Enhanced Out-of-Step Protection Scheme for the Acre/Rondônia Region of the Brazilian Power Grid

Tatiana Maria T. S. Alves and Kleber M. Silva

***Abstract*—This paper proposes an out-of-step tripping (OST) scheme to the electrical system that interconnects the Brazilian states of Acre and Rondônia. This solution aims to increase the reliability of supply to the loads of these states, which operate seasonally, exporting or importing energy to the National Interconnected System (NIS). The proposed solution allows the identification of the power swing phenomenon and the discrimination of swings according to the direction of the power flow and with actions at points in the system that allow the optimization of the load and generation balance, reducing disturbances footprints. The proposed solution was evaluated by means of electromechanical transient software. In addition, a test system was modeled in a Real-Time Digital Simulator (RTDS) in closed-loop using a Intelligent Electronic Devices (IEDs) installed in the field.**

***Keywords*—Data synchronization, electromagnetic transient, power swing, power system protection, real-time digital simulator.**

I. Introduction

THE Brazilian electrical system is a continental and complexity grid. As a consequence, operational challenges exist due to the diversity of energy sources with seasonal availability, comprising subsystems that operate throughout the year, sometimes as energy exporters and sometimes as energy importers. An example of this operational challenge is the system of the Brazilian states of Acre and Rondônia. This system consists of hydroelectric power plants whose operation depends on the flow of rivers. This grid connects the NIS synchronously through a 230 kV line and asynchronously through a back-to-back system. To explore more economical operating conditions without compromising reliability, this system has a special protection scheme to prevent out-of-step in the 230 kV interconnection and load shedding scheme, which are used to restore the balance between load and generation when this system is isolated under conditions in which the system operates exporting energy.

In the case of multiple contingencies, this system is subject to the phenomenon of power swings, which dynamically causes swings in the rotor angles of the synchronous machines and in the power flows of the transmission lines. These events can be stable, when the system moves to a new operating point, or unstable, leading to loss of synchronism of the power plants in the region with the rest of the NIS.

Currently, the out-of-step tripping (OST) scheme installed in the 230 kV Acre/Rondônia subsystem uses the traditional double blinder algorithm along with the logic of tripping on the way in. In other words, it acts before the loss of synchronism, when the system is operating with less degraded voltage conditions, but this logic is a challenge to avoid operation in the case of stable boundary swings. Concepts and applications of out-of-step protection functions are presented in [1], [2], [3], [4], and difficulties and challenges in the application of dual-blinder algorithms are discussed in [5], [6].

The Dual Blinder algorithm distinguishes the power oscillation phenomenon of a three-phase short circuit by the speed of the impedance measured by the relay, where faster variations characterize short circuits and slower oscillations. Therefore, its application in networks with high penetration of sources connected through inverters is also a challenge, since these network elements influence the dynamics of the system, making it faster [7], [8]. Although this region of the Brazilian electrical system does not have a high penetration of alternative renewable sources connected through inverters, there is an important source of power injection through a back-to-back system, which affects the dynamics of the network.

Some papers [9], [10] indicate that the performance of out-of-step protection contributed to the affecting in different systems around the world. This case was observed in Brazil, in the system on the states of Acre and Rondônia, the disturbance of 22.08.2024, where the loss of generation from the back-to-back system caused a power swing in the region, culminating in the incorrect operation of the OST scheme installed in its 230 kV interconnection. This maloperation isolated the Acre/Rondônia subsystem from the rest of the NIS, culminating in a total blackout of this region.

Therefore, to increase the reliability of the Acre/Rondônia subsystem, this paper proposes an enhanced OST scheme using off-the-shelf IEDs in the 230 kV transmission lines to implement a scheme for identifying the phenomenon of power swings and discriminating between stable and unstable swings, by taking optimized actions and exploring the control resources of the area. The proposed solution allows specific actions to be taken according to the seasonality of the region exporting or importing energy, with opening commands at different locations in the network. Thereby, it allows the optimization of the load and generation balance, besides reducing disturbances footprint. Moreover, the key idea is to use the readily available infrastructure in the field, not requiring additional equipment.

The proposed protection was evaluated through electromechanical transient simulations. Moreover, a system

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was modeled in detail with a faithful representation of the systemic controls, using a Real-Time Digital Simulator (RTDS) for closed-loop testing with the same protection IEDs installed in the field, allowing a complete test of both the settings and logics of the IEDs, and the network performance and stability during islanded operation.

II. Acre/Rondônia Subsystem of the Brazilian Power Grid

The states of Acre and Rondônia are located in the northern region of Brazil, and form a system composed mainly of hydropower plants (HPP), with the main ones in the region being the Samuel HPP (5x43.3 MW), the Santo Antônio 230 kV HPP (6x69.5 MW) and the Rondon II HPP (3x24.5 MW). This system is synchronously connected to the NIS via approximately 1,000 km of 230 kV transmission lines between the Jauru and Samuel substations, with five intermediate substations. The system also has an asynchronous source through a Capacitor Commutated Converter (CCC) Back-to-Back system (2 x 400 MW). Figure 1 shows the Acre/Rondônia system.

III. Power Blackout on August 22, 2024

The disturbance began at 04:47 PM on August 22, 2024, with an unblocking of pole 4 of Bipole 2 of the Rio Madeira High Voltage Direct Current (HVDC) transmission system, which connects the 500 kV Coletora Porto Velho substation, in the north of Brazil, to the 500 kV Araraquara 2 substation, in the southeast region and main load center of the NIS, to which pole 3 is connected. Poles 1 and 2 of Bipole 1 were blocked. Figure 2 shows a schematic diagram of the area affected by the disturbance [11].

Following this unblocking, the 500 kV Rio Madeira HVDC system, which operates asynchronously with the NIS, experienced a sharp drop in frequency, affecting generating units of the Santo Antônio and Jirau H68OST, which was expected due to the need for the plants to supply the new demand requested at the time of this unblocking of Pole 4. The frequency in this system reached the minimum value of 55 Hz, causing the automatic shutdown of the 14 generation units at the Jirau HPP and the 12 generation units the Santo Antônio HPP connected to the 500 kV grid. As a result, the Master Control blocked automatically poles 3 and 4 of Bipole 2 and the back-to-back converters 1 and 2. With the back-to-back off-service, a stable power swing took place in the Acre/Rondônia system, but the OST scheme (68OST) installed at the Ji-Paraná terminal of the 230 kV line between Ji-Paraná and Pimenta Bueno maloperated, causing separation of the Acre/Rondônia subsystem from the rest of the NIS. Figure 3 shows the oscillography from the Ji-Paraná terminal of the 230 kV Ji-Paraná - Pimenta Bueno C3 transmission line.

This diagram shows that the average velocity of the impedance measured by the function was 729 Ω/s, below the setting of 1,680 Ω/s, to distinguish faults and power swings, considering the power swing velocities of the impedance below the setting. This diagram was also used to calculate the angle of opening between the equivalent sources, using the line

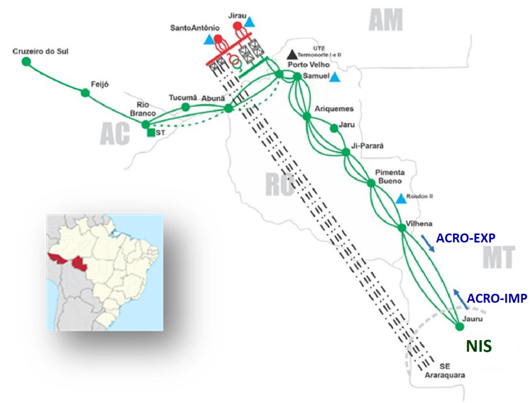

Fig. 1: Acre/Rondônia Subsystem.

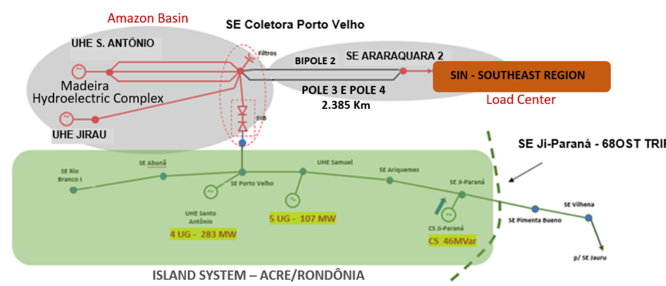

Fig. 2: Disturbance Area.

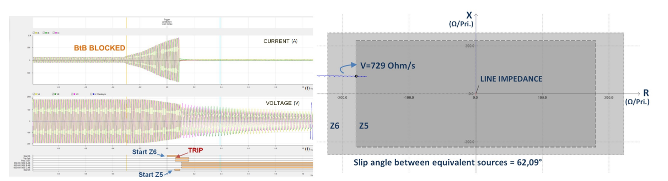

Fig. 3: Oscillography of TL 230 kV Ji-Paraná - Pimenta Bueno C3.

impedance and the impedance of the equivalent sources behind the Ji-Paraná and Pimenta Bueno buses, having obtained a value of 62.09° at the moment of activation of the 68OST function. In the electromechanical simulations carried out after the event, this swing was found to be stable.

As a result, the remaining generation deficit on the island formed by the Acre/Rondônia subsystem led to a drop in its frequency and the activation of the five stages of the load shedding scheme. However, the activation of this scheme was not sufficient to quickly return the frequency to normal operating conditions, which culminated in the shutdown of the five generating units at the Samuel HPP and the Ji-Paraná synchronous compensator due to the activation of their under-frequency protections. Finally, only four generating units of the Santo Antônio HPP connected to the 230 kV system remained on the island until they were shut down by their respective protections.

The shutdown of all generation in the island region led to a blackout in the Acre/Rondônia subsystem, which interrupted 205.3 MW of load in the state of Acre, 620 MW of load in the state of Rondônia.

IV. Existing 68OST Scheme in the Acre/Rondônia Subsystem

The OST scheme applied to the Acre/Rondônia subsystem consists of:

- The use of out-of-step blocking functions (68OSB) in all protections of the 230 kV interconnection lines, capable of blocking the operation of distance zones 2 and higher in the event of a power swing, leaving zone 1 unblocked.
- Application of OST functions (68OST) along with the logic of tipping on the way in at the Ji-Paraná terminal of the three circuits of the 230 kV Ji-Paraná - Pimenta Bueno transmission line, with cross-tripping between them.

The swing detection uses the dual-blinder method, which is based on the principle that the impedance measured by the relay in the R-X diagram moves slowly during power variations, and changes almost instantaneously from the load point to the fault point when short circuits take place. Therefore, to calculate the speed of the impedance in R-X diagram, the IED measures the time Δt that the impedance trajectory takes to travel the distance between the outer blinder and the inner blinder, and compares it with the OSBD (Out-of-Step Block Time Delay) and OSTD (Out-of-Step Trip Delay) timing settings. The implemented settings are shown in Tab. I.

The purpose of applying this OST scheme was to find the best point to identify the phenomenon, because electromechanical simulations revealed that the transmission line with the highest probability of forming the electrical center of the swing was the line 230 kV Ji-Paraná - Pimenta Bueno. The variation of this location is related to the contingency of the origin of the event, since the electrical center location is directly related to the resulting impedance of the network. Nevertheless, simulations have also shown that whenever the Acre/Rondônia subsystem is operating as an importer, there is a risk of poor performance of the applied 68OST function, so that its deactivation has been requested for cases in which the system is operating under this conditions for long periods of time. Therefore, if system goes to instability operating point, the disconnections would occur in an unplanned manner through the distance functions in zone 1, since they are unblocked.

To overcome this drawback, an enhanced 68OST scheme with logic of tipping on the way in has been defined. Basically, whenever the speed condition is reached, the trip is issued immediately after the measured impedance reaches the innermost blinder of the characteristic. However, since not all protection IEDs available in the Acre/Rondônia subsystem had a native logic with this function, a programmed logic was introduced in these IEDs using distance characteristics and associated timers. This logic was chosen in order to promote the opening of the system even if voltages are not degraded.

TABLE I: Settings 68OST - 230 KV Ji-Paraná – Pimenta Bueno Line

Settings		
IN (R/X) Ω	±180	±212
OUT (R/X) Ω	±222	±254
Short circuit and swing discriminator timer (OSTD)	25 ms	
Stable and unstable swing discriminator timer (OSBD)	1 s	

V. The Proposed 68OST Scheme for the Acre/Rondônia Subystem

The proposed solution is based on a more effective strategy to isolate the Acre/Rondônia subsystem in case of unstable power swings, taking different actions if the subsystem is operating as energy importer or exporter. In the case it is operating as an energy exporter, the ideal opening point to optimize the energy balance between load and generation is to include as much load as possible in the island to be formed, in order to avoid high over-frequencies that increase the risk of internal generation disconnections. On the other hand, in the case of Acre/Rondônia subsystem is operating as an importer, the ideal opening point is exactly the opposite, and the minimum inclusion of load in the island formed should be considered, in order to obtain lower under-frequencies, and thereby allowing the system to return to stability with minimum load shedding. The use the trip on the way in logic has also been identified, i.e., before the formation of an electrical center, to avoid local instabilities.

The proposed scheme was implemented using the readily available infrastructure in the field, not requiring neither retrofit of equipment nor additional ones. It was implemented in IEDs at the Vilhena terminal of the 230 kV Pimenta Bueno - Vilhena transmission line, opening the three circuits in the event of instability with the exporting Acre/Rondônia (ACRO-EXP), and in the IEDs of the 230 kV Samuel - Ariquemes transmission line opening its four circuits in the event of instability with the importing Acre/Rondônia (ACRO-IMP). Initially, dual blinder characteristics were used to achieve coordination. These characteristics were designed to be asymmetrical so that, depending on the direction of the power flow through the link, the breaker would only open at the intended point. Figure 4 illustrates the logic of the proposed scheme.

A. Inner Blinders Reactive Settings

The 68OST functions were designed to identify unstable power swings with the formation of electrical centers between

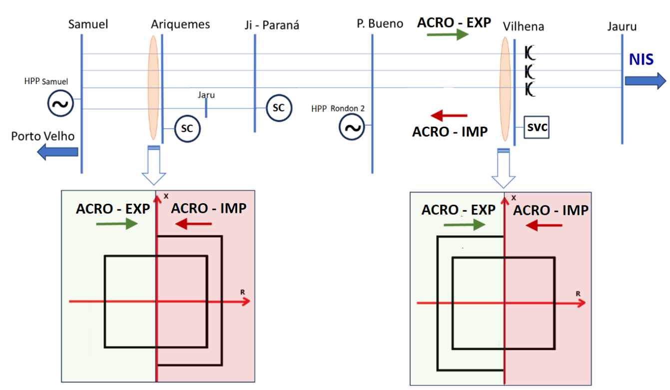

Fig. 4: Logic of proposed scheme.

the Samuel and Jauru substations by means of their reactive ranges. Since the power swing phenomenon is balanced, these reactive range adjustments of the characteristics of the tripping functions were obtained by simulating three-phase faults at the extreme points where it is desired to reach, identifying the impedance measured at the IED installation points.

B. Inner Blinders Resistive Settings

With regard to the resistive blinders, the adjustments of the inner blinders, where the tripping are emitted when using the predictive logic (i.e., the trip on the way in), was initially positioned with the opening criterion of 120° between the equivalent sources. Nevertheless, based on the results, the positioning of the blinds was revised according to the following criteria:

- 68OST – Vilhena terminal - The positioning criterion of 120° between the equivalent sources was used, taking into account the unavailability of one of the three parallel circuits. This is equivalent to 134° between equivalent sources for the whole system. This change in criteria was necessary because the studies revealed that the critical angle of the system is approximately 119°. Therefore, in unstable limit cases, a low impedance velocity was observed between the outer and inner blinders, making it difficult to distinguish between stable and unstable power swings. The positioning the inner blinder after the critical angle of the system, therefore, not only increases the safety of the function by increasing the probability that only unstable power swings reach the blinder, but also facilitates the distinguish between stable and unstable power swings, since the impedance velocity in this region for unstable swings is already positively accelerated.
- 68OST - Ariquemes terminal - In this case, the 120° matching between the equivalent sources took too long to obtain stability of the islands formed and to avoid local instabilities. Since the tendency for the formation of an electrical center of this system is in the section between Ji-Paraná and Pimenta Bueno, when the Ariquemes plant is opened late, it is found that the Ariquemes and Ji-Paraná synchronous compensator and the Rondon HPP, which were coherent with the Acre/Rondônia machines, lose synchronism with the NIS. In this way, the setting was obtained from the simulation, looking for the maximum opening angle for the separation of the system without local instabilities, with the internal blinder defined at 90° between the equivalent sources. Since the impedance of the lines of circuits C1 and C2 are almost double those of circuits C3 and C4, the resistance ranges of the blinders obtained were quite different, even if the same angle between the equivalent sources was taken as a reference.

C. OSTD and OSBD Timers

The OSTD timer is fixed at 25 ms in the IEDs. This setting was used as default. The OSBD timers were set according to the maximum speeds of the impedances measured in the stable limit cases. The following values were obtained:

- 68OST - Vilhena terminal - Adjusted after the simulations to 250 ms (15 cycles), which corresponds to 100 Ω/s in terms of speed.
- 68OST - Ariquemes terminal - Adjusted after simulations to 197 ms (≈12 cycles), corresponding to a speed of 127 Ω/s for circuits C1 and C2 and to 167 ms (≈10 cycles), corresponding to a speed of 150 Ω/s for circuits C3 and C4. Note that the difference in speed between parallel circuits is due to the difference in impedance between the circuits.

D. Outer Blinders Resistive Settings

They were defined from the inner blinder by adding the ΔR necessary to obtain the target speed, taking into account the standard OSTD timer of 25 ms, whose objective is to discriminate short-circuit from power swings. From the simulations, the following speeds were defined:

- 68OST - Vilhena terminal: 1,500 Ω/s for the three circuits.
- 68OST - Ariquemes terminal: 2,000 Ω/s for circuits C1 and C2 and 2,500 Ω/s for circuits C3 and C4.

VI. Electromechanical Transients Simulations

Several electromechanical transients simulations were carried out considering: different dispatch scenarios and number of generating units of the region's hydropower plants; light and heavy load levels; variations in the exchanges scenarios for the supply of the Acre/Rondônia subsystem to the NIS (ACRO-EXP) and the receipt of the Acre/Rondônia subsystem from the NIS (ACRO-IMP); and the amount of power transmitted by the back-to-back at the Coletora Porto velho substation.

Moreover, the variations in the active power flow between the 230 kV Samuel and Ariquemes substations were also evaluated. Currently, there are operational restrictions to prevent the operation of the 68OST function installed at the Ji-Paraná terminal of the 230 kV Ji-Paraná - Pimenta Bueno transmission line, as well as the variations in the active power flow between the 230 kV Ji-Paraná and Pimenta Bueno substations in situations of high back-to-back dispatch (over 500 MW).

A. Results of the ACRO-EXP

A total of 111 cases were simulated for different contingencies on the system, among which 28 were unstable and 83 were stable. The performance of the 68OST functions proposed for the Ariquemes and Vilhena substations was monitored. The 68OST function currently installed in the Ji-Paraná substation was also monitored for comparison. As expected, the 68OST functions proposed for the Vilhena and Ariquemes substations performed correctly in all simulated cases. Only the function installed at Vilhena operated correctly in the unstable cases, opening the system at the point designed for ACRO-EXP. In the stable cases, the 68OST functions of the Vilhena and Ariquemes substations did not work, allowing the system to stabilize at a new operating point. Conversely, the old 68OST currently employed in the Ji-Paraná substation worked in all the unstable cases, but issued a false trip for

45% of the simulated stable cases. The erroneous separation of the Acre/Rondônia subsystem from the NIS worsens the disturbance. Figure 5 shows the summary of the results for stable cases.

For the stable limit cases, it was also checked whether the impedance trajectory reached the set blinders. As a result, no intrusion was detected, which increases the security of 68OST function with the logic trip on the way in (see Figure 6). The behavior of the systems after disconnection during unstable cases was also evaluated, verifying the stabilization of the system at operating points with acceptable frequency and voltage levels. Figure 7 shows the voltages in an unstable case with and without the operation of the 68OST function proposed for Vilhena substation.

B. Results of the ACRO-IMP

A total of 31 cases were simulated for various contingencies in the system, of which 7 were unstable and 24 were stable. As in the ACRO-EXP cases, the 68OST functions proposed for the Vilhena and Ariquemes substations performed correctly in all simulated cases. There were not false trip for stable power swings, and in the unstable cases only the one installed in Ariquemes operated, disconnecting the system as designed. With regard to the old 68OST installed in the Ji-Paraná substation, its operation was also verified in all the unstable cases, but it also operated incorrectly for 21% of the simulated stable cases, aggravating the event and often leading to blackouts in Acre/Rondônia subsystem. For the cases marginally stable, it was also checked whether the impedance trajectory reached the adjusted blinders, and no invasion was detected. Figure 8 shows this result.

In unstable cases and after separation, the areas stabilized with acceptable frequency and voltage levels, avoiding local instabilities with the early opening of the system. It was also found that by opening this part of the network, it was possible to recover the island frequency with the activation of the load shedding scheme, which was not verified when opening in Ji-Paraná. Figures 9 and 10 show the results of this analysis by means of frequency curves.

VII. Simulation on the RTDS

To verify the performance of the 68OST settings in the RTDS environment, an equivalent network of the Acre/Rondônia subsystem was implemented. This network consists of the 230 kV system from the Rio Branco substation to the Jauru substation, a bus where a Thévenin equivalent was implemented, with its parameters calculated from electromechanical simulations, to represent the NIS. In the modeled system, all loads were reflected on the respective 230 kV buses.

For the local generation (Santo Antonio, Samuel and Rondon HPP), a detailed machine model was used with its respective voltage, speed and power stabilization controllers, converted from the electromechanical transient software database to the RSCAD/RTDS data format. For each of these generations, a preliminary validation stage was carried out by comparing the results in RTDS and in electromechanical transient software for machine-infinite bus systems.

The Ji-Paraná and Ariquemes synchronous generators and the Rio Branco and Vilhena static compensators were also included in the equivalent representation with the same level of detail as the generations. The back-to-back replica connecting the Porto Velho 230 kV collector bus to the Porto Velho 500kV bus, installed in the National Electric System Operator (ONS) RTDS simulator, was also included in the representation, thus having a dynamic behavior of the equipment as installed in the field.

A total of five cases were carried out, based on predefined cases, with variations in the number of machines in the

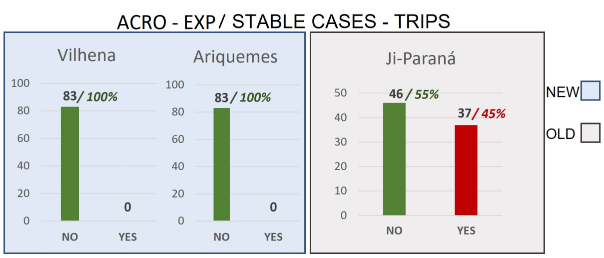

Fig. 5: Results for stable cases - ACRO-EXP.

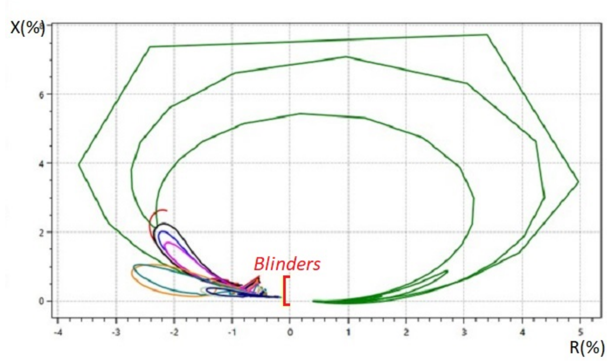

Fig. 6: Verification of the trajectory of stable cases - ACRO-EXP.

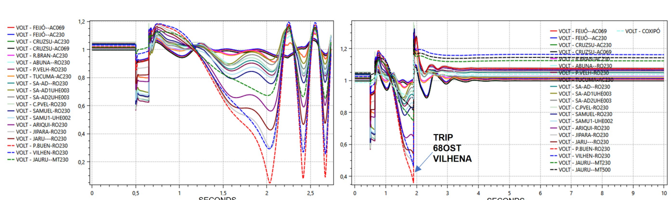

Fig. 7: Performance after trip of 68OST from Vilhena

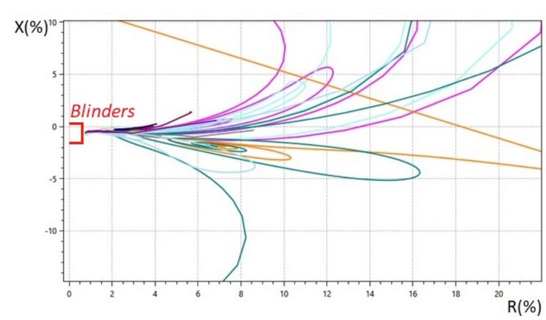

Fig. 8: Verification of the trajectory of stable cases - ACRO-IMP.

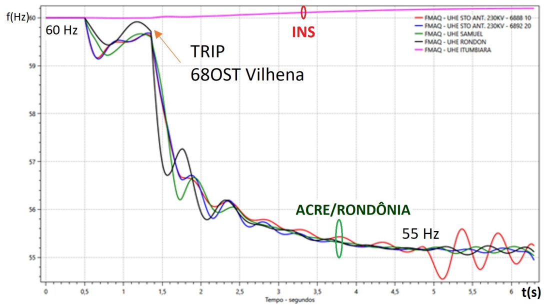

Fig. 9: Preventive opening at the point where there is formation of an electrical center, through the old 68OST of Vilhena.

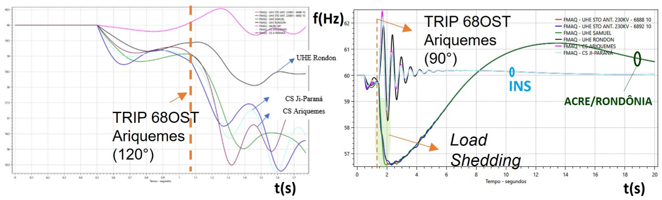

Fig. 10: Ariquemes terminal opening with angular opening between equivalent systems at 120° and 90° (selected setting).

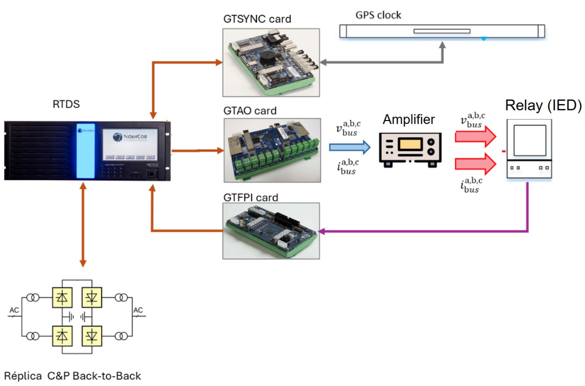

Fig. 11: Flowchart of the system represented in the RTDS.

generations, the load level and the exchange of incoming and outgoing feeders of the Acre/Rondônia subsystem (ACRO-IMP and ACRO-EXP, respectively). In all cases, the simulations were carried out with a simulation step of 50 μs.

A. RTDS Test Bench Setup

To develop the RTDS tests, a bench was implemented, which is schematically represented in Fig. 11. Fig. 12 shows a photograph of the implemented test bench.

Signal amplifiers (2 units, reference Ponovo PA30Bip-H) and IEDs 2 Siemens ref. SIPROTEC 4 (type 7SA612), 2 Siemens ref. SIPROTEC 5 (type 7SA87) and 1 Scheiner type P545, making a total of 5 IEDs. Only two ONS RTDS racks were used in these tests, one to model the equivalent Acre/Rondônia subsystem and another to represent the Porto Velho back-to-back and its integration with the existing control and protection replica at ONS.

Fig. 12: RTDS and IED.

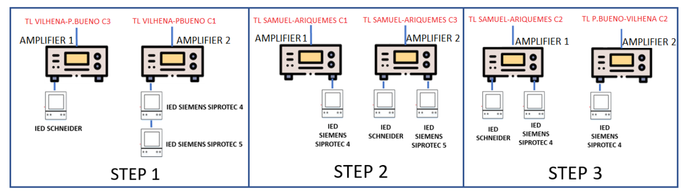

Fig. 13: Testing steps in RTDS.

B. Results of the RTDS

The tests were carried out in three stages, taking advantage of the available infrastructure to represent the configuration closest to that implemented in the field. Figure 13 shows the configuration assembled for the ACRO-EXP, ACRO-IMP and ACRO-EXP/ACRO-IMP tests. Based on the results, the following conclusions and changes were generated and forwarded to a new validation stage through simulations in the electromechanical transient software:

1) Stage 1 - ACRO-EXP: The ACRO-EXP cases were started with the adjustments of the 68OST functions at Vilhena, taking into account:

- Power swing with an impedance velocity between 1,000 and 100 Ω/s and triggering with an opening angle between the equivalent sources of 120°.

In these cases, some rejections of the 68OST of C3 at the Pimenta-Bueno-Vilhena C3 transmission line were verified, due to the verification of unstable power swings at very low speeds. After analysis, it was concluded that the critical angle of the system was close to 119°, therefore in the unstable power swings limits the speed between the blinders, with the internal blinder positioned at 120°, was very low, since the impedance was in a deceleration trend. In these cases it was decided to use the settings with the internal blinder positioned close to 134°.

- Power swing with impedance speed between 1,000 and 100 Ω/s and triggering with opening angle between equivalent sources at 134°.

In these cases, the operation of all 68OST functions installed at Vilhena was verified. However, the speeds observed in the highly unstable cases were literally higher than those verified in the electromechanical transients simulations, the highest being 950 Ω/s measured on the SIPROTEC 4 IEDs. The velocities in the RTDS environment are more accurate due to the microsecond integration steps. In this case, the external blinder of this section was readjusted to increase the maximum swing speed to 1,500 Ω/s.

- Power swing with impedance speed between 1,500 and 100 Ω/s and triggering with opening angle between equivalent sources at 134°.

For this group of settings, all the functions evaluated performed satisfactorily in both unstable and stable cases.

2) Stage 2 - ACRO-IMP: The ACRO-IMP cases were started with the settings of the Ariquemes 68OST functions, taking into account:

- Power swing with an impedance velocity between 2,500 and 197 Ω/s for C1 and C2, and between 2,000 and 150 Ω/s for C3 and C4, and triggering with an opening angle between the equivalent sources of 90°.

These settings performed well in the unstable and stable boundary cases, including the stable cases where parallel circuit contingencies were considered. However, it was observed that at higher impedance speeds, uncoupled opening of parallel circuits, at times in the range of 20 ms, could affect the performance of the dual-blinder logic. This reinforced the need to use cross-tripping between the system terminals to ensure opening.

In the case of more severe ACRO-IMP, it was also observed that the opening of the system in Ariquemes for the times obtained with the adjustments made was not sufficient to avoid local instabilities. In this situation, the tripping blinder of the SIPROTEC 5 IED of C4 of the 230 kV Samuel-Ariquemes transmission line was readjusted to trip at the point corresponding to the outermost characteristic of the Schneider IED of C3, which uses a double blinder. At this point, the angle between the equivalent sources is smaller, allowing, with certainty, since the algorithm proved to be robust in all the situations tested, the successful opening and good performance of the islands formed.

In the other circuits with Schneider IED, the original settings were maintained, since cross-tripping is used, allowing good performance of the 68OST of the section even in the extreme case evaluated. The use of the native SIPROTEC 5 algorithm avoided the need to check the 68OST settings using double blinders, which could reduce the reliability of the calculated settings.

For three-phase short circuits close to the reactive range limits of the 68OST function characteristics, the measured impedance could "enter" above or below these limits and stop between the blinders, affecting their performance. As a solution, the reactive range of the external blinders has been readjusted to avoid operation in this impedance path.

3) Stage 3 - ACRO-IMP and ACRO-EXP: These tests verified the coordination between the sections (Ariquemes and Vilhena), focusing on the SIPROTEC 4 IEDs used in C1 and C2 in Vilhena and in C2 in Ariquemes, whose IED algorithm does not allow the implementation of asymmetric characteristics. Therefore, in order to achieve coordination even in the event of unavailability or rejection in parallel system lines, ACRO-IMP and ACRO-EXP cases were tested using output tripping, i.e. the application of function 78OST in SIPROTEC 4 IEDs (trip on the way out).

In these simulations, correct functions actuation was verified, opening in Vilhena for the ACRO-EXP cases and in Ariquemes for the ACRO-IMP cases. However, the differences in actuation times were too small to guarantee full coordination, between 60 and 28 ms. This analysis led to the decision to leave the 68OST function of the SIPROTEC 4 IED in Ariquemes with the tripping disabled. It also indicated the need to change the 68OST function in the Vilhena terminal, in the SIPROTEC 4 IED, to 78OST, where the tripping occurs in the output of the internal characteristic. These measures will prevent lack of coordination, even in the unavailability cases evaluated. The need to upgrade the SIPROTEC 4 IEDs to the SIPROTEC 5 line was also highlighted, in order to increase the security of the solution, also taking into account the unavailability.

VIII. CONCLUSIONS

This paper introduces a solution based on 68OST functions for the 230 kV lines that connect the states of Acre and Rondônia in Brazil. This solution increases the security of the region's consumers and facilitates greater energy transfers. The proposed protection also stands out for its agility and low implementation costs, as it was designed using local resources and coordinated actions without the use of communication channels.

This paper also highlights the importance of carrying out RTDS tests in addition to the electromagnetic stability studies, since only through this test was possible to evaluate the performance of the joint operation of IED algorithms from different manufacturers, in addition to a more reliable assessment of impedance velocities and the performance of systemic controls applied by replicas.

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