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A digital scheme to minimize the influence of transformer magnetizing inrush or CT saturation on line protection

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ABSTRACT

For transformer magnetizing inrush or current transformer (CT) saturation, conventional blocking techniques result in interruption or severe delayed operation of protective relays. Besides, the reliability of CT saturation blocking (or compensation/reconstruction) techniques may be also disturbed by transformer magnetizing inrush. For improvement, this paper proposes a digital waveform reconstruction scheme, instead of blocking techniques, to eliminate distorted portions caused by magnetizing inrush or CT saturation from current signals, which minimizes the adverse effects on line protection. Concretely, the proposed scheme implements the portion segmentation, distortion portion identification, distortion portion elimination, and waveform reconstruction, according to calculated real time amplitude and ratio of boundary gradient. Case test results indicate the correctness and effectiveness of the proposed scheme. It is able to repair the waveform of CT saturation current. Moreover, it opens a new door to eliminate magnetizing inrush component from current signals in power lines. The reconstructed current waveform without distortion is outputted in real time, which contributes to the uninterrupted correct operation of protective relays in power lines.

1. Introduction

Transformer and current transformer (CT) are two kinds of electromagnetic devices installed in power system. Both of them often suffer from iron-core saturation due to their inherent excitation characteristics.

A transformer with saturated iron-core will produce magnetizing inrush current. The magnitude of magnetizing inrush current is usually high and the waveform is distorted, which may result in false tripping of transformer protective relays [1–3]. Due to penetration, magnetizing inrush could also be detected in power lines, and endanger the accuracy of line protection or other devices.

For CT, once iron-core saturation happens, instantaneous value of CT secondary current will drop immediately. It does not recover until CT deviates from the saturated state. CT saturation will cause the inaccurate phasor estimation, and threaten the proper operation of protective relays [4,5].

Given the above, both transformer magnetizing inrush and CT saturation will make protective relays receive distorted current signals, which will challenge the validity of protective relays. Especially, in power lines, the challenge is much greater, because a power line may be connected with multiple transformers and CTs.

To respond to these challenges, various techniques have been reported in the literature. There are many kinds of algorithms which are able to reliably identify and block inrush currents in differential current of transformers. These algorithms involve the use of methods such as non-saturation zone recognition [6], support vector machine [7], differential current gradient [8], mathematical morphology [9], and others [10,11]. CT saturation detection techniques, using Savitzky-Golay filter [12], multiresolution morphological gradient criterion [13], secondary current envelope detector [14], and so on, are also proposed to detect and block saturated secondary current of CT. In addition, some scientists have researched several techniques which are capable of compensating or reconstructing saturated secondary current, such as linear regression based method [15], least error squares based method [16], and the list goes on [17,18]. Refs. [19] and [20] have investigated the coupling effect of transformer inrush current and CT saturation, as well as the countermeasures. Most of the abovementioned techniques are very ingenious and practical. But there are still several open issues:

(1) Blocking technique is widely used in engineering. After magnetizing inrush or CT saturation is detected, the operation of some protection functions will be blocked, which causes the interruption or delayed operation of these protection functions. That is a drawback of blocking technique.

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(2) Once magnetizing inrush current penetrates to power lines, it will be superimposed on normal operating sinusoidal current, which increases difficulties in magnetizing inrush detection [21,22]. The abovementioned magnetizing inrush detection and blocking techniques are designed for differential circuit of transformers. They may not be suitable for sinusoidal current superimposed with inrush in power lines. Moreover, some existing CT saturation detection and reconstruction techniques may be incorrectly touched off by line current superimposed with inrush, so that undesired results could be obtained.
(3) Reconstruction technique repairs the distortion of signal waveform in real time, and compensates the adverse effects without relay protection interruption. It seems to be an effective approach. However, existing reconstruction techniques usually focus exclusively on CT saturation. Although the algorithm presented in [19] is designed to reconstruct not only distorted fault current but also distorted inrush current, but they cannot remove the adverse effects of transformer magnetizing inrush on protective relays, and magnetizing inrush blocking technique still needs to be used, which causes interruption of protection.

To minimize the adverse influences of magnetizing inrush or CT saturation on line protection without abovementioned drawbacks, this paper proposes a new digital scheme. The proposed scheme eliminates distorted portions caused by magnetizing inrush or CT saturation from current signals, and outputs reconstructed current without distortion in real time. Better than traditional blocking techniques which cause the interruption or delayed operation of some protection functions, the proposed scheme will contribute to the uninterrupted operation of protective relays. Better than traditional reconstruction techniques, the proposed scheme is capable of removing magnetizing inrush components from line currents.

The rest of this paper is organized as follow: Section 2 presents the proposed scheme, its architecture, its principle, and its algorithm. Section 3 and Section 4 include the case test results of the proposed scheme. Finally, Section 5 summarizes this paper.

2. The proposed scheme

2.1. Description of the proposed scheme

The proposed scheme eliminates distorted portions caused by magnetizing inrush or CT saturation, and repairs the current waveform. As depicted in Fig. 1, it is composed of the stable-amplitude (SA) portion determination unit and the distortion elimination and reconstruction unit. The former unit implements the portion segmentation according to *RTA* and *ARTA*. Based on the behavior of *RBG*, the latter unit determines whether a portion should be eliminated or retained, and reconstructs the current signal. Where, the *RTA* represents calculated real time amplitude; the *ARTA* represents amended real time amplitude; the *RBG* represents the ratio of boundary gradient. They will be described in further detail below.

According to the description in introduction section, there are some potential distorted current signals in power lines. They are obtained by the simulation model shown in Fig. 2. And their waveforms are shown in Fig. 3.

These potential distorted current signals can be categorized as follows:

(1) CT saturation current, as shown in Fig. 3(a). It is generated because a sinusoidal current is non-linearly transferred by a saturated CT.
(2) Inrush current. It is produced by a transformer with iron-core saturation. Fig. 3(b) shows an inrush current which is generated by no-load switching-in the transformer T with iron-core saturation when K3 is open. Fig. 3(c) shows another inrush current which is superimposed on normal operating sinusoidal current. It is generated by no-load switching-in the transformer T with iron-core saturation when K3 is closed.

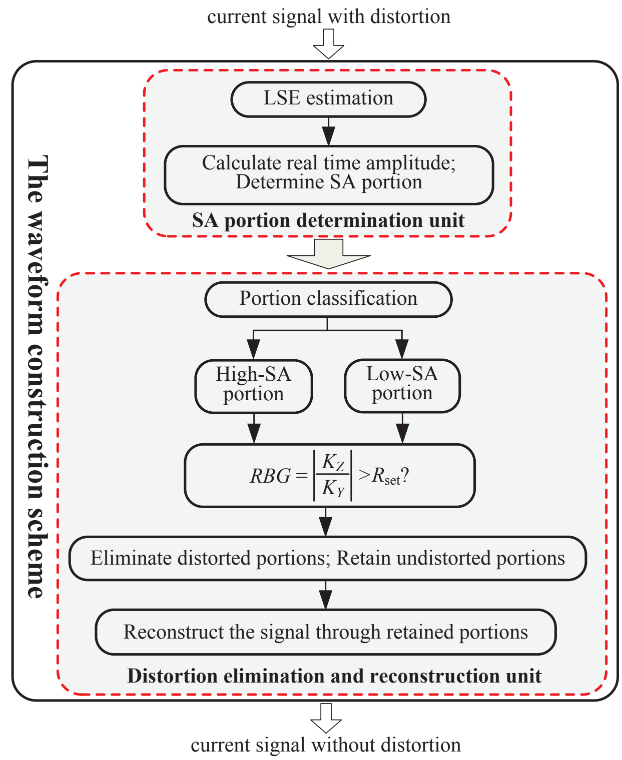

Fig. 1. Framework of the proposed scheme.

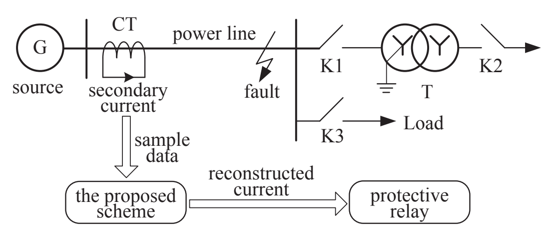

Fig. 2. The simulation system.

In power line, these two kinds of distorted waveform can appear in secondary side of CT, which make protective relays receive distorted current signals.

The main aim of the proposed scheme is to eliminate the distortion from the current signal, and reconstruct it. The reconstructed signal will be sent to protective relays so that protective relays can operate without the disturbance from transformer magnetizing inrush or CT saturation.

2.2. SA portion determination unit

2.2.1. Real time amplitude of signal

Least square estimation (LSE) method [23,24] is utilized to estimate the real time amplitude of a current signal, which is illustrated in detailed as follows.

The current signal can be mathematically described as

$$\begin{aligned} i(t) &= I_D + I_A\sin(\omega t + \theta) \\ &= I_D + I_A\cos\theta\sin\omega t + I_A\sin\theta\cos\omega t \end{aligned} \quad (1)$$

where $i(t)$ is the instantaneous current at time t. I_D is the instantaneous direct current (DC) component. I_A, ω, and θ denote the amplitude, angular velocity, and phase angle of the sinusoidal component, respectively.