

Time Coordination by Time Adaptive Function

Coordinación de Relevadores de Sobrecorriente con Funciones Adaptativas de Tiempo

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Abstract

This paper presents a new coordination process for time overcurrent relays. The purpose of the coordination is to find a time element function that allows it to operate using a constant back-up time delay for any fault current. Then, a simple methodology is proposed that improves the time coordination even with the presence of distributed generation. Experiments were carried out in a laboratory test situation using signals from a power electrical system physics simulator. A virtual prototype of the time overcurrent relay with adaptive algorithms was developed using real time acquired signals. The tests showed the enhanced performance of the overcurrent relay.

Key words: Time overcurrent relay, coordination, distributed generation.

Resumen

En este artículo se presenta un nuevo proceso de coordinación de relevadores de sobrecorriente de tiempo inverso. El objetivo del proceso de coordinación propuesto es determinar una función de tiempo que permita un intervalo constante de tiempo de respaldo para cualquier valor de corriente de falla. Se propone una metodología que mejora la coordinación aun con la presencia de generación distribuida. Se realizaron pruebas de laboratorio usando señales provenientes de un simulador físico de sistemas eléctricos de potencia. Se desarrollo un prototipo virtual de un relevador de sobrecorriente con los algoritmos adaptativos propuestos y se realizó la validación de los mismos usando señales en tiempo real. Las pruebas realizadas mostraron un mejor desempeño del relevador de sobrecorriente.

Palabras clave: Relevador de tiempo inverso, coordinación, generación distribuida.

1 Introduction

The application of time overcurrent relays in power systems has serious limitations in terms of sensitivity and high back-up times for minimum fault currents. The high load current and different time curves for overcurrent protection devices, such as fuses and reclosers, reduce the reliability and security of the relay. The overcurrent coordination is carried out using maximum fault currents (3–5% of all faults) during maximum demand conditions (lasting only for a total of a few minutes per day) because of the convergence of overcurrent relay time curves for high fault currents; for other fault types and other current demand situations, the time curves diverge for minimum fault currents, and the back-up times are much longer.

The appearance of cogeneration, distributed generation (GD), and unconventional sources may result in a change of the fault response [Girgis and Brahma, 2001; So and Li, 2002]. The configuration of overcurrent relays must be carried out with due consideration of these additional contributions to the fault current [IEEE Std. 242, 1990]. Given the nature of the sources, the initial contribution of the GD is high and reduced after a few cycles [IEEE Std C37.95, 2002]. The operation times of the overcurrent relays can be excessive for a topologically diverse network.

The applications of overcurrent relays in distribution networks have been reported [ANSI/IEEE Std 141, 1986; Chen, et al., 2003; Tunyagul, et al., 2000; Vishwakarma and Moravej, 2001; Lotfi-fard, et al., 2007; Zamora, et al., 2007]. There are few alternatives for enhancement of the performance of overcurrent relays without recourse to the use of other types of protection, like differential or distance relays, that involve great economic investment. Because the distribution lines are numerous in power systems the use of overcurrent relays will be hardly displaced by other more efficient protection technologies.

There are interesting proposals for the introduction of communication channels that allow changing the settings of relays in close to real time for low voltage networks [Shah, et al., 1988; Sachdev, et al., 1995]. However, in radial networks with one or two sources, such communication systems or other principles of protection imply a significant economic cost, amplified by the great number of radial networks in power systems.

The main goal of the coordination process is to find a time function that gives a constant back-up time delay for any fault current. The proposed relay has a time curve that is similar to the primary device. The coordination process is automatic between the proposed relay and the overcurrent primary device (fuse, relay or recloser). Finally, the proposed relay does not require communication channels since the process is handled with the information locally available, that is, at the relay location.

2 Time Coordination

The basic idea for time coordination is to satisfy equation (1) [ANSI/IEEE Std 141, 1986] for any current value.

$$T_{backup} = T_{primary} \left(I_k^{primary} \right) + CTI \quad (1)$$

where T_{backup} is the time curve of the back-up relay, $T_{primary} \left(I_k^{primary} \right)$ is the time curve of the primary overcurrent device, $I_k^{primary}$ is the operating current of the primary device for each sample k , and CTI is the coordinating time interval (0.2-0.4 s). The operating current of the primary relay is calculated using the pick-up current of the primary device and the fault current $I_k^{primary} = I_k^{system} / I_{pickup}^{primary}$.

The main purpose is to find a time element function T_{backup} that ensures that the back-up relay operates with a constant time delay relative to the primary device, for any fault current. For this to happen, it is necessary that the operation time of the backup can be determined from the time curve of the primary.

Figure 1 shows the overcurrent relay coordination system. The coordination was done using a computer simulation. *Relay A* is the back-up relay, and *Relay B* is the primary relay. By raising the load current (pick-up setting), the back-up time is increased, although both relays have the same time curve. To obtain the same back-up time delay (CTI) for all fault currents, two different mechanisms are possible: the first is to change the dial time for each fault current (curves 2, 3 and 4 in Fig. 1); and the second — a better solution — is to change curve 5. Curve 5 is not obtained using a dial time setting of the primary relay (curve 1) due to the load current. In order to change the overcurrent relay time curve, curve 5 needs to change its shape.

In Fig. 1, we observed that curve 5 is similar to curve 1. For this to occur, it is necessary to use the pick-up setting of the primary device to calculate the operating current. Then the proposed relay emulates the dynamics of the primary device to obtain a fast backup time operation. A minimum time curve for the backup device is obtained, because this is asymptotic to the primary pickup current. By comparing the conventional relay with the proposed relay, the first follows curve 4 whilst the second follows curve 5 of Fig. 1. A reduction of backup time is obtained with the proposed relay. On the basis of these results, we considered the pick-up current of the back-up relay to be only a fault detector.

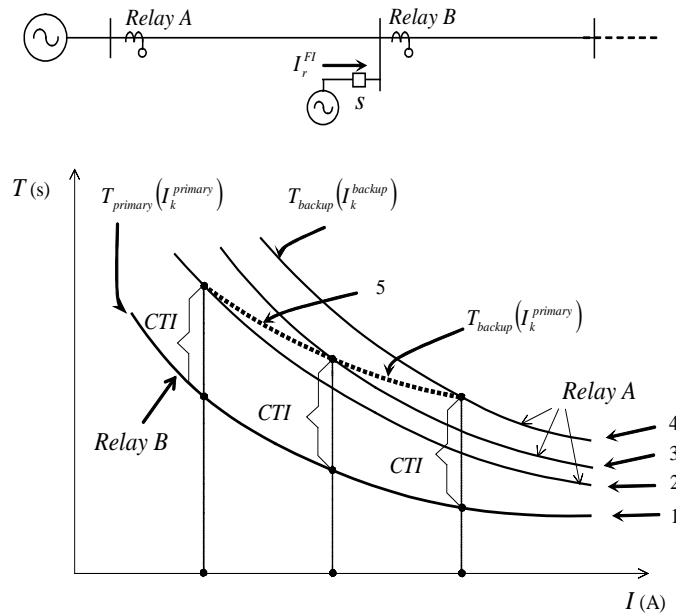


Fig. 1. Adaptive time curve of overcurrent relay

The equation describing the proposed relay is obtained. The operating current used is the one in the primary relay:

$$G_k = \Delta t \sum_{k=1} H(I_k^{primary}) \tag{2}$$

where: $H(I_k^{primary}) = \frac{1}{T_{primary}(I_k^{primary}) + CTI}$

The operating condition [IEEE Std C37.112, 1996] is obtained when:

$$G_k = \Delta t \sum_{k=1}^{k_{op}} H(I_k^{primary}) = 1 \tag{3}$$

The relay operation is complete when $k = k_{op}$ and equation (3) is satisfied.

The infeed current effect in the overcurrent coordination is shown in Fig. 1. Consider the situation when switch S closed. The infeed current I_r^{FI} accelerates the operation of the Relay B, though the backup time is the same (equal to the time of Relay A) and the CTI is bigger. With the coordination proposed the CTI is the same (Curve 5 equal to curve 1 in Fig. 1). Under these circumstances the proposed backup relay is faster than a conventional backup relay.

The off-line computed time curve proposed is calculated using equation (2). If the time curve of the primary overcurrent device is analytical (digital relays), the setting curve is computed to directly substitute for the function $T_{primary}(I_k^{primary})$. When the characteristic is not available (for example in fuses, electromechanical relays and reclosers), it is possible to calculate analytical expressions using fitting curve algorithms [Sachdev, et al., 1995].

3 Coordination

The coordination example was carried out in the typical 13.8 kV distribution systems shown in Fig. 2. It is not necessary to consider a more complex power system configuration, as the use of a complex power system does not reach an unexpected place. Most scenarios have the same effect on the operating current so the time overcurrent relay coordination process is carried out using pairs of relays. The coordination example is demonstrated in the radial lines with the assistance of the commercial software Aspen Oneliner. We observed that the back-up time of *Relay B* (section *a-b*) is greater than that of the *proposed Relay B*. Therefore, the coordination proposed allows a rapid time curve to be selected for *Relay A*. The coordination between the *proposed Relay B* and *Relay C* is carried out in the same relay. Using the time curve (see equation (2)), coordination is automatic; even when there is an increase in the maximum fault current (topology changes or additional power generation), coordination is carried out and setting changes are not necessary.

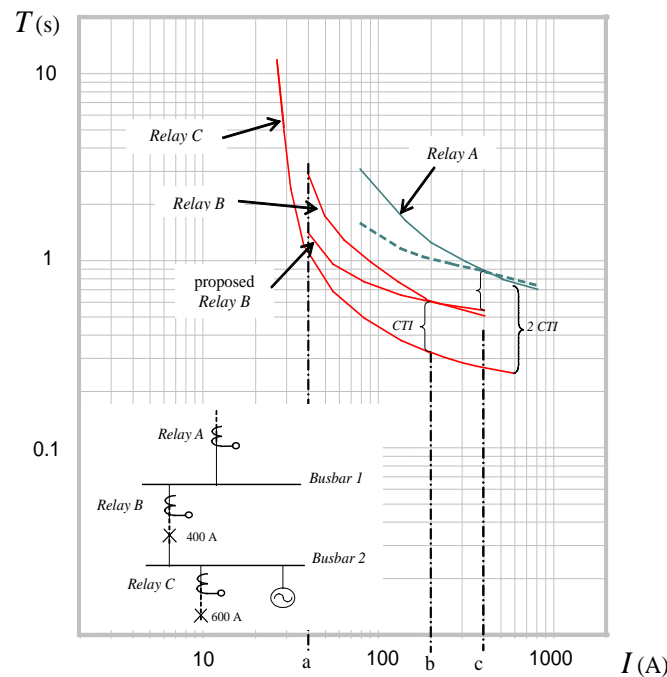


Fig. 2. Time coordination example of overcurrent relays

The coordination between the fuse, the proposed relay (*B*) and the conventional relay (*A*) is shown in Fig 3. The proposed relay curve is the same (plus *CTI*) as that of the maximum clearing time fuse curve. The coordination process between the conventional relay and the fuse can be achieved with *2CTI* as a coordination interval or directly with the proposed time curve.

In Fig. 4, the coordination of a recloser and relay is shown using a 13.8 kV radial systems. The proposed coordination is achieved with minimal back-up time.

In the coordination test shown, we have observed that the minimum back-up time is obtained. In addition, the coordination process occurs with the relay. Following this, coordination between the proposed relay and the overcurrent protection device (such as an electromechanical relay, fuse or recloser) is automatically obtained. The data necessary for coordination of the proposed relay is the data for the voltage system and impedance line. For data protection, the time curve and pick-up of the primary device are needed. With this information available, coordination is achieved.

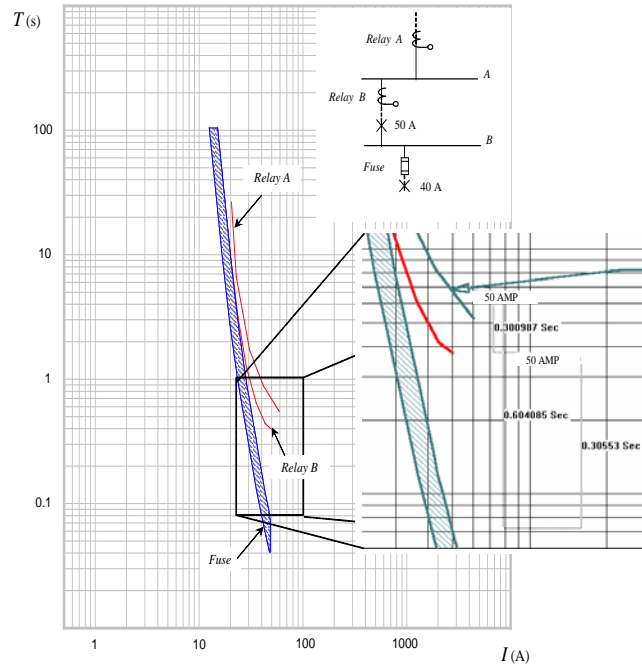


Fig. 3. Time coordination example of fuse and overcurrent relay

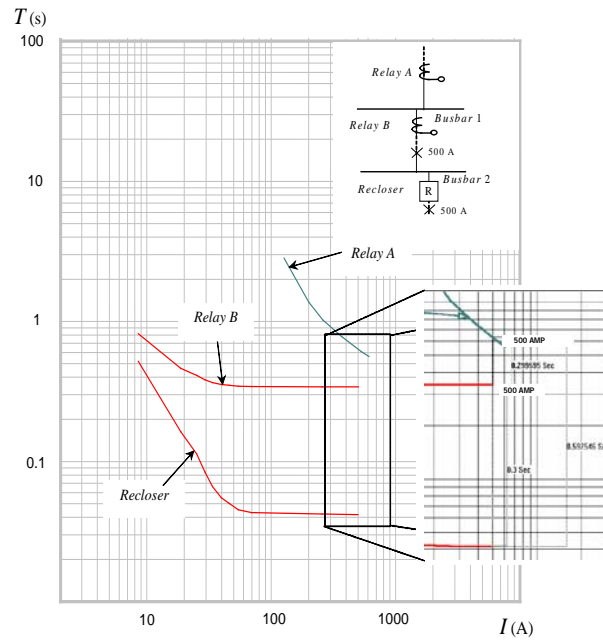


Fig. 4. Time coordination example for the recloser and overcurrent relay

4 Implementation

The structure of the system for testing the application of the proposed relay consists of a signal-conditioning module to concentrate and condition the input and output signals, a data acquisition card, and a personal computer where the relay operating programs reside. The test signal is obtained in three variations: a) through the output signal of current transformers (real signal acquisition module), b) by reading file data (signal file module), or c) through the manipulation of internal controls (internal generation module). A real-time acquisition card is used to acquire the signal. The aliasing effect is solved using an analog filter or oversampling the input signal. The computer graphic interfaces, communication ports, and input/output connections of the acquisition card are available to handle signaling and control functions.

The block diagram of the adaptive relay is shown in Fig. 5, exhibiting the main functions of each subroutine. The input signal acquisition subroutine includes a test module, with two alternatives: a) acquisition through the reading of an external file; this option allows data extraction from files in ASCII format generated in simulation programs (such as EMTP), or data files containing real fault registers; b) generation of internal signals; this option offers a great versatility for the simulation of different operating states, variation of parameters, digital processing and noise contamination in the signal.

The main function of the digital filtering subroutine is to compute the operating current $I_k^{primary}$. The protection subroutine computes the adaptive time operation (2), and includes the overcurrent relay logic algorithms (operation condition verification $G_k=1$). The output subroutine generates the output trip signal to the breaker, and displays graphical results of the algorithms.

The adaptive relay was developed with the assistance of the commercial software Labview. The adaptive relay front panel is shown in Fig. 6. The backup device time curve section computes the time curve of the backup device. There are three options available: a) IEEE Standard [IEEE Std C37.112, 1996], b) IEC Standard [IEC Standard 255-4, 1976] and c) Equation edition workspace with Six A-F controls and time reset control. The total operation time is also shown in this section.

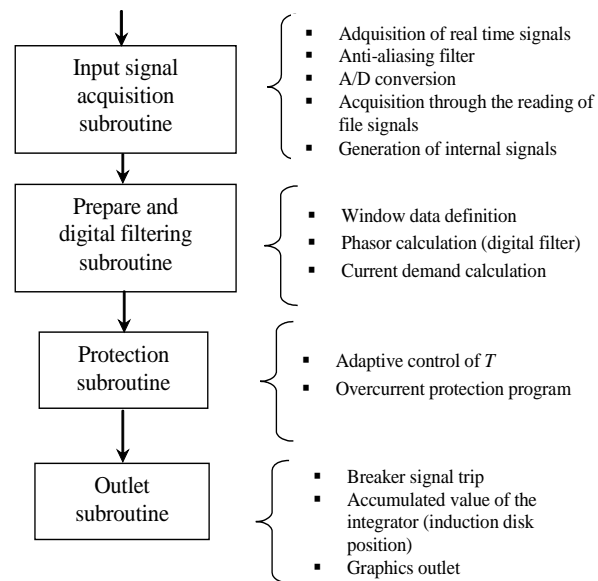


Fig. 5. Subroutines of overcurrent adaptive relay

The pickup current of the primary device is defined in the I_{pickup} control of the pickup current section. This value is used to compute the operating current. The instantaneous element is simulated in “50” section. The cold load section

includes two steps of the pickup current in the relay setting. The level indicator section simulates the dynamics of the disk induction of an electromechanical relay or the accumulated value G_k in a digital relay.

The parameters of the anti-aliasing filter are fixed in the low pass filter section. The recording of the input/output signals is done in a text file. The digital filter results are in the frequency response graphics whilst the input signal and the pickup current are displayed graphically in the panel.

5 Test

A fault log was used to test the signal file. This two-phase fault was logged in a 34.5-kV distribution grid. Figure 7 shows the record of the phase relay event and Table I shows the relay adjustment and its operating time. For the sake of simplicity, the values shown are relative to the system’s primary relay. The pickup current of the primary relay is 190 A and the pickup current of the backup relay is 286 A. As the operating current of the proposed relay is accomplished with the primary pickup current the operating time is modified. The operating time of a conventional relay is calculated by the application (Fig. 6) and verified in Fig. 7. If the adaptive time coordination is used, the operating time is reduced by 0.2745 s. This is a quantitative example of the benefit of the proposed coordination.

Table I. Overcurrent relay setting

Conventional	Proposed
$I_{pickup}=430$ A	$I_{pickup}=275$ A (at the time of the fault)
Moderate inverse curve [IEEE Std C37.112, 1996], Dial=0.2	
Time=0.7067 s or 42.4 cycles (f=60hz).	Time=0.4322 s or 25.9 cycles (f=60hz)

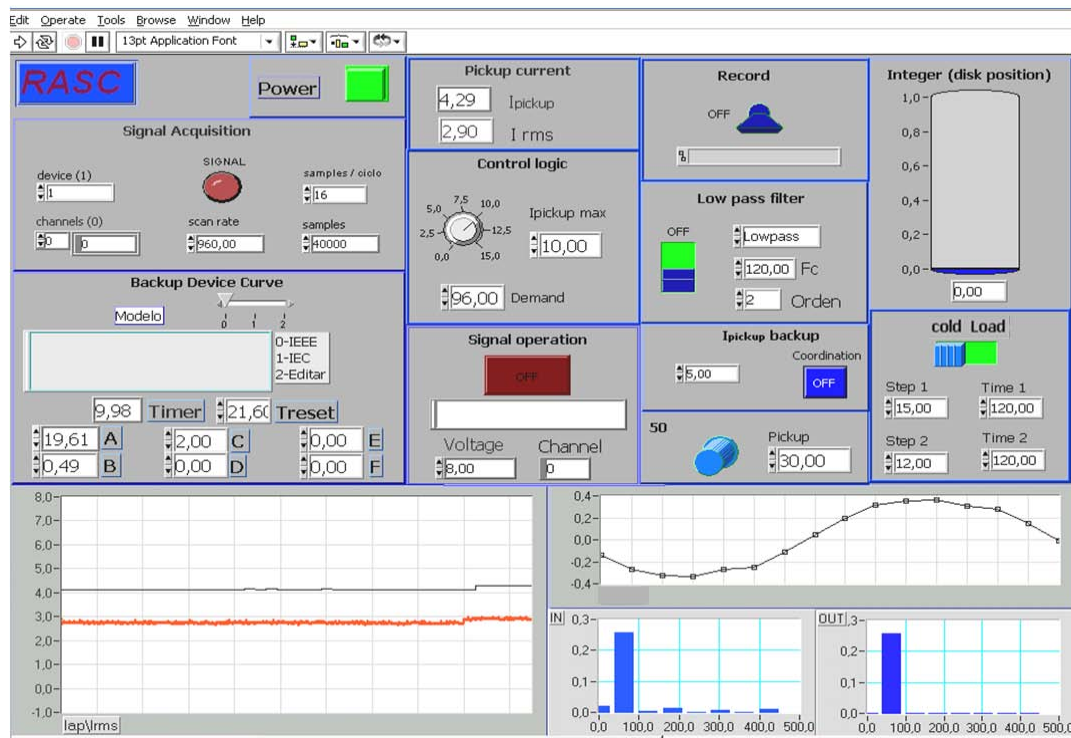


Fig. 6. Adaptive relay front panel

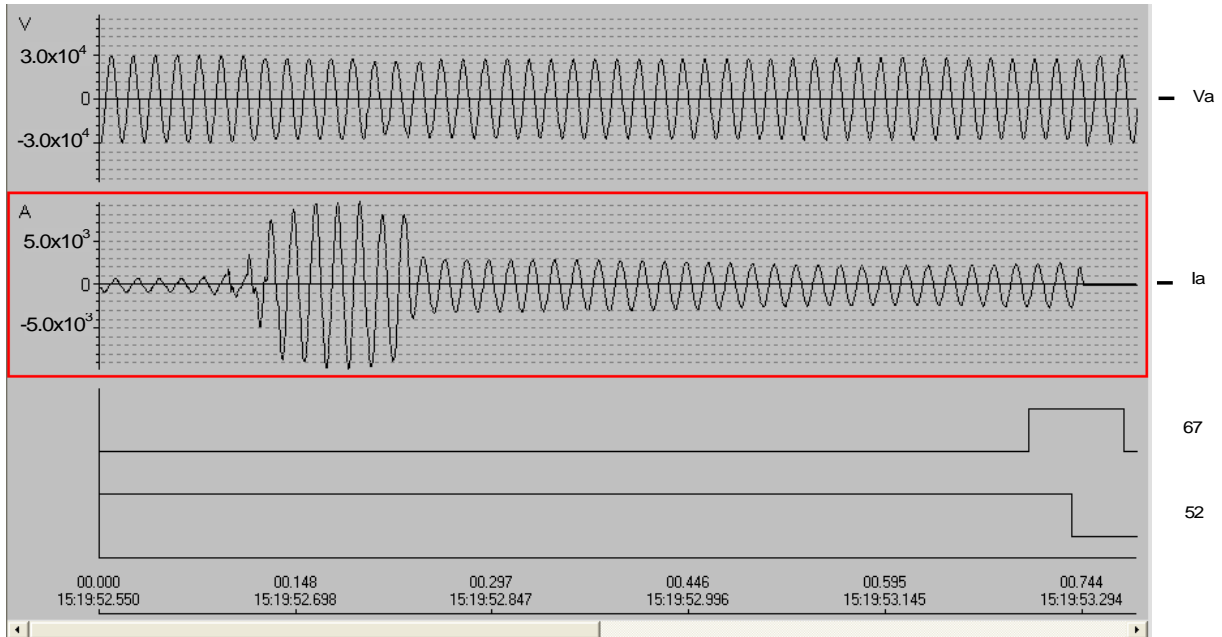


Fig. 7. Fault signal recorded in a 34.5-kV distribution network

The time coordination between *Relay B*, *Relay A* and the proposed *Relay A** (Fig. 8) was evaluated with the application tool (Fig. 6) in a dynamic fault current situation. The fault current signal and the integration process of the overcurrent relays with variable fault currents were obtained in both laboratory tests and by digital simulation. The output of the integrator was recorded. The dynamic fault current ($I_{shortcircuit}$) and the integrated value in *Relay B* ($G_k^{primary}$), *Relay A* (G_k^{backup}) and the proposed *Relay A** ($G_k^{backup*}$) are shown in Fig. 9. For all relays, the time curves are inverse type [IEEE Std C37.112, 1996]. We observed that the time interval between *Relay B* and *Relay A* is 0.61 s, although the operation time difference between *Relay A** and *Relay B* is 0.3 s (*CTI*). This highlights the advantage of the proposed time relay versus a conventional relay in back-up zones.

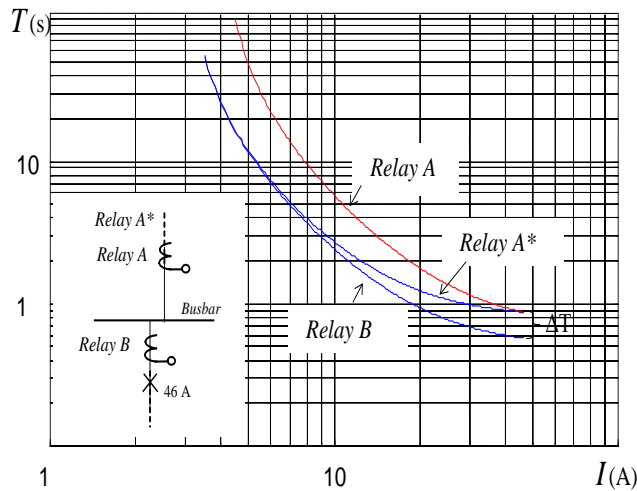


Fig. 8. Time coordination in laboratory test

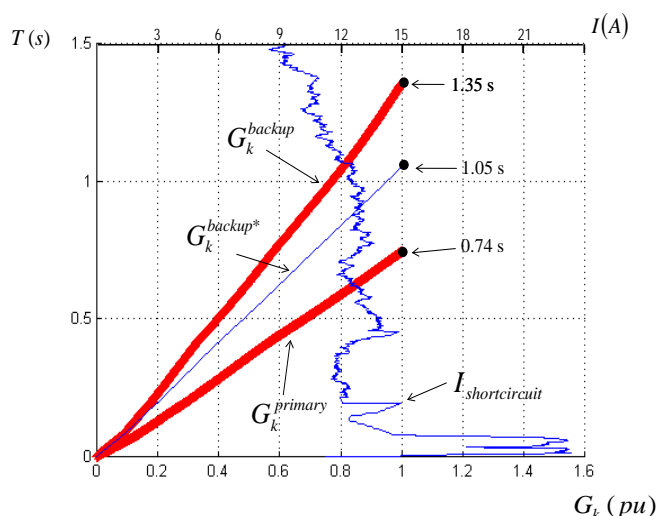


Fig. 9. Accumulated value of the relays integrators in laboratory test

6 Conclusions

The coordination method presented in this work requires an analytical expression for the primary device in the dynamic equation of the proposed relay. With this, the proposed relay emulates the operation of the primary device to obtain a constant backup time. This operation time is smaller than the backup time of conventional relays. The time operation of the other relays (the back-up of the proposed relay) is also reduced and the final effect in the network is a reduction of time operation for relays.

The main benefits of the proposed coordination process for overcurrent relays by the proposed relay are: the back-up time is independent of the magnitude of the fault current, resulting in a reduced back-up time compared with a conventional overcurrent relay system; coordination is carried out by the proposed criterion; the coordination is independent of any future system changes (such as topology, generation and load); and the proposed overcurrent relay is obtained with only a small change in the firmware's relay and without any additional cost.

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