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Transmission line protection systems with aided communication channels—Part II: Comparative performance analysis

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ABSTRACT

Following the Part I paper, a comparative performance analysis is presented, considering four different transmission line protection schemes, equipped with aided communication channels. In the Part I paper, the performance analysis methodology was presented, which is based on a probabilistic approach to protection system successful operation. The system performance takes in account equipment reliability factors such as failure rate and time to repair, and is assessed by the availability index. In the present paper, new performance indicators are introduced, which are applicable to transmission line protection system design, as well as to describe its probabilistic operation in other power system studies.

Four different transmission line protection schemes with aided communication channels, operating in today's transmission networks, are compared. The results obtained for the performance indicators allow quantifying the benefits of the different design options. In particular, the effect of relay and communication channel redundancy, as well as communication channel sharing, is highlighted.

Furthermore, results show that the newly defined performance indicators can be used in a cost/benefit analysis, as well as to assess maintenance strategies and communication reliability requirements.

1. Introduction

A performance analysis methodology for transmission line primary protection systems was presented in the Part I paper [1], this methodology is based on a probabilistic approach to protection system successful operation.

A transmission line primary protection system [2] encompasses the communication infrastructure used in teleprotection schemes, further to the infrastructure installed in the substation bay, such as protection relays, measurement transformers, and circuit breakers [3]. The adoption of the IEC61850 by most manufacturers and utilities opens new possibilities, especially regarding the intra-substation signaling by means of GOOSE and Sample Value messaging, as referred in the Technical Report [4].

Utilities frequently face the need to assess their protection practices due to technology improvements, cost justifications or organizational changes. Such assessment includes a comparative analyzes for ranking according to predefined merit factors. The analysis may focus on algorithm comparison between protections from different vendors, by analyzing possible relay mal-functions (fail to trip or mal-trip) under special system conditions [5,6], or on the protection scheme reliability, by including component failure and consequences [7–9]. The present paper addresses the latest.

Nowadays, a mix of different transmission line protection schemes is found in operation in most utilities. This is a consequence of protection philosophy, technology, and requirements having gone through a constant evolution throughout the past decades. Some of the oldest line protection systems still in service are from the 1970s. By then, the duplication of distance protection relays was not a common practice, and local overcurrent backup relays were installed instead. However, a single communication channel used by a teleprotection scheme was already common. Duplication of distance protection was only common practice – mainly on higher voltage levels, 400 kV and above – whenever fault clearance time was a very critical requirement. Later on, during the 1980s, that duplication principle was adopted at lower voltage levels, mainly due to quality of service concerns, and also because of cost reduction obtained by static technology. Usually, the duplication of distance protection was not followed by the duplication of communication channels. Since the 1990s, the duplication of both distance relays and communication channels has been the common standard.

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As regards the communication infrastructure, utilities have adopted different approaches. Some operate their own communication infrastructure, which is designed according to internally specified reliability levels. Others rent communication channels to external companies, reliability levels being specified in the so-called Service Level Agreement contracts [10,11]. In any case, a communication channel is an expensive part of the entire line protection system. Therefore, its duplication has always been decided with extra care.

Considering the different schemes adopted to perform a transmission line primary protection, an increasing complexity, defined by the number of involved elements and connections, does not necessarily lead to a performance improvement [12].

The methodology presented in the Part I paper is applied to four protection schemes with aided communication channels, in order to assess their performance. The comparative analysis of the different schemes can be used for transmission line primary protection system design, and also allows to establish maintenance policies and to specify communication service levels. The four chosen transmission line schemes were picked from currently co-existing systems, in order to have a reference regarding protection system performance. This work is intended to establish a framework for the design of future transmission line primary protection systems.

2. Analysis of line protection systems with aided communication channels

The analysis of line protection systems with aided communication channels is carried out by using the methodology previously presented in Part I paper. This methodology is based on a probabilistic approach to protection system successful operation, by means of Monte Carlo simulation.

This approach corresponds to simulating the operation of a large number of systems during a long time span, which is divided into one-hour-duration time intervals (trials). The simulation starts with all units in operation and, as the simulation evolves, the states of the units change, according to their fail/repair rates. The system success at the end of each trial is determined by the fulfilment of at least one of the system tie-sets.

At the end of each Monte Carlo simulation, the system probability of success is computed from the results obtained for all the corresponding trials. The Monte Carlo simulation considers a time span equivalent to 12 000 h of operation, and the simulation is repeated for $N = 300$ times, from which the mean, E, and the 95% and 99.7% confidence intervals are computed, thus characterizing the system successful operation.

Because the system performance is dependent on fault location, the overall Monte Carlo simulation is carried out for a significant number of locations along the transmission line. Due to symmetry, only the first half of the line is considered.

The methodology is applied to four schemes, Scheme 1 being the simplest scheme, with the lowest number of components and connections, and Scheme 4 the most complex scheme, with the highest number of components and connections.

2.1. Scheme 1: Single distance protection with single aided communication channel

A basic transmission line protection system, consisting of one distance protection at each line end, and a single aided communication channel, is presented in Fig. 1. The following elements/functions are identified:

a. X_1—zone 1 distance protection function;
b. M—protection relay;
c. CT and VT—measurement transformers;
d. CB—circuit breaker;
e. DCPS—auxiliary power supply;
f. comm.–communication system;
g. OF—communication link.

The probability of success of this scheme was evaluated in the Part I paper, considering the reliability data presented in Table 1.

This protection scheme corresponds to a pure chain topology in which, for the successful operation of the system, all elements need to function properly. For its availability analysis, several reliability graphs are considered, each one corresponding to a single operation mode.

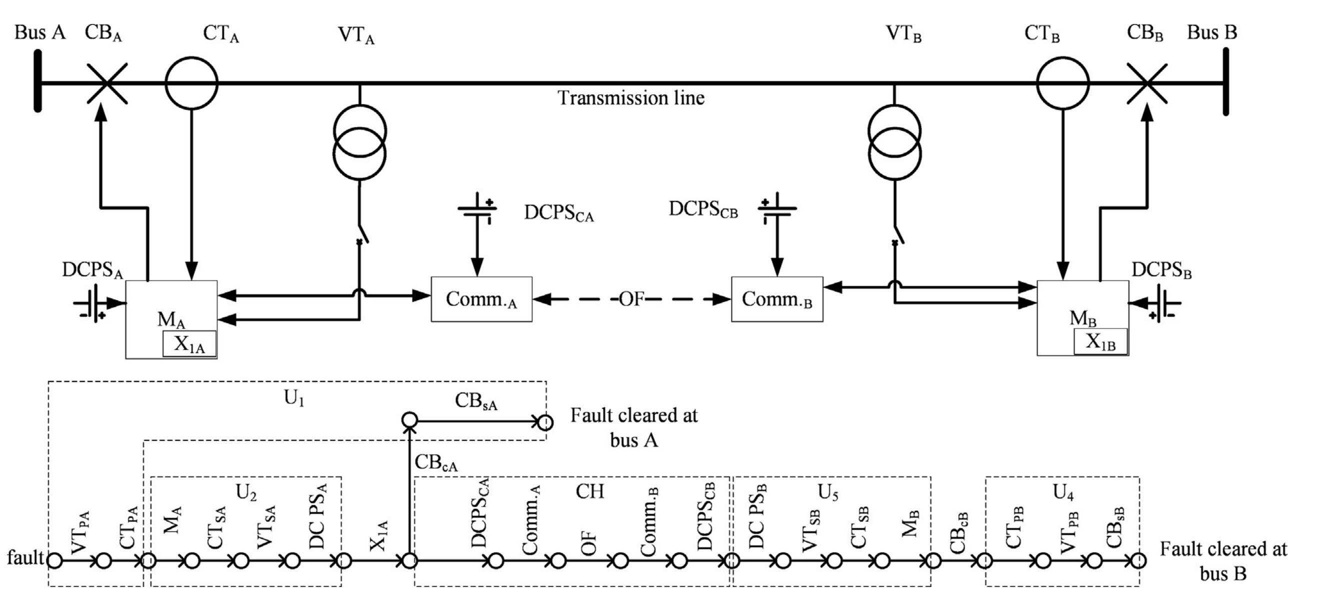

Fig. 1. Single distance protection with single aided communication channel—reliability and reliability graphs of the fault clearance process triggered by the Bus A distance protection (tie-setT_2).