Electric Power Systems Research 136 (2016) 8–11

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Analysis of overtravel in induction disc overcurrent relays

Elmer Sorrentino *

Universidad Simón Bolívar, Dpto. de Conversión y Transporte de Energía, Apdo. Postal 89.000, Caracas 1080, Venezuela

ARTICLE INFO

Article history:
Received 12 December 2015
Received in revised form 26 January 2016
Accepted 1 February 2016
Available online 20 February 2016

Keywords:
Induction disc overcurrent relay
Overtravel
Distribution system protection
Electromechanical modeling

ABSTRACT

This article analyzes the overtravel in induction disc overcurrent relays. Based on experimental results, obtained from tests on three relays from different manufacturers, it is verified that the equivalent overtravel time can be considered constant for a wide range of settings in the device. Dynamic equations of the device are analyzed, in order to find the root of this behavior. This analysis was performed in two ways: by assuming a first-order differential equation, and by assuming a second-order differential equation. Both methods allow to demonstrate the fact of a constant value for the equivalent overtravel time. The method based on a first-order differential equation is very simple, and this fact is attractive from a pedagogical perspective; however, it is based on assumptions which are not rigorously valid. Thus, the method based on a second-order differential equation should be preferred for the sake of accuracy.

1. Introduction

Induction Disc Overcurrent Relays (named IDOR here, to abbreviate) are electromechanical devices which have been widely applied for the protection of electric power distribution systems around the world. Nowadays, the predominant technology of protective relays is based on microprocessors, but there are IDOR still operating in diverse electrical systems. The "overtravel" of IDOR is a term related to the fact of an additional disc displacement, due to its inertia, after the overcurrent has been properly interrupted by a downstream protective device. An undesired trip of IDOR could occur due to the overtravel. Therefore, overtravel of the IDOR has been usually considered by the inclusion of a time interval (0.1 s) between time-current curves, in order to obtain selectivity [1–4]. Here, this time interval is called "equivalent time due to the overtravel" (Δt). Usually, Δt is considered constant (i.e., independent of relay settings and overcurrent values), and some documents mention that this assumption could be an unjustified approximation [3,4]. Certainly, it is not evident that Δt could be considered constant when the values of overcurrent (and, consequently, the initial values of disc speed for the overtravel condition) can be considerably different. Actually, this research project was begun by guessing that the afore-mentioned "usual approximation" would be in some sense unaccurate; however, the experimental results definitively indicated that the afore-mentioned usual approximation was excellent. Due to this reason, a deep review of the motion equation was necessary, for the purpose of this article. Consequently, the structure of this article begins with a conceptual overview about different time intervals related to the overtravel, followed by the presentation of the experimental results, and the article finishes with two different ways to justify (based on the equation motion of the IDOR) that the equivalent time due to the overtravel can be considered as a constant.

A contribution of this article is the theoretical justification for the fact of having a constant value for Δt in IDOR. On the other hand, the theoretical analysis also emphasizes the difference between Δt and other time intervals related to the overtravel, in order to avoid confusions about this subject. Additionally, the experimental results of this article show that Δt can be considered constant for a wide range of overcurrent values and relay settings (an experimental verification about this point was not available in the literature; this experimental verification is important because some documents [3,4] mention reasonable doubts about this point). Thus, this article shows a clear justification to keep the use of a constant additional time interval for considering the overtravel of the IDOR, in the coordination of an upstream IDOR with downstream devices, and this coordination is still necessary in diverse existing installations.

2. Equivalent time due to the overtravel

The time-current curves of IDOR show the tripping time (t_T) for a given constant overcurrent. If that overcurrent is injected for a time lower than t_T, the relay could operate due to the overtravel. The injection of that current can be stopped at the moment when the disc overtravel would be just enough to reach the trip position with speed equal to zero. The required injection time in order to

* Tel.: +58 212 906 3720.
E-mail address: elmersor@usb.ve

http://dx.doi.org/10.1016/j.epsr.2016.02.003
0378-7796/

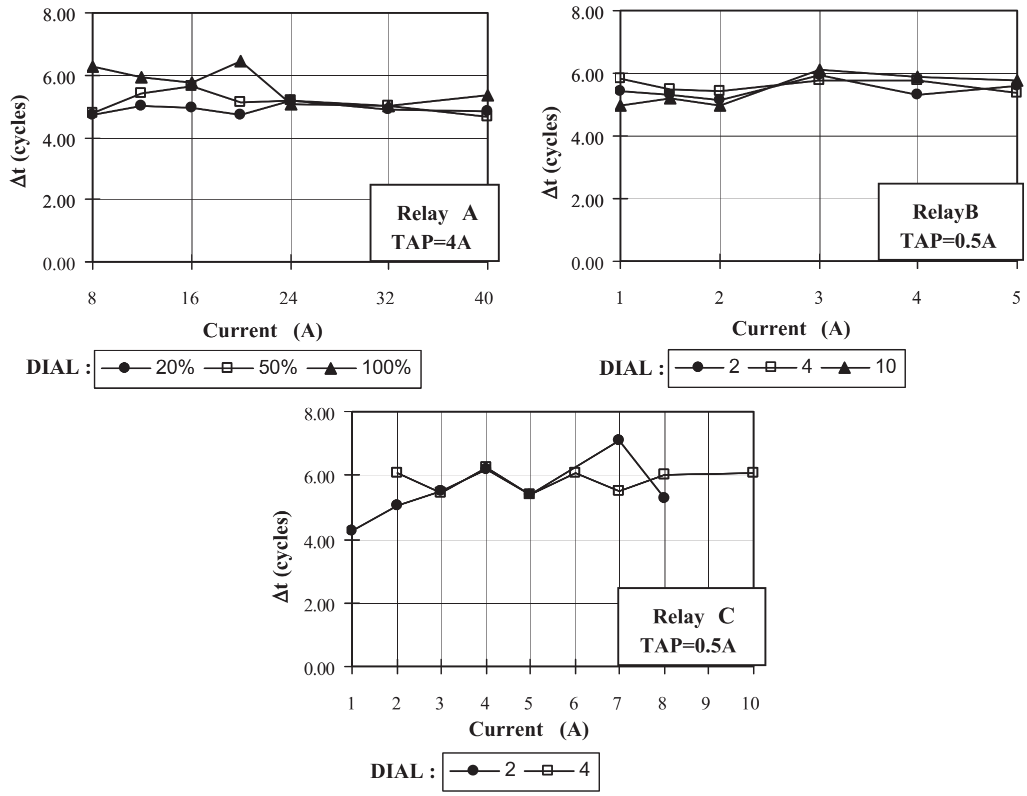

Fig. 1. Experimental measurement of the equivalent times due to the overtravel (Δt).

obtain this condition is simply called "limit-time" (t_L) here. t_T and t_L ($t_L < t_T$) depend on the magnitude of the current and the IDOR settings. Actually, t_L also depends on the current during the overtravel but this current is assumed to be null in this article. Therefore, the equivalent time due to the overtravel (Δt) is

$$\Delta t = t_T - t_L \tag{1}$$

On the other hand, the overtravel time is the required time to reach the speed (ω) equal to zero (without trip). A different definition (t_0) is the overtravel time to reach the trip condition just with $\omega = 0$. Thus, t_0 really is the overtravel time for the condition for the measurement of t_L, but the equivalent time due to the overtravel (Δt) is not the overtravel time of the disc.

3. Experimental results

The procedure for the measurement of Δt is: (a) first, the operation time (t_T) is measured for a given overcurrent; (b) later, the same overcurrent is injected during a time lower than t_T, in order to find the limit condition (t_L) between trip and no-trip.

Δt was measured for 3 relays (relay A:BBC, model ICM21; relay B:General Electric, model IAC78; relay C:Westinghouse, model CO11). Results are shown in Fig. 1. Time resolution is 0.5 cycles for t_L, and 0.01 cycles for t_T (cycles at 60 Hz).

4. Analysis of relay equations

4.1. General overview

The following simplifications are assumed in this article:

(a) The restraint torque due to the permanent magnet is assumed to be only dependent on disc speed.
(b) The restraint torques due to the permanent magnet and due to friction are assumed to be proportional to disc speed. Thus, both effects can be grouped in a variable, T_P.
(c) The restraint torque due to the spring (T_R) is assumed to be proportional to the disc position.
(d) For the last part of the disc travel with overcurrent, the disc speed is assumed to be constant. If the overcurrent were not finished, it is assumed that the disc would move during the last part of its travel with the same instantaneous speed that the disc has at the end of the overcurrent (ω_0). ω_0 is different for each value of overcurrent, and ω_0 is the initial speed for the overtravel condition. Therefore, it is assumed that for the limit condition of the trip with overtravel, the angular displacement ($\Delta\theta$) which is required for the trip condition is related to the speed ω_0 and with Δt by the rule of an uniform movement:

$$\Delta t = \frac{\Delta\theta}{\omega_0} \tag{2}$$

Assumption of uniform movement (with current) is not exact, but it is a good approximation due to the braking effect of magnet. Thus, Eq. (2) implies that $\Delta\theta$ is proportional to ω_0.

Initial conditions are at the instant when the overcurrent finishes ($t = 0$, $\theta = 0$, $\omega = \omega_0$). Only restraint torques are present (T_P, T_R), and the condition of interest is the limit for the relay operation with overtravel ($t = t_0$, $\theta = \Delta\theta$, $\omega = 0$).

4.2. Analysis based on a first-order differential equation

Disc motion is described by a first-order differential equation by assuming that torque due to the spring is constant:

$$J\left(\frac{d\omega}{dt}\right) + T_P + T_R = 0 \tag{3}$$