Combined Fault Detector and Faulted Phase Selector for Transmission Lines Based on Adaptive Cumulative Sum Method

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***Abstract*—In this paper, a novel approach is proposed for fault detection in transmission lines. This idea is based on the adaptive cumulative sum method (ACUSUM), whose structure is adaptive with the current passing through the corresponding line. The proposed ACUSUM algorithm can detect even low magnitude faults with high resistances. By using the proposed method, just a few milliseconds after fault inception, the fault detection unit permits the main protection algorithm to become activated. Moreover, ACUSUM output indices can discriminate faulted phases within only 1 ms after fault registration. This new faulted-phase selector can also be applied to double-circuit transmission lines to detect cross-faults as well as intercircuit faults. The results have shown that the proposed method has good performance in speed and accuracy as a combined fault detector and faulted-phase selector algorithm.**

***Index Terms*—Fault detection, faulted-phase selection, protection, transmission lines.**

I. Introduction

GENERALY, in microprocessor-based (digital) devices, there is a signal conditioning part which refers to preparing the analog input signal for the desired digital processing by passing it through analog circuits for transducing in magnitude, transforming in type (current to voltage) and filtering. Analogously, digital signal conditioning (DSC) can be introduced as preparing the digital input signal (the analog-to-digital output signal) for final digital processing (i.e., the main assigned function/mission of the digital device) by applying digital filters and/or computational routines.

DSC may contain digital filters to eliminate different frequency bands, fault detection units (FDUs), faulted-phase selection units (FPSUs), current-transformer (CT) saturation detection and compensation unit (CTCU), arcing fault detection unit (AFDU), and dc component removal unit (DCRU). This paper deals with the first stages of DSC (i.e., FDU and FPSU), through introducing a novel adaptive approach.

With the inception of a fault in a power system, the voltage and current waveforms deviate from sinusoidal forms. The sample-to-sample comparison of the current or voltage signal and/or comparison of the present sample with the corresponding sample at one or two previous cycles are straightforward approaches for fault detection by FDUs [1], [2]. However, these techniques are affected when system frequency deviates from the nominal value, with the presence of noise in the signal or also load changing. The proposed current slope-based fault detector has the same shortcomings [3]. High-frequency components of the signal can be useful for the fault detection task where the wavelet transform can be an effective tool [4] although complexity, computational burden, and the need for high-frequency sampling devices are typical problems with wavelet-based methods. Artificial neural networks (ANN) has also been used in the fault detection domain. In general, performance of an ANN-based method directly depends on its training process and its predefined structure. Due to the fact that there is no routine procedure for designing an ANN, these methods may leave their attraction [5]. One of the latest ideas in fault detection domain is detecting the specific patterns of sound produced by the fault using a microphone array and an infrared thermal imaging camera [6]. This method, belonging to hardware-based method, needs specific filters to remove the noise signals caused by the wind, bird chirpings, or other external influences.

Recently, a new cumulative sum-based fault detector (CUSUM) has been proposed, offering more advantages over traditional methods [7]. This algorithm has good performance in speed and accuracy aspects. With a sampling frequency of 1 kHz, the CUSUM algorithm can detect a fault just 3 ms after its inception (except the faults with zero inception angle). This algorithm is immune to noise and frequency drift in the signal as well as load changing at the cost of ignoring high resistance faults and missing required dependability for FDUs. The security assessment for the CUSUM algorithm in transient conditions, such as lightning and line energization, has shown perfect performance [8]. Another fault detector based on phase space transformation has been proposed which, in comparison with CUSUM, has the ability to separate faults from capacitor switching [9], though its greater complexity and larger computational burden rather than CUSUM cannot be ignored. Moreover, similar to CUSUM, this approach cannot detect high resistance faults (HRFs) where current magnitude remains less than predefined load current.

Obviously, an FDU should discriminate faults from normal states of the power system network and quickly activate the main relay algorithm. In other words, the performance of a

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protection algorithm depends on the combination of performances of FDU and the main relay algorithm. In this respect, overall dependability depends on AND operation of dependability performance of both the FDU and relay algorithm while overall security depends on OR operation of their security performances. Therefore, a robust fault detector algorithm should have perfect dependability and appropriate security. The proposed ACUSUM, as an adaptive scheme, has perfect dependability (even against high resistance faults) while its security is appropriate for this task since it is only violated under load increase (i.e., load increase is assumed as a fault). It should be noted that when this condition is delivered to the corresponding protection algorithm, it will be easily rejected.

On the other hand, faulted-phase selection plays a vital role in the protection of transmission lines. Generally, a faulted-phase selector provides the opportunity to employ single-phase switching and consequently improves system availability and reduces maintenance costs. Speed is the main concern to assess the performance of an accurate faulted-phase selection algorithm, in order to ensure that not a large time delay is imposed on the main protection algorithm. In [10], a faulted-phase selection method based on the wavelet singular entropy (WSE) method using superimposed components has been proposed which employs wavelet and singular value decomposition. A combination of wavelet transform and a neural network trained by the particle swarm optimization (PSO) algorithm is offered in [11]. In another approach [12], faulted phases are distinguished by means of the decision tree (DT) algorithm which is formerly trained by applying the odd harmonics of measured signals, up to the 19th. This method needs voltages and currents of only one side of protected line. A pattern recognition approach, which contains multilevel wavelet transform in addition to principal component analysis and support vector machines, has been employed in [13] for this task. Recently, based-on single-end measurements, using the time-shift invariant property of the sinusoidal waveform, an idea has been proposed which extracts distinctive fault features by applying the determinant function on a data window of postfault data [14].

In this paper, the proposed ACUSUM algorithm is also employed as a faulted-phase selector where investigations have shown that the phase selection task is accomplished only in 1 ms after fault registration, even for faults with zero inception angles, while the calculation burden is kept at very low amounts.

The rest of this paper is organized as follows. Section II gives an explanation of the ACUSUM algorithm. In Section III, the performance of the proposed algorithm as a fault detector (its dependability and security) is discussed and compared with the CUSUM algorithm under different conditions. Section IV explains the proposed faulted-phase selector based on the ACUSUM method and the results of its assessment. Finally, conclusions are given in Section V.

II. Proposed Fault Detector

In order to explain the proposed fault detector based on the ACUSUM algorithm, it is better to begin with the CUSUM algorithm.

A. CUSUM Algorithm

CUSUM is an algorithm which is used in many fields for the detection of abrupt variations [7]. As signals in power networks alternate, the two-sided CUSUM algorithm has been suitably designed for power system relaying applications [7]. As a fault detector, the CUSUM method takes the current samples of any phase and delivers two input signals as

$$s1_k = y_k \tag{1}$$
$$s2_k = -y_k \tag{2}$$

where y_k represents the kth sample of the current signal. Then, the two-sided CUSUM indices are expressed as [7]

$$g1_k = \max[(g1_{k-1} + s1_k - I_{\text{static}}), 0] \tag{3}$$
$$g2_k = \max[(g2_{k-1} + s2_k - I_{\text{static}}), 0] \tag{4}$$

where $g1_k$ and $g2_k$ represent the fault occurrence at positive and negative half cycles, respectively, and I_{static} is a drift parameter which provides a low-pass filtering effect. For fault detection applications in power system relaying, the value of I_{static} should be equal to the "pickup value" of the corresponding relay [7]. The max-operation produces a positive or zero value for either $g1$ or $g2$ with an increase in the level of signal (i.e., whenever either $s1$ or $s2$ becomes greater than I_{static}, the corresponding g-index starts growing. It is supposed that a fault will be registered, and a trigger signal will be issued, if the following criterion is fulfilled at three consecutive samples:

$$\text{Trigger signal} = \text{erg} = \begin{cases} 1, & \text{if } g1_k > h \text{ or } g2_k > h \\ 0, & \text{else} \end{cases} \tag{5}$$

where h is an arbitrary threshold and should be ideally zero.

B. ACUSUM Algorithm

As mentioned in the CUSUM algorithm, the drift parameter I_{static} is chosen once and the CUSUM algorithm works with this value from then on. This may cause some maloperations upon faults with high resistances (discussed in sequel). In the ACUSUM algorithm, the indices in (3) and (4) are substituted with

$$p1_k = \max[(p1_{k-1} + s1_k - \beta I_{\text{dyn},k}), 0] \tag{6}$$
$$p2_k = \max[(p2_{k-1} + s2_k - \beta I_{\text{dyn},k}), 0] \tag{7}$$

where $I_{\text{dyn},k}$ is not fixed and is adjusted by the rms value of the corresponding line current from the previous cycles, and β is a setting parameter that raises or lowers $\beta I_{\text{dyn},k}$ when it takes values greater or less than one, respectively. Obviously, choosing values greater than 1 for this parameter makes currents with larger magnitudes than existing load current and less than βI_{dyn} unseen to ACUSUM which may be suitable whenever load increases are forecasted and it is desired that FDU