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# Overcurrent relay with unconventional curves and its application in industrial power systems

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ABSTRACT

This paper presents a generalized formulation of an inverse time overcurrent relay that can generate non-conventional inverse time curves. The proposed model considers a variable time dial position as a function of the fault current; the interaction of two dynamics, the digital representation of the movement of the induction disc (such as conventional relays) and the time dial result in time curves that can be designed for any specific protection coordination problem. The proposed relay does not require more input data that conventional relay, only the fault current in the relay location is required. The proposed model has greater flexibility for the creation of time curves than conventional relay models because it allows the incorporation of independent functions of the time lever that will result in several time curves depending on the defined application criteria. A comparison of the curve fitting between the proposed model and the curve standard model was evaluated using two cases of an industrial power system, for which the non-conventional curves allow the reduction of operation times, mechanical stress and thermal effects. Furthermore, this approach could also prevent damage to the primary equipment.



## 1. Introduction

The coordination of protective devices should be calculated after load-flow and short-circuit studies. These studies have been developed based on equipment specifications and the topology of the power grid. The coordination study of protective devices was developed to determine the settings of the protection devices [1,2]. In the specific case of industrial power systems, protective devices generally operate under the overcurrent principle to present dynamic responses that are similar to different disturbances in the system, which ensures the selectivity of the protection. Industrial systems have a greater diversity of overcurrent protection devices than other sections of the electric network due to the different types of loads and electrical components; electromechanical relays, digital relays, fuses and switches of low voltage are commonly used.

The time curves of overcurrent relays are appropriate for equipment protection because they allow temporary overload conditions. In addition, the coordination is simplified by the convergence of time curves. Conversely, coordination is not always calculated by using the maximum current in industrial power systems due to the large variety of time curves and damage curves of the protection system equipment. Furthermore, the time curves are asymptotic to the pickup current. Thus, the time positively correlates with the power demand. These conditions can result in long operation times of protective relays.

The use of negative sequence relays [3] provides a solution to the lack of sensitivity problem. However, the complexity of the protection scheme is increased because this type of relay must be coordinated with relays that respond to positive and negative sequences.

The protection coordination should consider the critical operating scenarios on the electric network [4]; the main objective of this approach is the protection of primary equipment, for which coordination is established for the maximum short circuit current (phase and ground). Commonly, fault currents that are not maximized result in large operating times. Reducing the operation time of the protection system is desirable because it increases the lifetime of the equipment and improves the voltage quality. Methods to reduce the stress in primary equipment via changes in the shape of the time curves and in the optimization of the coordination process are presented in [5–9].

Time curves may intersect during the coordination process, and the intersection point can be determined [10,20]. However, due to the diversity of the time curves of the protection relay and the damage curves of the primary electrical equipment, the resulting times from the coordination process allow fault currents to last up to several seconds. In the literature, different solutions that seek to minimize the duration of the fault current flowing through

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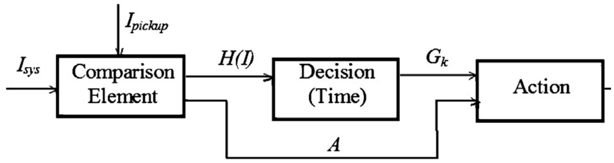


**Fig. 1.** Digital versions of the inverse time overcurrent relay.

the primary electrical equipment by improving the performance of the overcurrent relays have been proposed. A relay that modifies the time curve of the overcurrent relay as a support of the second operation zone of a distance relay has been proposed in [11]. A relay with a universal time curve that allows coordination with a wide variety of time curves of overcurrent relays of different technologies has been proposed in [12]. An overcurrent relay model that facilitates the selection of curves using a combination of database and algorithms of curves settings based on polynomial models is presented in [13]. In this paper, we propose an inverse time overcurrent relay (phase or ground) with the capacity to generate non-conventional time curves. The conventional relay model was modified with dynamic dial function to increase its degrees of freedom and generate time curves that reduce the time interval with other relay curves or damage curve of equipment, enhancing the specific coordination scenario.

In some cases, the use of time curves established by the standards may have limitations in the protection of power systems, mainly in industrial power systems. The inadequate coordination of protection devices results in an increase in the operation times, in which increases the mechanical or electrical stress in the primary electrical equipment.

This work focused on using time curves that are not conventional as a solution to coordination problems, rather than specifying the type of function that will solve a specific problem. The complexity associated with an increase in the variety of time curves requires improved coordination; however, this complex issue can be solved by adapting the tools that allow the coordination via a graphical interaction and defining the time curve parameters as an input. This modification will result in more suitable operation times. Thus, the time curve model parameters can be supplied to the relay as part of the physical setting of the relay. The changes suggested in the proposed functions are only at software level, such as in [21]. The modification of the firmware of the relay function will allow the determination of the proposed time curve. This approach does not require additional entries; the hardware from the relay does not need to be modified.

## 2. Digital time overcurrent relay

The modeling of digital relays must emulate the operation of electromechanical relays [14]. Fig. 1 shows a simplified diagram of a generalized version of the digital inverse time overcurrent relay modeled by means of functions [15]. The function generator receives the phasor $I_{sys}$ as an input, which represents the fundamental component of the current. The values of the setting $I_{pickup}$ form the output signals of $H(I)$ and $A$, where $I = I_{sys}/I_{pickup}$ is the pickup current multiple [16]

$$A = \frac{K_d \theta}{\tau_s} \tag{1}$$

where $K_d$ is damper magnet, $\theta$ is dial travel, $\tau_s$ is retension spring.

When the operation condition is completed, $I_{sys} > I_{pickup}$, the integrator introduces the time variable into the process. The output signal of the integrator is defined as follows:

$$G_k = \Delta t \sum H(I_k) \tag{2}$$

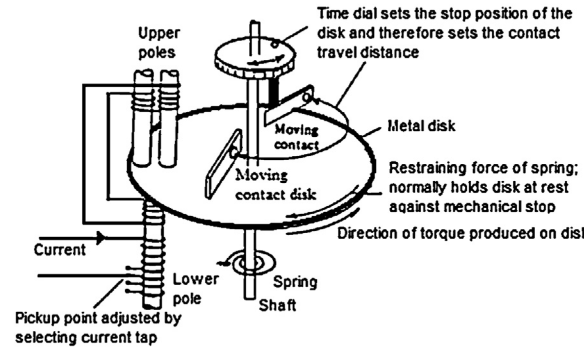


**Fig. 2.** Analog pattern of electromechanical relay for the proposed relay.

where $G_k$ represents the value of the accumulated integrator at the instant of processing the sample $k$, and $\Delta t$ is the sampling period.

The operating condition is fulfilled when the amplitude of the signal $G_k$ is equal to $A$. The trip signal is then generated.

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

The relay is operated at the instant that $k$ reaches a value equal to $k_{op}$ and satisfies (3). This equation considers the integration of a dynamic fault current to preserve the coordination between relays.

The time curve is created by considering a constant fault current. At this condition, $I$ = constant value. Thus:

$$\begin{aligned} (k_{op}\Delta t)H(I) &= A \\ T(I)H(I) &= A \\ T(I) &= \frac{A}{H(I)} \end{aligned} \tag{4}$$

According to [15], $H(I)$ is $I^n - 1$. Furthermore, the time saturation, $B$, is included.

## 3. Proposed overcurrent relay model

The definition of the constant $A$ has a direct physical relationship with the electromechanical relays, in which the induction disc is the only component that is moved by the interaction of the induced currents. Furthermore, the angular distance of the movement of the disc to the closure of contacts, the action of the damper magnet and the retention spring, which are parameters that are defined in [16], are constant. In this paper, we proposed to modify the function $A$ such that it is variable and depends on the input. This assumption increases the degrees of freedom of the analytical expression that defines the time curve of the relay. The equivalent electromechanical relay in Fig. 2 was used to assign a dynamic behavior to the dial lever such that $\theta$ is a function of the current, $\theta(I)$.

$$A(I) = \frac{K_d \theta(I)}{\tau_S} \tag{5}$$

The objective was to define functions, $A(I)$, that can alter the dynamic response of the relay and accelerate or reduce the operation time depending on the specific application.

Therefore, the digital time overcurrent relay is modified as shown in Fig. 3 as a result of change in operating conditions and the dynamic manipulation of $A(I)$, which depends on the current $I$.

Substituting (4) in (3) results in the following:

$$\Delta t \sum_{k=1}^{k_{op}} \frac{A}{T(I_k)} = A$$