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Short Communication

Effect of an additional large disturbance during power swings on the impedance seen by the out-of-step blocking function

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A R T I C L E I N F O

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A B S T R A C T

This short article analyzes the effect of an additional large disturbance during power swings on the apparent impedances seen by the out-of-step blocking function of a distance relay. An additional large disturbance during power swings can imply a sudden change of the apparent impedance, which should be considered for the setting of out-of-step functions. The goal of this article is to describe this phenomenon, which has not been previously shown in the literature. A Venezuelan case is taken as an example, and the analyzed additional large disturbance is due to the operation of a special protective scheme for the islanding of one specific area. Maximization of the region between concentric characteristics and minimization of correspondent setting time can be useful actions to improve the expected behavior of out-of-step blocking functions. However, these actions are insufficient for the analyzed example, and two non-traditional solutions were proposed. In general, as these additional large disturbances could fortuitously occur when the apparent impedance is near of the trip region, the logical proper solution should be provided by future improvements of the algorithms from relay manufacturers.

1. Introduction

The detection of speed of changes in apparent impedances seen by distance functions during power swings is usually applied for out-of-step blocking of distance functions [1,2]. There are also other detecting options which have been described in the engineering literature [3,4]. This subject has been analyzed from the perspective of protective relaying (e.g., [1]) and from the perspective of power system analysis (e.g., [2]). In 2005, the IEEE Power System Relaying Committee of the IEEE Power Engineering Society published a clear report [3] which describes the effect of power swings on distance functions as well as the available options for the out-of-step blocking of distance functions. The basic literature on this subject is abundant, and the review of the aforementioned Refs. [1–4] could be very helpful for those readers which have no previous knowledge about this topic.

Research articles related to out-of-step blocking of distance functions are also abundant. For example, some relatively recent articles have been led to the proposal of different methods for detecting the out-of-step condition [5–15], to the detection of faults during power swings [16–25], to the blocking of zone-3 distance functions [26–28], or to the analysis of power system and protective relays under power swings [29–31]. Some of the proposed methods for detecting the out-of-step condition have been based on the use of synchrophasors [5–7], data mining [8], discrimination index based on Taylor Series [9], analysis of locus of admittance trajectory [10], analysis of swing locus in the R-X plane [11], analysis of electrical center of the system [12], the use of superimposed quantities [13], or continuous impedance monitoring [14,15]. On the other hand, some of the proposed methods to detect symmetrical faults during power swings have been based on the use of wavelets [16–19], support vector machines [20], the analysis of changes in computed values of apparent resistances and reactances [21], analysis of mathematical morphology [22], combination of S-transform and probabilistic neural network [23], extracting components of the current waveform using Prony method [24], or the use of superimposed measurements [25]. Some of the proposed methods for blocking the zone-3 of distance functions have been based on the use of superimposed quantities [26], the relative speed of a theoretical equivalent machine [27], or the selection of relays to be blocked using a deterministic–probabilistic approach [28]. Some of recent interesting analysis of power system and protective relays under power swings have been related to the verification of five conjectures related to power system controlled separation during power swings [29], an engineering study for setting the out-of-step blocking function in the Uruguayan electric power system [30], and the study of the behavior of the signals of distance relays during power swings (including the memory-polarized distance functions) [31].

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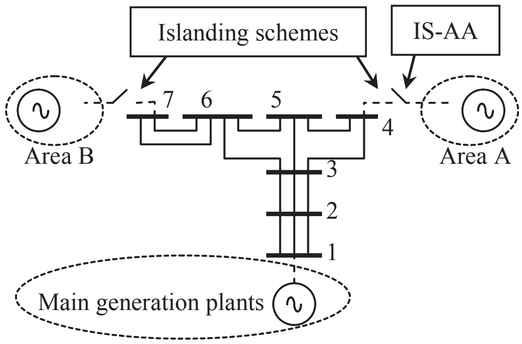

Fig. 1. Simplified scheme of Venezuelan 765 kV transmission system.

In general, the literature [1–31] tends to analyze the power swings considering that the transmission grid does not have any other large disturbance (different than a fault) during the power swing. However, other large disturbances (e.g., important generation outages) can occur during the dynamics of a previous large disturbance [32–35]. A new large disturbance during a power swing can imply a sudden change of the apparent impedance when it is reaching the vicinity of the trip region. Therefore, blocking functions could be ineffective because these changes of apparent impedance are not slow. The goal of this short article is to describe this phenomenon, which has not been previously shown in the literature. A Venezuelan case is taken as an example because this condition was detected during a study for setting the out-of-step blocking functions.

2. Power system taken as an example

2.1. Brief description of the power system

A simplified single line diagram to describe the 765 kV transmission system of Venezuelan national grid is shown in Fig. 1. Main generation plants are near to busbar 1. Areas A and B have special protective schemes for islanding them under some specific circumstances. These areas have enough generation to survive to a large disturbance by supplying their own demands with some local automatic load shedding. Almost all the buses shown in Fig. 1 are also interconnected by other voltage levels (mainly at 400 kV), which are not shown in Fig. 1. The exception is bus 2 because it corresponds to a substation which is only for switching purposes (i.e., there is no switchyard at other voltage level at the physical location of bus 2).

All the dynamic simulations of the study for setting the out-of-step blocking functions were performed with a commercial software [36], where the Venezuelan power system is modeled by using 2510 nodes. Almost all the load is modeled as 60% of constant power and 40% of constant impedance (the exceptions are in some areas whose load models are dynamic nonlinear models). Three demand scenarios were analyzed (high, medium and low levels of load) in the study for setting the out-of-step blocking functions. The maximum load in the high-demand scenario is 18,437 MW.

A simple fault in a line of this system, cleared in zone-1 time (67 ms), does not cause a power swing which could be relevant for the out-of-step blocking functions. However, when a 765 kV line is out-of-service, a fault in other 765 kV line could cause an important power swing even though the fault is cleared in zone-1 time. In general, these and other power swings were analyzed in order to properly set the out-of-step blocking functions.

2.2. Scenario of interest for the purpose of this article

Obviously, many dynamic simulations under diverse scenarios were performed for the study for setting the out-of-step blocking functions. However, only one scenario is interesting for the purpose of this article.

The scenario of interest for the purpose of this article has the following main characteristics: (a) the total demand is 16,590 MW, which corresponds to the medium level of load; (b) the main generation area is exporting 7925 MW, by the 765 kV system and by interconnections at other voltage levels which are not shown in Fig. 1; c) line 3–4 or line 3–5 is out-of-service due to maintenance needs. Summarized data of 765 kV transmission lines and generation conditions for this scenario are shown in Appendix A.

Only if line 3–4 or line 3–5 is out-of-service, and a fault in the other of these lines (i.e., line 3–5 or line 3–4, respectively) is cleared in 67 ms, the islanding scheme of Area A (IS-AA) coincidentally trips just when the apparent impedances for relays of line 5–6 are near of the out-of-step characteristics, as shown in Section 3.2. These are the cases of interest for this article. For the sake of brevity, only cases when line 3–4 is out-of-service are shown in Section 3.

2.3. Brief description of relay functions

Analyzed relays [37] have different options for protective functions. Distance functions have quadrilateral characteristics for the analyzed case. Analyzed out-of-step blocking functions are concentric characteristics in the R-X plane, and they are almost rectangular (vertical segments in first and third quadrants have the line impedance angle, which is close to 90°). Section 3 shows some graphic examples of these functions. The applied software for dynamic simulations [36] has a model for this relay which was useful to analyze the out-of-step blocking functions. Three distance zones are applied for protecting these 765 kV lines, and their reaches were previously selected by applying the traditional criteria for these cases. Out-of-step blocking function has a setting timer (T_1) for the first power swing and another timer for successive power swings. Both cases were analyzed for setting the out-of-step blocking functions, but only the first power swing is interesting for the purpose of this article. If the time interval (Δt) to cross between the external and internal concentric characteristics is greater than T_1, then the selected distance zones are blocked during a waiting time. Further details about relay functions can be found in the manual of the relay [37].

2.4. Criteria for setting out-of-step blocking functions

Initial criteria for the settings of out-step-blocking functions were: (a) external concentric characteristic should be set lower than 90% of the starting zone of distance functions; (b) internal concentric characteristic should be set greater than 120% of zone-2 characteristic; (c) T_1 = 85 ms. In some cases, analyzed power swings are faster than the out-of-step blocking function by applying these criteria. To solve this problem, the internal concentric characteristic should be set smaller than zone-2 characteristic and T_1 should be set smaller than 85 ms (and greater than 67 ms). Zone-2 time is set to 400 ms, and the apparent impedance does not remain for this long time within this zone during power swings; therefore, the setting of internal concentric characteristic smaller than zone-2 characteristic is feasible.

3. Results from simulations

Graphical results in this short article are shown without considering the trip action of distance functions, in order to see the trajectories of apparent impedances more clearly.

3.1. Apparent impedances without operation of IS-AA

Fig. 2 shows apparent impedances seen at both line ends of line 5–6 for the analyzed case. In this case, the operation of the islanding scheme of area A (IS-AA) was blocked in the simulation, in order to see the system behavior under these conditions. The time intervals (Δt) between the entering to the external and internal concentric