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# A direct method for assessing distance-protection behavior during power swings

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ABSTRACT

The aim of this work is to include the distance-protection behavior in direct methods for transient stability assessments. In this way the direct methods assess an electric-power system's behavior more realistically and hence more reliably. In order to consider the delayed tripping zones of distance-protection relays, the time component was added to the Lyapunov energy function. The main innovation is that the dwell time of the post-fault impedance trajectory inside various tripping zones is calculated based on the speed of the transformation between the kinetic and the potential energy parts of the Lyapunov function. It enables the identification of unwanted trips during power swings. The tripping-zone settings can be revised accordingly. The method was verified by a comparison between the direct method and the well-known, time-domain, numerical-simulation method on a single-machine, infinite-bus test system where the results have to be identical. The application of the proposed method on a multi-machine power system gives good results.



## 1. Introduction

Protection security assessments are an emerging part of dynamic security assessments. In recent research [1–3] it has been established that in the process of transient stability assessments for electric power systems (EPSs) the protection relays can have an important role. In the past, protection relays were only considered in steady-state analyses [1]. This has changed in recent years, as now they are also considered in time-domain numerical simulations for transient stability assessments [2,3].

An alternative to the time-domain simulations for transient stability assessments is the direct methods. Their advantage is, besides the speed, a quantitative assessment of the stability margins. However, protection relays have not been considered in the direct methods up until now and, consequently, the results may be inaccurate or even completely incorrect. This paper provides an answer to the question of how to assess the tripping behavior of distance-protection (DP) relays when direct methods are applied. In this field some research was already made for overcurrent and differential protection [4]. DP is partly analyzed in [4] as well, but only the detection of impedance inside the tripping zones is considered, without any time components that define the activation of the time-delayed zones. In recent years special attention was paid to protection behavior during large power swings. The report of a special IEEE working group [5] provides a brief discussion of power-swing and out-of-step phenomena, how these phenomena affect the protective relaying, and explains many of the methods available to detect these phenomena. In [6] out-of-step protection fundamentals and advances together with the fundamentals of power-system stability are described. In [7,8] a more detailed tutorials on power-swing blocking and out-of-step tripping together with the advanced non-conventional methods are presented.

The goal of this paper is to combine the direct method for transient stability assessment with an assessment of the unwanted tripping of DP relays during power swings. The proposed method describes how to assess the unwanted tripping of the distance relay with conventional power-swing blocking (PSB) algorithms. In addition, the guidelines for the consideration of distance relays without PSB are given. The proposed method is presented on distance relays with polygonal characteristics; however, other types of characteristics (e.g., non-dynamic MHO characteristics) can be considered accordingly. In the case of non-conventional (i.e., advanced) PSB algorithms it can be assumed that unwanted tripping will not occur, consequently there is no need for a consideration of these relays. Consideration of the dynamic characteristics

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that are changing during the power swing needs further research. These characteristics are, therefore, not considered in the paper.

Direct methods are based on the Lyapunov energy function for an EPS. In our derivations, this function is based on a structure-preserving frame that allows more realistic representations of the power system's components as well as a simultaneous consideration of the protection relays located at different points in the EPS.

## 2. Distance-protection behavior during large transients

DP relays calculate the impedances on-line on the basis of current and voltage measurements for the protected line. The DP relay in our following considerations is called DP1. Under no-fault conditions DP1 is measuring the "load" impedance (point "1" in Fig. 1). Under fault conditions, the selectivity of the DP is maintained by various tripping zones with different R-X-impedance reaches and time delays. In the case of a fault occurrence in undelayed zone 1, an immediate trip follows—in this case our method is not the point of the discussion. In the case of a fault outside zone 1, the impedance might jump from the "load" to one of the outer zones (2 or 3) and the fault might be cleared with a certain time delay. The longer the delay time, the larger the accelerations of the generator rotors that are present. For fault clearing we can distinguish two cases: (a) the fault will be cleared by DP1; (b) the fault will be cleared by some other protection relay in the grid and DP1 should not trip. In (a) no post-fault "scenario" is measured by DP1. In scenario (b) the measured impedance of DP1 jumps from point "2" to point "3a" (i.e., outside the protection zones) or to point "3b" (i.e., inside the protection zones). Points "3a" and "3b" (Fig. 1) are the starting points of the post-fault impedance trajectory that correspond to larger rotor angles, larger power flows and possible lower voltages, compared to the pre-fault (i.e., load) values. Depending on the amount of acceleration of the generator rotors, large rotor-angle excursions and large power swings occur.

During these transient phenomena the impedance measured by DP1 can also move inside the protection zones again (as in case " 3a"—blue-dashed[1] trajectory) or even remain inside the protection zones (in case "3b"—red-dotted trajectory) for a dedicated time duration. If this dwell time is longer than the zone-specific trip delay time, then an unwanted line tripping after the fault clearing might occur.

In order to prevent unwanted tripping during power swings, an additional functionality, i.e., power-swing blocking (PSB), is provided in the form of an additional outer zone, defined by the so-called "power-swing characteristic", in Fig. 1 represented by a dashed-line polygon. The principle of PSB is based on the fact that during a power swing the impedance is gradually changing, while at the moment of a fault's occurrence the impedance "jumps" immediately to a fault-impedance point. So, when the time needed for an impedance to cross the area from the power-swing characteristic to one of the tripping zones exceeds a certain value, the PSB is activated and tripping is blocked [11]. Some alternative methods also exist [12,13]. In case "3a", the crossing of the area between the power-swing characteristic and tripping zone 3 is not immediate and the PSB is activated. In case "3b" the post-fault impedance trajectory does not cross the power-swing characteristic and the PSB is not activated. An unwanted tripping of the line is possible if the dwell time is longer than the zone-specific trip delay time.

It should be noted that some modern DP relays have advanced PSB algorithms that analyze the shape and the speed of the trajectory and can also detect power-swing phenomena such as in case-

[1] For interpretation of color in 'Fig. 1', the reader is referred to the web version of this article.

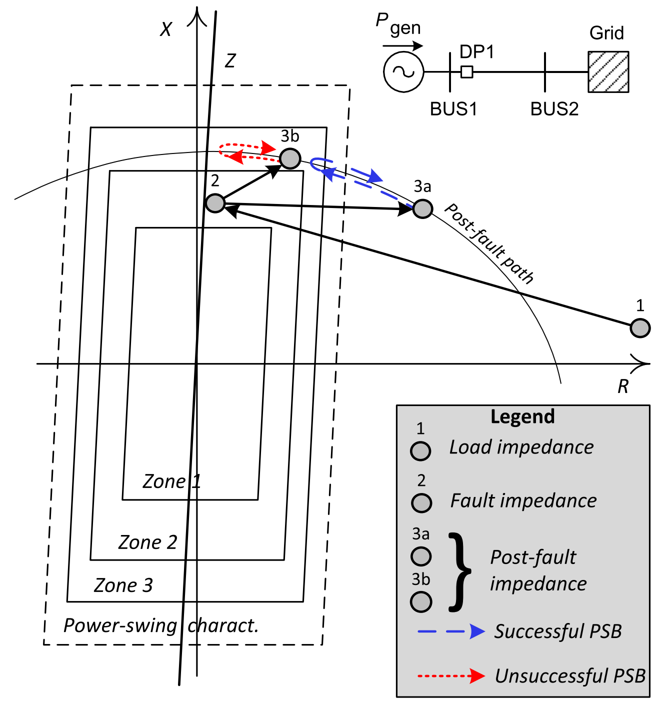


**Fig. 1.** Transitions from load (1) to fault impedance (2) and to post-fault impedances (3a, 3b).

"3b". In this case the unwanted tripping will not occur, consequently there is no need for a consideration of these relays in the proposed method. However, their application is rare in real EPSs.

Some older-type DP relays without PSB are also present in EPSs. For these relays the impedance immediately after the fault clearing is not an important figure, because a power-swing characteristic as an additional outer zone does not exist. Only the dwell time of the post-fault trajectory inside the protection zones is relevant for the unwanted tripping.

Normally, an assessment of unwanted tripping is performed by repeating the numerical simulations for various fault-clearing times. This might be time consuming and has limited potential for on-line implementation. The method proposed avoids this hurdle and, consequently, this method has the potential for applications in on-line dynamic protection security assessment. Of course, time-domain numerical simulations cannot be avoided when accurate analyses are required, like in the testing of power-swing blocking functions [14].

## 3. Direct method for a transient stability assessment based on a Lyapunov energy function

In the presented work the behavior of the DP is incorporated into the direct method for the transient stability assessment. The latter is based on the well-known Lyapunov energy function, which is described in [15,16], and applied for various dynamic analyses of EPSs, e.g., [9,10,17]. For the readers' convenience the basics of the direct method are briefly described in this section.

### 3.1. Structure of the Lyapunov energy function

In [15], the Lyapunov energy function $V_t$ is constructed on the structure-preserving frame and is defined as the sum of the so-called "kinetic energy" and "potential energy":

$$V_t = V_k + V_p + K \qquad (1)$$