Probabilistic assessment of the short-circuit duration on the 220 kV transmission line basing on simulation analysis

Ryszard Frąckowiak
Poznań University of Technology
60-965 Poznań, ul. Piotrowo 3a, e-mail: ryszard.frackowiak@put.poznan.pl

Piotr Piechocki
Polskie Sieci Elektroenergetyczne –Zachód S.A.
60-354 Poznań, ul. Marcelińska 71, e-mail: piotr.piechocki@pse-operator.pl

In the paper, the problem of defining the short circuit duration time for the short-circuit effect calculations, especially thermal and electromagnetic ones, has been discussed. In author's opinion, the results of probabilistic research could be helpful when resolving the problem. Therefore, a tailored simulation model based on the analysis of the protections and circuit breakers operation during the transmission lines fault clearance has been developed. Due to the results of simulation study, the found values of the fault duration time could be related to the expected risk of their exceeding depending on both the protection system configuration and the type of the circuit breakers applied.

1. Introduction

The fault conditions are defined basing on the knowledge on the short-circuit current's waveform and characteristic parameters. In general, the parameters are random [1]. For practical reasons, the short-circuit magnitudes are found using the deterministic techniques with a series of simplifications. One of the significant parameters affecting the thermal and dynamic effects in the electric power substations is the short-circuit duration. When incorrect short-circuit duration times are assumed in the practical calculations, the economic loss can result from the over-sizing or damage to the devices. In the paper, the developed simulation model for the duration time of the transmission line short-circuit is presented along with the examples of results of the probabilistic analysis of this parameter.

2. Simulation model development

2.1. Concept of the model

The short circuit duration time for finding the short-circuit effects is computed referring to the knowledge on the operation time of the EAZ system as well as the operation time of the circuit breakers clearing the disturbances in the grid. The following relationship has been used to find the short circuit duration time value:

$$T_k = t_{zz} + t_{zw} \qquad (1)$$

where: T_k – short circuit duration time, t_{zz} – the protection's operation time measured between the moment the short circuit occurs and the moment the „open" pulse appears at the protection's output, t_{zw} – the circuit-breaker operation time measured between the time the „open" pulse is received and the short-circuit current is broken.

The general rule of finding the T_k value according to the formula (1) using the Monte Carlo simulation technique has been presented in Fig. 1 in the form of consecutive simulation steps.

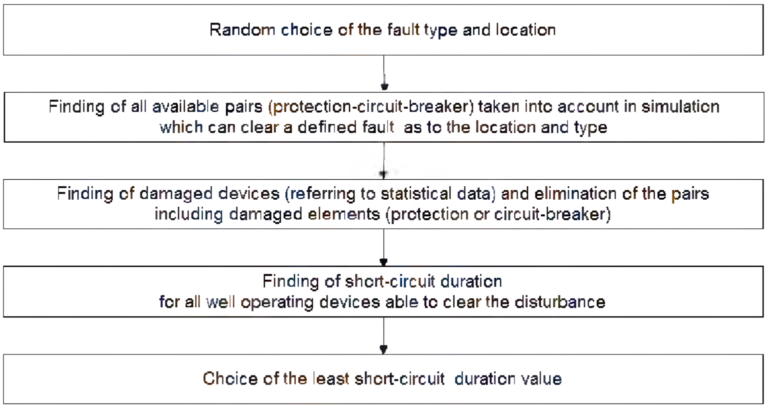

Fig. 1. Steps of finding the short-circuit duration time using simulation

For a randomly indicated short-circuit location (for instance, a point in the electric power line) and a short-circuit type, all pairs of devices (protection - circuit-breaker) able to clear the flow of the short-circuit current are to be defined. Then, the damaged devices are chosen on the random basis and the pairs in which at least one element (protection or circuit-breaker) is damaged are eliminated. If a circuit- breaker in the bay of the considered substation is damaged, the efficiency of the circuit-breaker back-up system (called LRW system) is being determined. For all protection – circuit-breaker pairs with both devices working, the protection and circuit-breaker operation time is found using an adequate probability distributions; then, the possible values of the short-circuit duration are derived. Finally, the least value from the set of the derived time values is decided to be the short-circuit duration.

2.2. Layout and initial assumptions

Detailed requirements concerning the protections installed in the HV and LV substation's bays as well as the power automatic equipment are given by *Instrukcja Ruchu i Eksploatacji Sieci Przesyłowej (IRiESP)* [2].

The layout of the system section containing the considered 220 kV substation is shown in Fig. 2; the protections and circuit-breakers involved into the clearance of faults in the line AB as well as the examples of the reach of the time zones of the considered protections in other locations (for a distance protection in the C station and for the continuity-bond protection) have been marked.

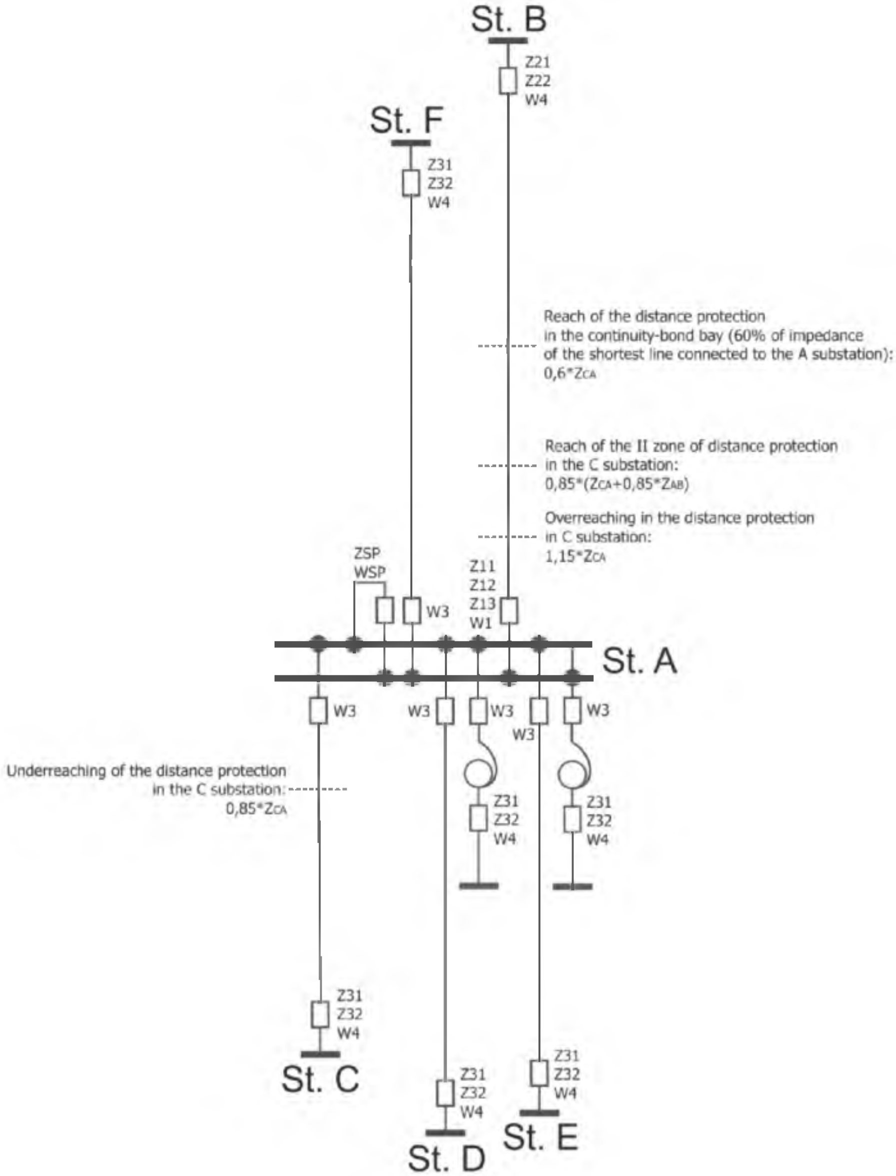

Fig. 2. Layout of the 220kV grid section under consideration

To construct a model of the short-circuit duration, some initial assumptions have been introduced:

- the protections within the considered bay of the AB (Z11, Z12, Z13), protections in the bay at the opposite end of the line (Z21, Z22) and on the opposite ends of the branches connected to the considered 220kV substation (in the adjacent substations) are taken intio account;
- bays of the line under consideration are assumed to be equipped with two distance protections and one overcurrent earth-fault protection, with no unit protection;
- simultaneous operation of the distance protections on individual lines is assumed i.e. they can be operating individually on each line);
- the automatic reclosing equipment on lines is considered (it can be switched on individually for each line);
- protection in the continuity bond's bay is taken into account;
- the LRW system is taken into account.

The LRW system unreliability is not considered whilst the unreliability of circuit-breakers excited by this suystem is taken into account. According to the observations, the DLF, SB6 and ONI circuit breakers are installed in the considered 220kV grid.

2.3. General computation algorithm and program

General algorithm for finding the duration of the short-circuit on the AB line is shown in Fig. 3.

According to the applied rule of the simulation computations (Fig.1). in the first simulation step all the protection-circuit breaker pairs that can be involved into the clearance of the faults on the line under consideration are found; then, the operation time zones of the protections appropriate to the location where the disturbance occurs are assigned to them. Detailed description of the algorithm for finding the time settings of all protections under consideration, according to the assumed rules, have been described in [3].

Referring to the presented algorithm, a computer program has been developed to map how the bays of the considered substations can be provided with the appropriate protections. For each operation zone of the distance protection, a time setting is chosen. The protections' operation times for each defined time setting are mapped using the logarithmic-normal, normal or exponential distribution [4].

In addition, each line can be configurated in the way that both the automatic reclosing equipment's operation and the correlated (duplicated) operation f protection are taken into account. With the program, modelling of the continuity-bond's operation as well as operation of the protection related to the latter can be carried out including the choice of settings as well as operation of the circuit-breaker back-up.

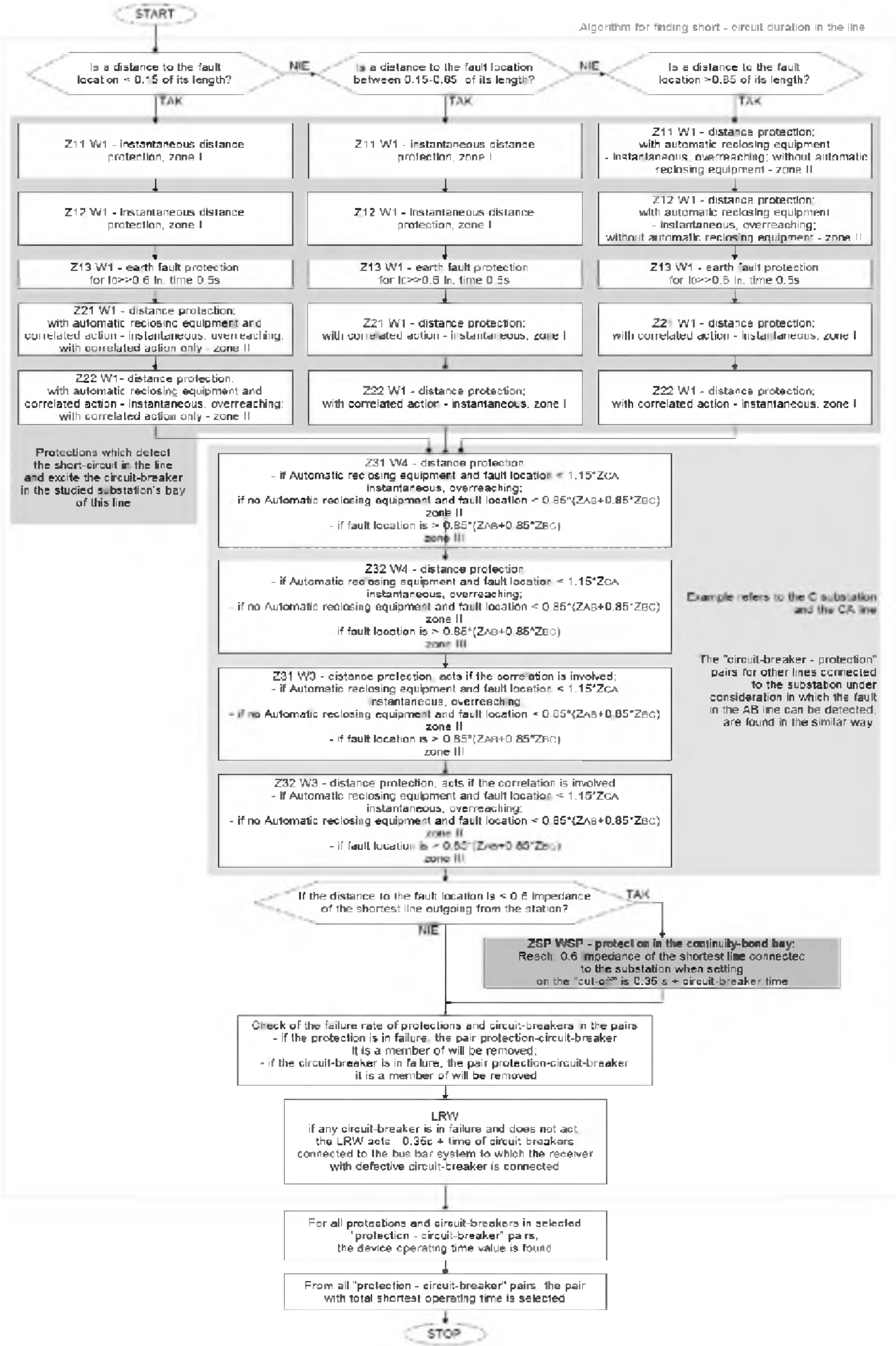

Fig. 3. General algorithm for finding the duration time of the short-circuit on the line

3. Simulation results

The short-circuit duration distributions on the AB line have been found for four chosen EAZ configurations in the 220kV substation (Fig.2) described in Table 1.

Table 1. Specific features taken into account during the EAZ configuration studies

	Configuration 1	Configuration 2	Configuration 3	Configuration 4
Circuit-breaker back-up system	yes	no	yes	no
Automatic reclosing equipment	yes	yes	no	no
Correlated (duplicated) operation of protections	yes	yes	no	no

In the study, data on the fault-related disturbance statistics presented in [3] has been used. In addition, the assumptions as below have been introduced:

- protections in the considered substation's bays as well as those om the opposite ends are the LZ-32 distance protections,
- protection in the bus bar coupling bay is the LH1 distance protection, the bus bar coupling bay switched on,
- in all bays the DLF circuit-breakers are used
- the faults were simulated in the AB line whilst the probabilistic analysis of the fault duration has been carried out in the location where the W1 circuit-breaker in the bay of the line under consideration has been installed.

In Fig. 4, an annual frequency of exceeding of the particular values of the short-circuit duration is shown for four different EAZ configurations. The substation's bay are assumed to be equipped with the DLF circuit breakers with a logarithmic-normal operation time distribution [5], and their unreliability is 0.03. The results indicate that majority of faults in the 220 kV line under consideration will be interrupted either with the operating time of the under-reaching of the distance protection or with the time of the overreaching. If the automatic reclosing equipment and the correlated (duplicated) operation of protections are missing, the probability of occurrence of the fault duration related to both the circuit-breaker back-up and the distance protections in the second zone are increasing.

In Table 2, time values for each of the four EAZ configurations are compared at defined R_{az}, risk levels.

For risk of 10^{-1} 1/a we can see that the value T_k is strongly related to the line equipment, i.e. well operating automatic reclosing equipment and correlated/duplicated operation of the distance protections. For configurations 3 and 4, an important percentage of faults is cleared by W1 circuit-breaker with operating time of the II zone of the distance protection.

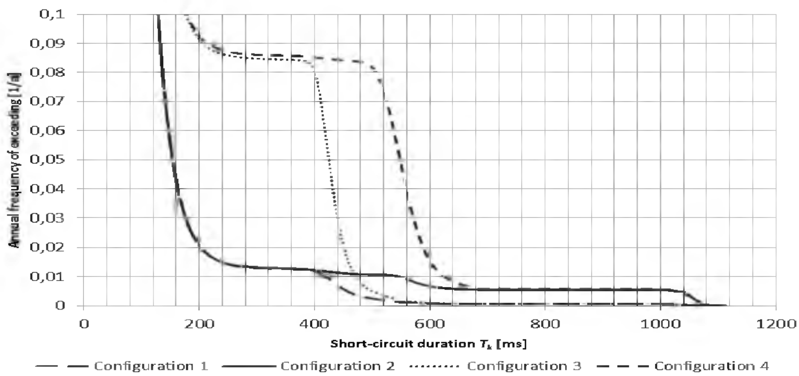

Fig. 4. Annual frequency of exceeding of the particular values of the short-circuit duration for four different EAZ configurations

Table 2. Short-circuit duration for chosen exceeding risk levels for EAZ configurations under consideration EAZ

R_{az}, 1/a	T_k, ms			
	Configuration 1	Configuration 2	Configuration 3	Configuration 4
10^{-1}	128	128	177	178
10^{-2}	418	543	470	625
10^{-3}	565	1070	590	1072

Probability of occurrence of highest fault duration values is strongly limited by the circuit-breaker back-up system (LRW system). For configurations 1 and 3, the risk of exceeding 500 ms is lower than 10^{-2} 1/a, and the risk of exceeding 600 ms is lower than 10^{-3} 1/a. For configurations without LRW system, when the W1 circuit-breaker is in failure, the disturbances in the line are detected by the protections in adjacent substations that operate with settings of the second or even third zone of the distance protection.

Short-circuit duration distribution is evidently affected by the circuit-breakers' unreliability. For illustration, if the circuit-breakers unreliability index q_w is assumed to be 0.02, the short-circuit duration for configuration 1 and 2 is 250 ms at the exceeding risk of 10^{-2} (Table 3). The analysis results are also strongly affected by the true circuit-breaker's operating time (specified by an adequate theoretical distribution). Simulations carried out for the SB6 circuit-breaker have shown that, for configurations 1 and 2, the time 100ms corresponds to the risk 10^{-1} 1/a whilst a time of 150 ms corresponds to the risk 10^{-2} 1/a (for q_w of the circuit-breaker equal to 0.02).

Table 3. Short-circuit duration values at chosen exceeding risk levels for different circuit-breaker's features (1 and 2 EAZ configuration)

R_{az}, 1/a	T_k, ms					
	DLF, q_w = 0,03		DLF, q_w = 0,02		SB6, q_w = 0,02	
	Conf.1	Conf.2	Conf.1	Conf.2	Conf.1	Conf.2
10^{-1}	128	128	127	127	101	101
10^{-2}	418	543	250	250	154	154
10^{-3}	565	1070	515	1065	459	1055

4. Conclusions

It is expected that the works undertaken by the authors and aiming to develop the simulation model and to carry out the probabilistic analyses will contribute to construct indications supporting the choice of the short-circuit duration helpful when finding the effects of the fault current flow in the electric power substations.

The short-circuit duration model developed for faults on the line as well as the examples of simulation analyses confirm that the model is useful in the probabilistic assessment of the short-circuit duration for defined configurations of the substations and EAZ.

In further works, the extension of the short-circuit duration model for the disturbances on other grid elements as well as the preparation of assessment of the fault current flow effects using the developed models are planned.

References

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