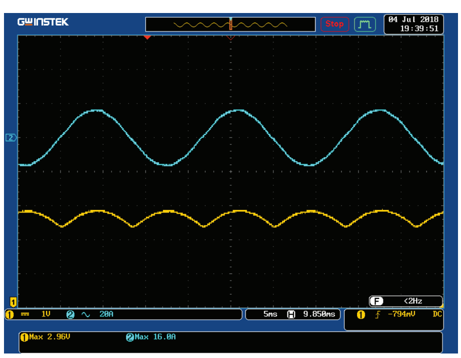


(c) Load current with soft-start

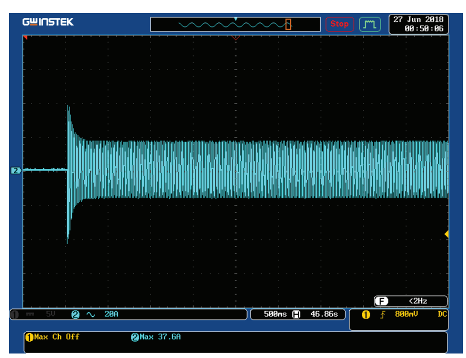


(d) Short-circuit current

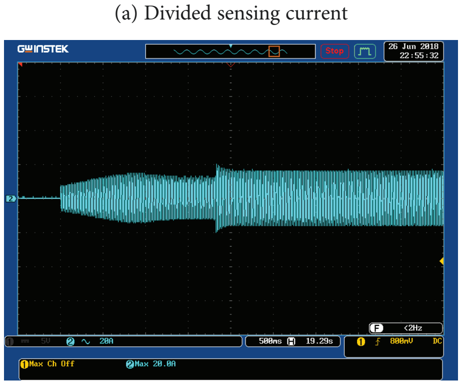
Figure 9: Waveforms of 750 W linear load.



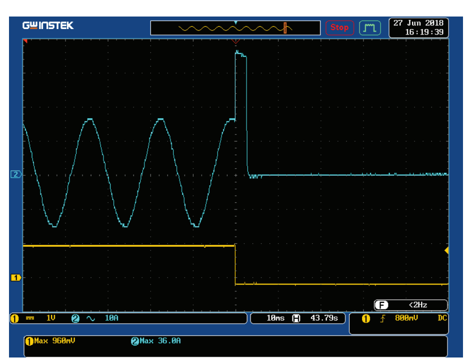
(a) Divided sensing current



(b) Load current without soft-start

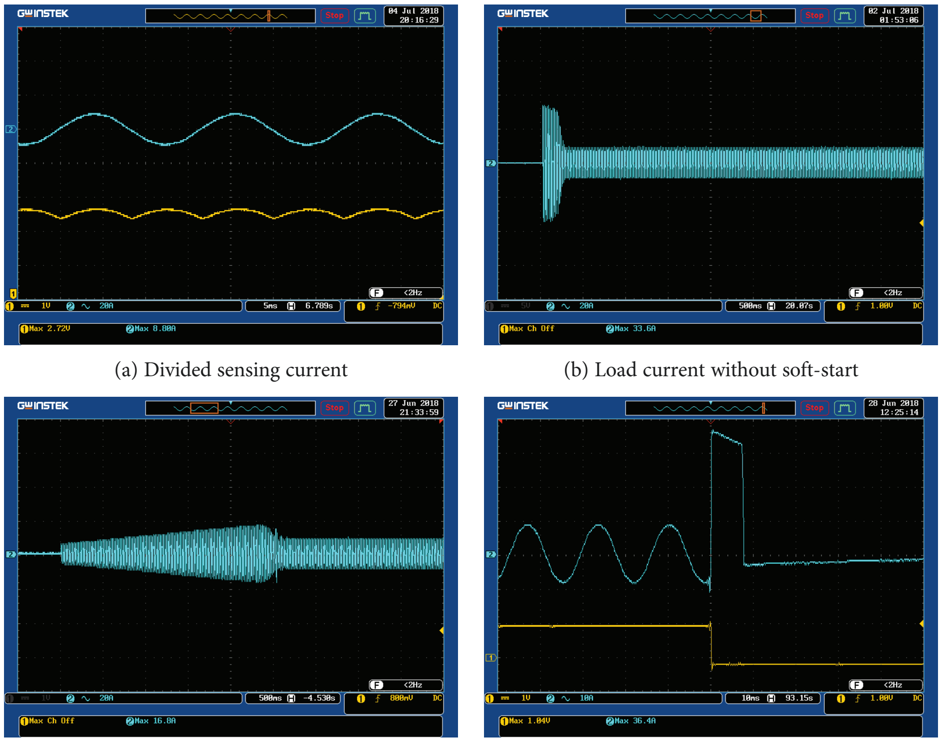


(c) Load current with soft-start



(d) Short-circuit current

Figure 10: Waveforms of 1500 W linear load.



(a) Divided sensing current

(b) Load current without soft-start

(c) Load current with soft-start

(d) Short-circuit current

Figure 11: Waveforms of motor load.

Table 1: Comparison between different devices.

Item	Fast fuse	Traditional breaker	The electronic breaker [18]	The proposed model
Size (current)	Large (>20 A)	Large (>20 A)	Small (<5 A)	Large (>20 A)
Construction	Simple	Complex	Medium	Medium
Cost	Very low	Medium	<Medium	Medium
Reaction time	≈50 ms	≈100 ms	<10 ms	<10 ms

4. Conclusions

The most widely used overload or short-circuit protection devices employ either fuses or breakers. However, their reaction time usually requires at least 50 ms even more. This paper has integrated surge current suppression and current divider sensing methods to realize a fast large current electronic breaker. From experimental results, it proves that the maximum surge current can be effectively suppressed below 20 A from 37.6 A. Also, the load current entering the current sensor can be reduced more than half of the original value based on the divider circuit. It means that the sensing current can be amplified to a high measurement range in practice. Besides, it is found that the soft-start period of motors (nonlinear) is longer than light bulbs (linear load). The response time for short circuit in every case takes less than 10 ms to sufficiently protect the load. Accordingly, the proposed model is confirmed far superior to traditional protection devices in terms of fast, accurate, and reliable performance. Therefore, this scheme is more efficient and feasible for high-current load protection in industrial applications.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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