Application of WAMPAC-System in Paraguay's ANDE Power System

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Abstract

This paper presents the application of WAMPAC System in Paraguay's ANDE Power System. The different stages starting from power system studies over testing to commissioning in the field are described. The project had the goal to secure inter-connected operation of ITAIPU hydro power plant and YACYRETA hydro power plant through ANDE's power system.

The already implemented ECCANDE (Esquema de Control ante Contingencias de Ande) WAMPAC system ensures the stability by using PMU measurements from critical circuits and substations as well as the status of various circuit breakers. Different criteria like voltage angle differences and active power flows are used to initiate corrective actions like system separation and load-shedding. A pair of redundant Phasor Data Concentrators (PDCs) from SIEMENS (SIGUARD PDP) is in service to observe the measurements and to decide which actions are required.

Within this paper the authors will share the learnings and experiences during the whole process of implementing such a complex WAMPAC system.

1 Motivation

Higher demand of power supply and power system stability requirements are steadily imposing innovative solutions based on Wide Area Monitoring equipment such as PMUs, since traditional operation systems might not react properly on critical contingencies in the power system. Therefore, the monitoring system is extended with protection and control capabilities, resulting in a Wide Area Monitoring, Protection, Automation and Control system (WAMPAC) [1], [2], [3].

The goal of such a system is to secure and observe operation in normal conditions, and in case of contingencies which could bring the network to the brink of instability, the WAMPAC system automatically initiates actions on the grid. These actions can range from controlling generators, opening interconnectors to load shedding [1], [2], [4], [5].

ANDE, the state-owned electricity utility from Paraguay, in partnership with ITAIPU BINACIONAL (ITAIPU), and ENTIDAD BINACIONAL YACYRETA (EBY) designed such a WAMPAC system (Esquema de Control ante Contingencias de Ande = ECCANDE), to ensure a secure and reliable interconnection between ITAIPU hydro power plant (to Brazil) and YACYRETA hydro power plant (to Argentina) through ANDE's power system. The interconnection is realized via 500kV and 220kV transmission lines, tying together two subsystems which operated separately until now. The WAMPAC system was developed, tested, and commissioned together with SIEMENS.

2 ECCANDE WAMPAC System

Upon the detection of a severe contingency in the system, the ECCANDE system performs basically two main actions: it splits back the two subsystems, and it activates a set of undervoltage and underfrequency load shedding schemes. This WAMPAC-system was designed to act with 4 logics to internal contingencies associated to transmission line openings within ANDE's power system, 3 logics for external contingencies, associated to voltage angle differences and active power flows in the system and a direct transfer trip (from ITAIPU). Each contingency lead to a different reaction in the power system, depending on the topology and the magnitudes, the ECCANDE will actuate. The ECCANDE system is very complex because various PMUs are used to monitor the condition of the system. In sum 16 substations are involved in the 220kV and 500kV system.

The following Figure 1 shows the simplified power system which was used to investigate the dynamic system behavior in case of interconnection and islanding conditions. The interconnection is done in the 500kV level in substation Villa Hayes (VHA) and in 220kV level in substation Guarambaré (GUA). The hydro power plant in Itaipu has 14 GW of installed power one part is 60Hz directly feeding to the Brazilian grid and the other part is 50Hz directly feeding to the ANDE power system. Between both parts a HVDC coupling is installed. The Yacyretá hydro power plant has a power of 3 GW.

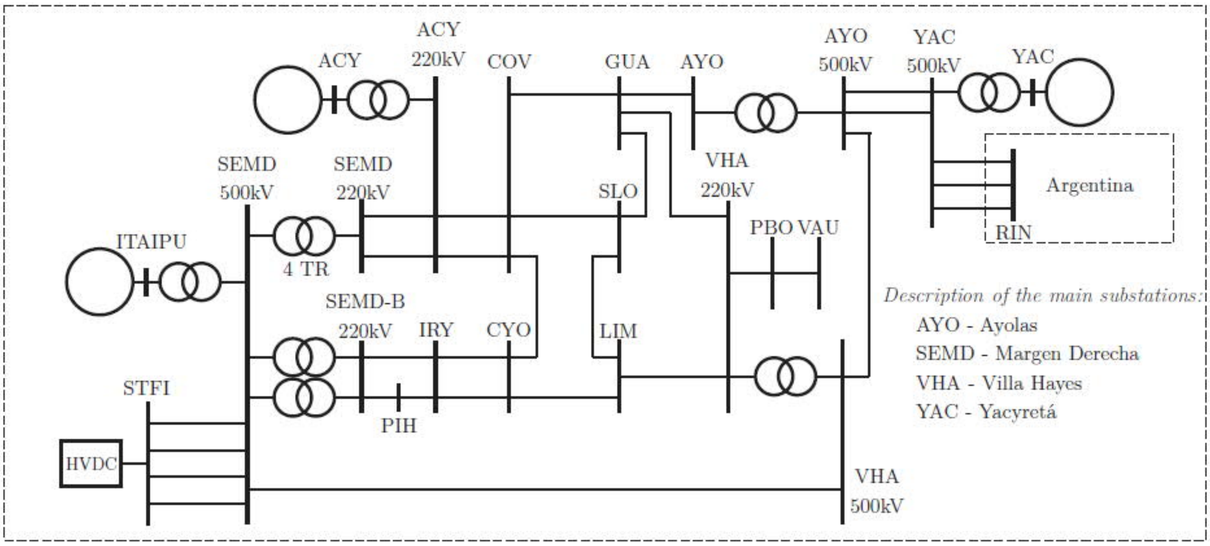

Fig. 1 – Simplified Power System Single-Line-Diagram

Based on a broad analysis of the power system with various load flow scenarios and dynamic simulations, logics were developed which ensure a secure power supply for ANDE's power system in case of these contingencies. The logics have different input parameters which range from circuit breaker positions to phasor data and active power metering. The logics monitor the system configuration and decide whether the ECCANDE system is armed or not. The decision to trip the ECCANDE is based on the detection of the outage of some critical 500kV and 220kV lines and on the voltage angle difference between strategic busbars of ITAIPU plant and near YACYRETA plant, reflecting the current interconnection between ITAIPU, YACYRETA and ANDE.

Depending on the pre-event load flow scenario and/or blocking of PSS in ITAIPU power plant, load shedding may be initiated. Consequently, the power system instabilities subside, and the resulting separated grid recovers.

The design and the different architectures which are used in the substations are described in chapter 3 in detail. The logics and schemes which are implemented in the WAMPAC system are described in chapter 4. The whole commissioning and testing procedures are described in chapter 5.

3 Design and Engineering of ECCANDE

The ECCANDE system is made up of many different components such as PMUs, protection relays, automation, and communication equipment, monitoring and processing software. All different parts must be combined to fulfill the complex requirements of the abovementioned ECCANDE system. ANDE, in collaboration with ITAIPU and EBY, found a comprehensive solution together with SIEMENS. The design was made in close cooperation among all partners of this project. The monitoring, control and protection schemes were realized with SIPROTEC5 PMUs, SIGUARD PDP, and RTU A8000 in a complete redundant scheme.

The overall architecture is shown in Figure 2 in conjunction with the simplified single line diagram of the network. The different building blocks are depicted, like PMUs, PDCs, and the substations where the load shedding will be initiated. The diagram also highlights the 6 circuit breakers that are closed during interconnected operation of both power subsystems (SS-1 and SS-2) and which will be opened if a critical contingency is detected by the WAMPAC system. These logics will be described in chapter 4.

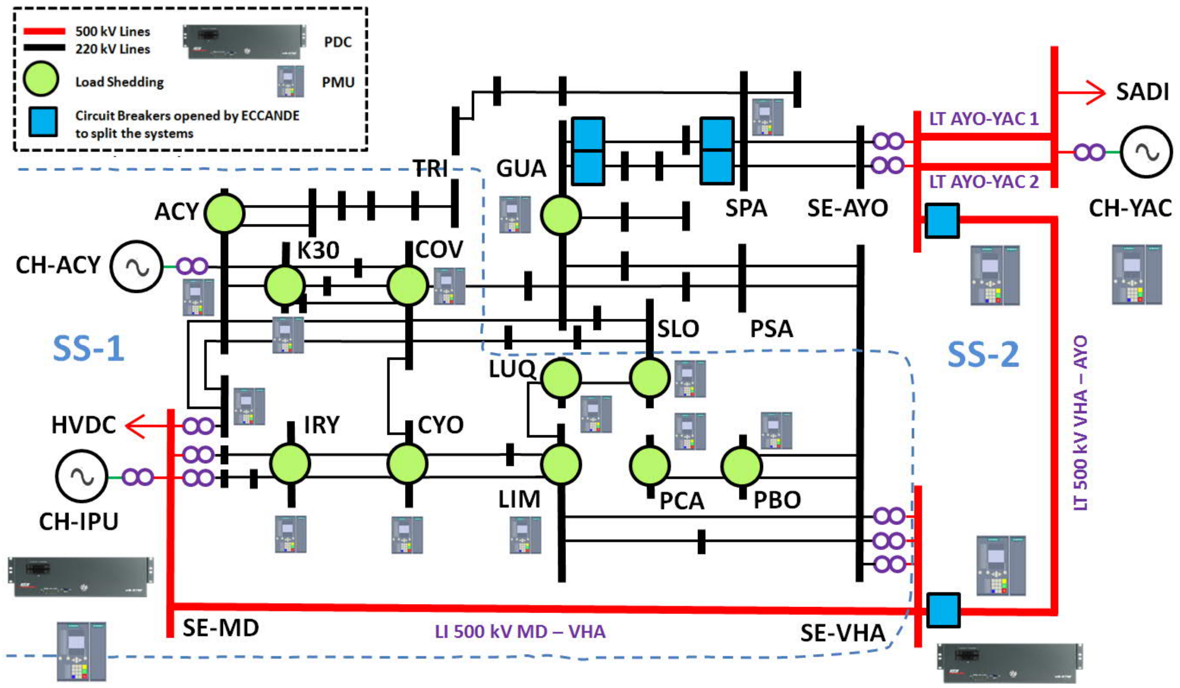

Fig. 2 – ECCANDE architecture alongside the simplified power network

The sensor building blocks are Phasor Measurement Units (PMUs) which make a valuable contribution to the dynamic monitoring of transient processes in electrical transmission and distribution systems. The advantage over standard RMS values is for one thing that the phasor values of currents and voltages are transmitted, with their magnitude and angle. Secondly, each measured value includes the exact time stamp and therefore should be assigned within the transmission path in which it originates independent of the time delay. The phasors and analog values are transmitted by the PMU with a configurable reporting rate. Due to the high-precision time synchronization (via GPS), the measured values from different substations that are far remote from each other can be compared, and conclusions about the system state and dynamic events, such as power flow, can be drawn from the phase angles and dynamic curves.

The PMU function transmits its data via an integrated Ethernet module using a standardized protocol IEEE C37.118. The evaluation can be done with a Wide Area Monitoring System e.g, with SIGUARD PDP (Phasor Data Processor). The time of the PMUs must be synchronized via GPS with an accuracy of < 5 us. This enables the PMUs to acquire the measured values with amplitude and phase as phasors (indicator values) with high precision and to transmit them via the communication interface. These PMUs are connected to the current and voltage transformers.

For the central intelligence and data processing the SIGUARD PDP (Phasor Data Processing) is used. It is a software for monitoring the status of power transmission in extensive power systems. When critical states are approached e.g. frequency stability, voltage stability, transmission stability, and power swings, this is detected early and displayed. The thresholds at which a critical state is reached and required interventions can be defined and subsequently changed at any time. It also works together with PMUs (Phasor Measurement Units) as a PDC. The time-synchronized measured values from regionally widely distributed measuring points can be collected and evaluated.

The ECCANDE system receives information from 16 substations, depending on the location and its configuration in the system, the architecture in the substation is different. The project was designed with three types of communication architectures:

- Substations with high relevance with PDC server,
- Substations with high relevance without PDC server,
- Single substations.

In substations with high relevance for the system there are PMUs in redundant configuration (main& backup). These PMUs are collecting and sending the information by C37.118 to the redundant PDC servers, which receive the information from the PMUs of all substations. The PDC servers send the substation information, and the logic and system status to the RTUs by IEC 60870-5-104. The RTUs distribute the information sending GOOSE messages about the logic's status and trips by IEC 61850 to the PMUs and sending substations and logic status to the HMI and Control centers of all three parties (ITAIPU, EBY and ANDE) by IEC 60870-5-104.

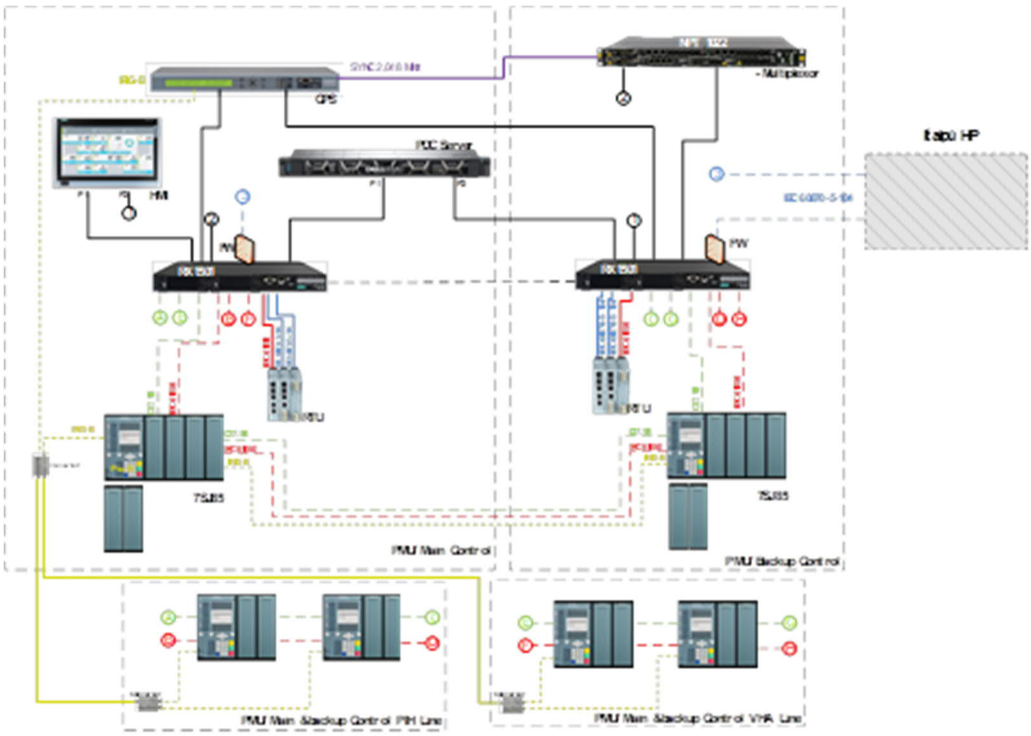

Fig. 3 –Communication architecture of substations with PDC servers

Figure 3 shows the communication architecture of substations with PDC servers. The purpose of this topology is to collect and transmit local measurements through redundant PMUs and to receive and send the information of the other substations using a Multiplexer, with a redundant connection to two communication switches. The GPS is used to synchronize PMUs using IRIG-B protocol, NTP protocol for computers, PDC and RTU, and a signal of 2,048 MHz for the Multiplexers network.

As stated before, this communication topology is redundant, having one PDC in substation Villa Hayes (VHA) and the other one in substation Margen Derecha (SEMD), at Itaipú power plant. Both PDCs operate in a Hot-hot configuration.

Figure 4 shows the communication architecture of substations without PDC server. This topology is like Figure 3 with a Multiplexer, a redundant connection to two communication switches, GPS, HMI, and redundant PMU. The difference is that there is no PDC server in these substations. This topology is implemented at a couple of strategic acquisition sites such as Ayolas (AYO) and Yacyretá (YAC).

Figure 5 shows the communication architecture for a single substation. This topology considers only one PMU connected directly to the Multiplexer, and a GPS for the time synchronization by IRIG-B. The PMU sends the information by C37.118 and receives the information by IEC 61850. This topology is employed mainly at the load-shedding substations.

A dedicated and redundant MPLS communications network, built upon OPGW and ADSS fiber optics, is implemented throughout the country, linked by 23 multiplexers, using the C37.118, IEC 60870-5-104 and IEC 61850 protocols, as illustrated in Figure 6. Under this configuration a low latency in the system was guaranteed to ensure the needed operation times for the WAMPAC-system even with distances longer than 400km.

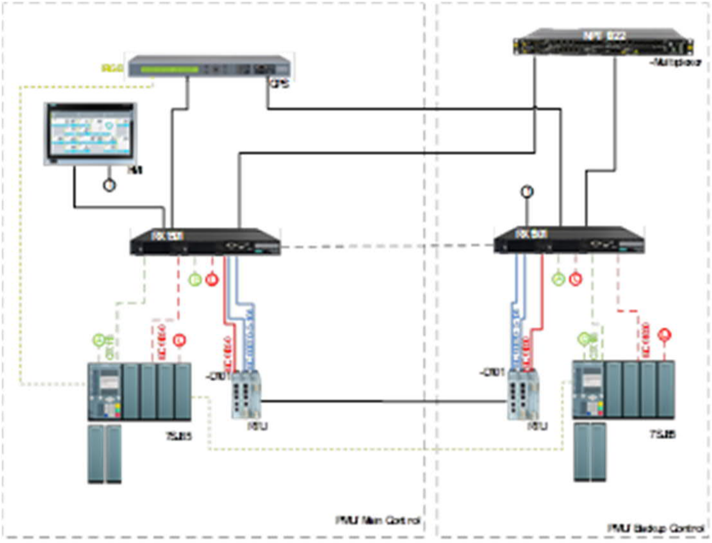

Fig. 4 –Communication architecture of substations without PDC server

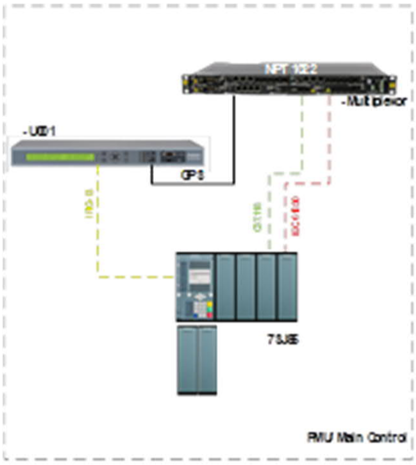

Fig. 5 –Communication architecture for a single substation

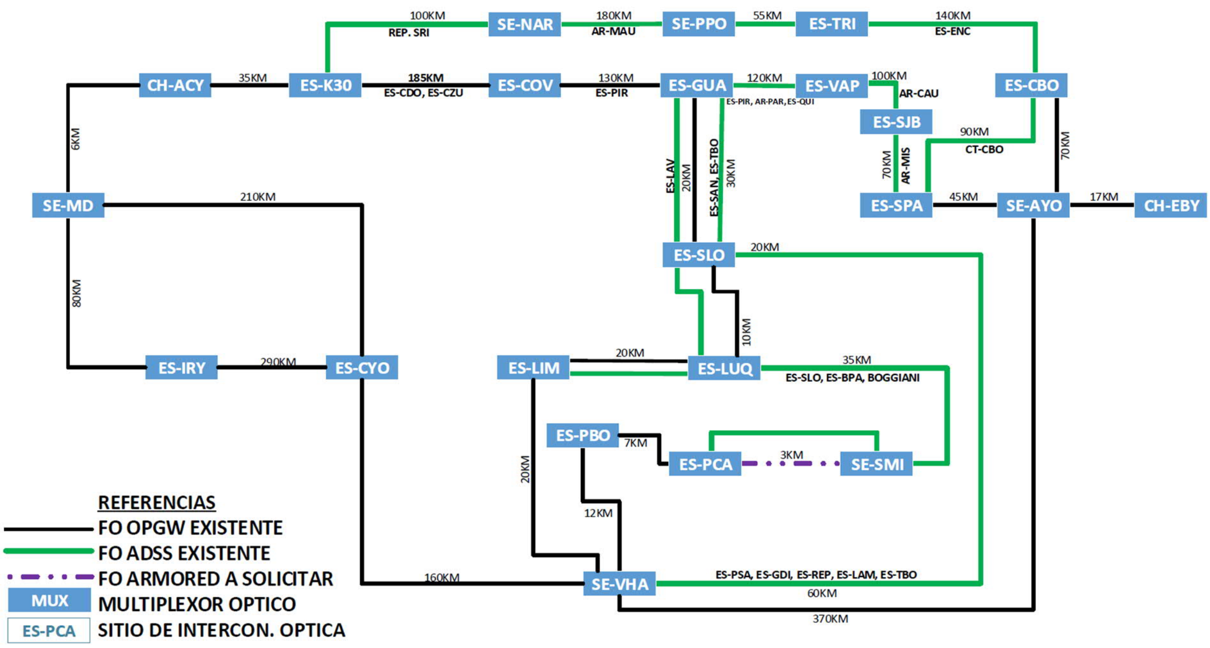

Fig. 6 – Illustration of WAMPAC communications

4 Contingencies and Logics

Based on all the collected phasor data and status signals a set of logics was developed to overcome transient and frequency stability problems for different contingencies while the system is interconnected. Four different internal logics are implemented which are event driven, because they only actuate if binary status signals change (e.g. trip of a critical line). These values can be directly transferred to the PDCs (SIGUARD PDP) which process all signals from the PMUs. The 3 external logics include measurements of active power flow and voltage angles. These logics are parameter based and actuate according to pre-defined thresholds, because these contingencies are affected by changes in the neighboring systems (e.g. Argentina) or due to non-monitored equipment. One contingency could be the loss of machines in hydro power plant of ITAIPU or in YACYRETA. The system studies showed that after each contingency load-shedding might be needed depending on the initial load flow case, so a decentralized under-frequency and under-voltage scheme is implemented.

Figure 7 shows the main flowchart of the ECCANDE logic. Before the system will actuate different parameters must be checked and observed. Especially for external contingencies the arming conditions must be fulfilled. This is done by checking if the power system is interconnected and synchronized or not. Based on the angle difference of the line side voltages of the two 500 kV lines at the VHA substation this decision is made, if the voltage angle difference is lower than an absolute value of 5° and all the circuit breakers pertaining to both lines are closed, then the system is interconnected. In case of internal logics, a minimal active power flow on the 500-kV-transmission corridors must be detected otherwise the ECCANDE system will not actuate because no action from system stability perspective is required.

The under-frequency (81U) load shedding scheme is running always in parallel to the central logic and has main and backup stages. The under-voltage scheme (27) is only enabled if the ECCANDE system actuates and trips. The logic will release the under-voltage scheme depending on the detected contingency. All logics can be blocked manually by the HMI-interface.

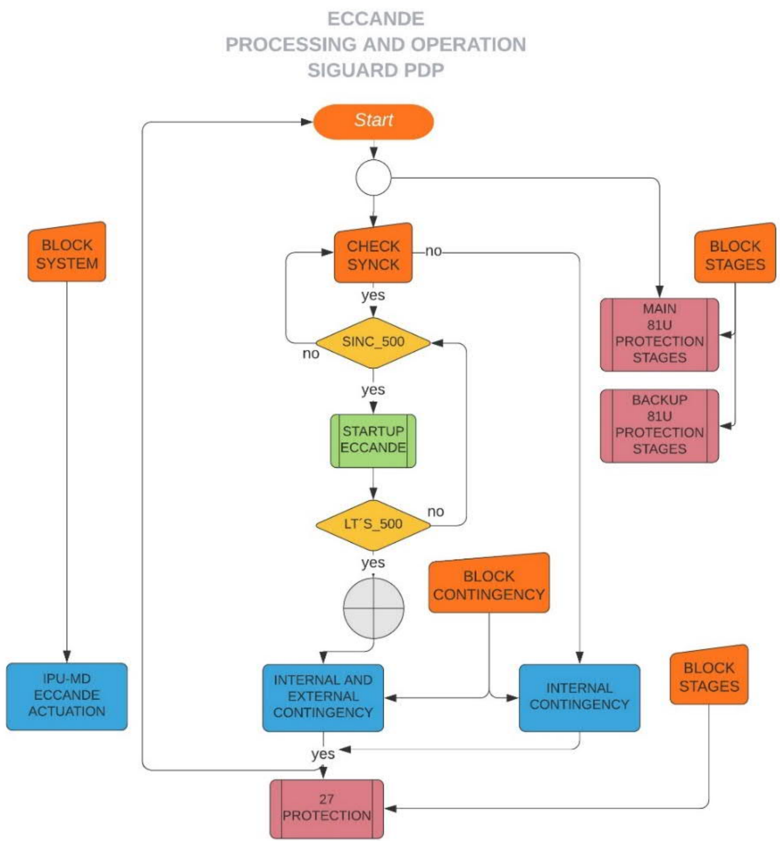

Fig. 7 – Main flowchart of ECCANDE logic.

4.1 Internal Contingencies and Logics

The most severe disturbances that can lead to system stability issues by the disconnection of Paraguayan transmission lines were considered as internal logic. These logics are event-oriented, and their terminology is related to the substations' names presented in Fig. 2:

- Logic 1 - EVENT: Opening of 500kV MD-VHA IL
- Logic 2 - EVENT: Opening of 500kV MD-VHA IL and 500kV AYO-VHA TL
- Logic 3 - EVENT: Opening of 500kV AYO-VHA TL or of the 500kV AYO-YAC 1 and 2 TLs
- Logic 4 - EVENT: Opening of 220kV MD-ACY 1 and 2 IL or of the 220kV MD-IRY IL and 220kV MD-PIH IL

TL=Transmission Line; IL=Interconnection Line

The general operation of internal logics is exemplified by Logic 1, illustrated in Figure 8. There are four central conditions to enable each logic: states of line's circuit breakers ensuring the transmission line is connected, ECCANDE is initialized, HMI blocking and active power flow above the minimum reference, which is delayed 100ms to avoid the effect of transients on the enabling condition. If all those enabling conditions are present in the logic, a line's terminal opening of MD-VHA will provide the trip signal to all circuit breakers depicted in Figure 2. So, the ECCANDE system will separate the two power subsystems.

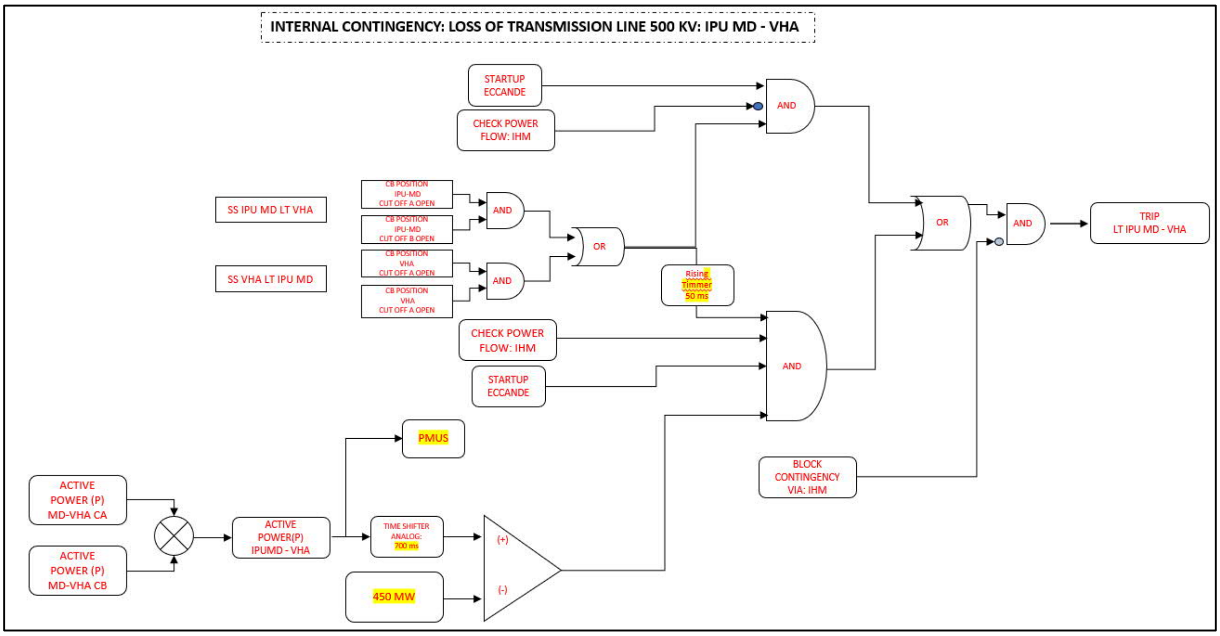

Fig. 8 – Internal Logic 1 – Opening of LI 500kV MD-VHA.

The internal logics 2 to 4 operate in the same manner as internal logic 1. Differences are in the number of observed circuit breakers and in the threshold of the minimal active power flow.

4.2 External Contingencies and Logics

The external logics are related to severe disturbances associated to the shutdown of non-monitored equipment by the WAMPAC panels. Those unsafety conditions were related to monitored quantities by a large electromechanical simulation study, defining the following external logics.

External Logics are parameter-based actions:

- External logic 1: OVERFLOW logic on 500kV AYO-YAC 1 and 2 LIs

- External logic 2: REVERSE flow logic on 500kV AYO-YAC 1 and 2 LIs
- External logic 3: ANGLE logic – Voltage Angle Difference between 500kV MD & AYO busbars

External logic 1 and 2 work similar with different direction of the active power flow between AYO and YAC, in the following external logic 2 is described more in detail. The external logic 2 is described by the reverse power flow on AYO-YAC 1 and 2 500kV transmission lines, as illustrated in Figure 9. If the total active power flow from AYO to YAC is higher than 450 MW, the ECCANDE system trips and splits the system by tripping all the 500 and 220 kV connections shown in Figure 2, with a tripping time less than 200 ms including circuit breaker operation.

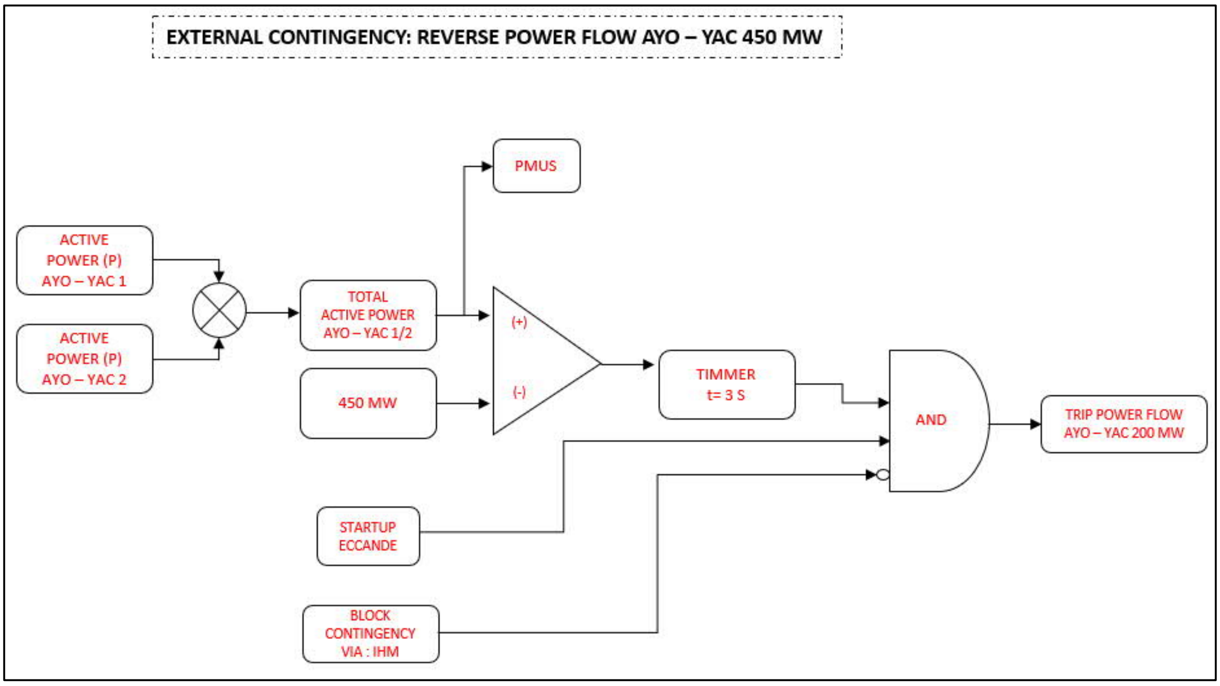

Fig. 9 – Reverse Power Flow Logic

The external logic 3 makes use of the phasor measurements by utilizing the voltage angle difference between the busbars of SE-MD and AYO, as simplified illustrated in Figure 10. Through this external logic the overall stability condition of the ANDE power system is monitored during interconnection, as the ECCANDE system checks the voltage angle difference between both sides of the interconnection and compares it to a pre-defined threshold. Various power system stability studies figured out that the most effective value to split the system, is if the absolute angle difference exceeds 80° between SE-MD and AYO.

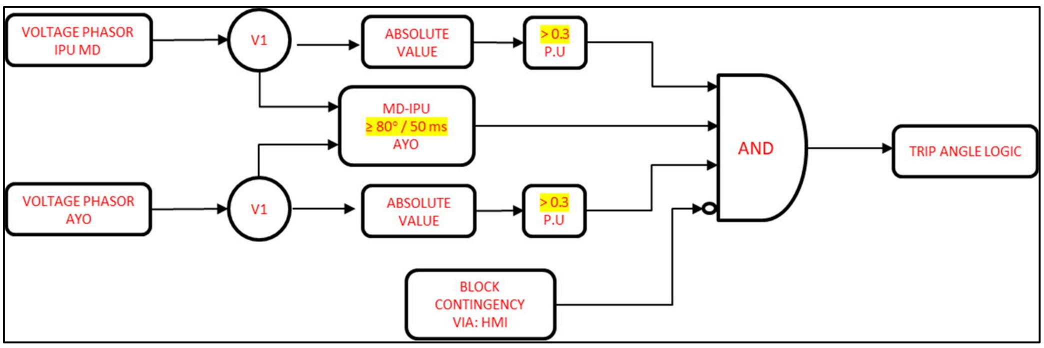

Fig. 10 – Angle Logic

4.3 Undervoltage-Control- and Underfrequency-Load-Shedding-Scheme

The load shedding schemes, which will be activated, if the ECCANDE system trips, are installed at the 220kV transmission system level. All substations with feeders which will be shed are marked in Figure 2. The load shedding schemes are realized via a stepwise under-frequency scheme and a stepwise under-voltage scheme (in case of availability, capacitor banks will be switched on at certain locations). For both schemes different feeders in different substations are coordinated (tripped) via protocol IEC61850-GOOSE message communication.

Both schemes actuate post system-splitting and are response-based actions. The respective substations and stages are described in the following:

- Underfrequency load shedding scheme: stages GUA (1), LIM (2), PBO (3), PCA (4), LUQ (5), COV (6), ACY (7), K30 (8), NORTH (9) which are always activated
- Under-voltage load shedding scheme: set I (stages 1, 2, A and B) and set II (stages 3, 4 and 5); which will be enabled by the operation of the ECCANDE system

The under-frequency main scheme has 9 stages with a grading of the frequency threshold, the delay time is set equal to 300ms for all the stages. The backup scheme has 8 stages with the same frequency thresholds except the first stage of the main scheme. The time delays are delayed in relation to the stages of the main scheme.

The under-voltage control scheme has 5 stages (1..5) for load shedding with 9 substations involved (corresponding to stages in the under-frequency scheme). Additional 2 stages (A, B) are related to capacitor banks which will be switched on if available, both will actuate under 0.9 p.u. with a time delay of 300ms. The set I actuates under 0.9 p.u. therefore the voltages at PCA, PBO and SLO are observed. If one out of these falls below the threshold, the delay timer starts for all stages in set I. For set II the voltages of COV and CYO are compared to 0.95 p.u., the delay timer also starts for all if any busbar voltage falls below the threshold. All three stages of set II are delayed in relation to set I and have a time grading of 300ms. The control for starting the delay timers in different substations is realized with IEC61850 GOOSE commands.

5 Testing and Commissioning

Before field commissioning, FAT was carried out in Colombia and additionally the system was tested in a RTDS laboratory in Germany. A reduced equivalent dynamic model with generator controllers (including PSSs), SVCs, HVDC load, and dynamic loads, was implemented, and tested together with a subset of PMUs. The protection functionality of the ECCANDE system was proved by simulating the most critical contingencies.

5.1 Factory Acceptance Test in Colombia

The Factory Acceptance Tests (FAT) were carried out without the physical presence of the customer due to COVID 19 situation. Through virtual meetings and reports, the development of the FAT was shared and discussed. The functional tests for the WAMPAC system were performed for about two months.

In the factory, the 24 PMUs were tested based on the proposed communication architecture, by testing the C37.118 protocol to the redundant PDC servers, by testing the IEC 60870-5-104 protocol between the PDC servers and the two redundant RTU pairs, and by testing the IEC 61850 (GOOSE) protocol communication from RTUs to 24 PMUs. All communication and functional tests were performed using the multiplexers and the MPLS protocol, which made it possible to carry out a process of debugging which helped to fulfill the performance requirements (contingency action time less than 150 ms) and to reduce the commissioning time on site (less than two months).

5.2 RTDS Hardware-in-the-Loop Test in Germany

For the RTDS simulation a subset of load flow cases was selected to represent different power exchange and power flow scenarios in the main transmission lines of the ANDE system. A list of events to be simulated in the different cases of load flow was also drawn up, whose main objectives were:

- Evaluate the behavior of the analog quantities measured and calculated by ECCANDE in the face of the occurrence of short circuits, loss of voltage signals, and loss of synchronism signal.

- Evaluate the impact of the different behavior of analog quantities on the implemented logic.
- Assess the overall performance of implemented logic.

The RTDS power system model corresponds to the single-line-diagram of Figure 1 and includes all equivalent machines, transmission lines, SVCs, the HVDC to Brazil in ITAIPU, capacitor banks and dynamic loads. All controllers of the machines were implemented according to the models which were used in the power system dynamic study. The comparison of the model in RTDS with the model of ANATEM which was used by ANDE and ITAIPU for the power system study showed the same behavior for different load flow cases and fault scenarios. After this approval the hardware setup was built up according to Figure 11.

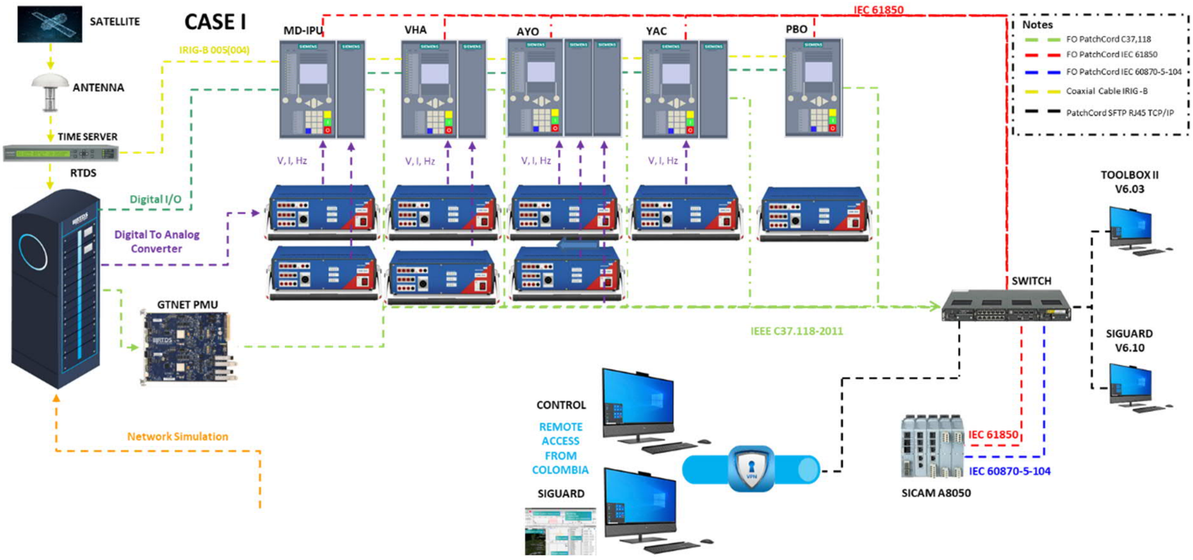

Fig. 11 – RTDS-laboratory architecture.

The four most relevant acquisition substations (MD, VHA, AYO, YAC) for the internal and external logics were implemented by four PMUs as hardware devices (SIPROTEC 5 IEDs) with time synchronization via IRIG-B. The trip signals of these devices were connected to the RTDS to actuate the circuit breakers which split the system. The remaining PMUs were simulated via RTDS GTNET card which was connected to the central network switch in the laboratory. One additional hardware device was used to demonstrate the functionality of under-frequency and under-voltage load shedding (PMU at PBO substation). This device was combined with the under-frequency and under-voltage scheme which were implemented in RTDS to get the overall power system response for all contingencies.

The central data processor (SIGUARD PDP) was implemented on a server and connected to all PMUs (hardware / simulated by RTDS) via a network switch (Ruggedcom). One RTU hardware device (SICAM A8000 CP8050) was used for the communication via IEC61850 to the devices and via IEC60870-5-104 to the PDP. As Amplifiers CMS356 from Omicron were used.

The approximately 100 tests were divided into special cases and batch tests. The special cases included cases like the interconnection maneuver, where the correct arming of the ECCANDE system was tested by checking the synchronism conditions. The batch tests included different load flow scenarios and fault conditions, mainly single phase to ground faults with the following loss of a transmission equipment as well as the loss of one or two machines in ITAIPU or YACYRETA to check the right behavior of the logic.

On the illustration of RTDS tests, the actuation of Logic 1 is described in more detail.

This simulation considered applying a single-phase short-circuit in the LI 500kV MD-VHA for 100ms, followed by opening the line in both terminals. The active power flow in LI 500kV MD VHA was above the reference of Internal Logic 1, and the flow of LT 500kV AYO-VHA was below the reference of Internal Logic 3.

Figure 12 shows the PDP records with the most relevant quantities, from which it can be stated that:

- The event causes transients in the flow measured on the line, which had to be considered in the logic design.
- The performance of Internal Logic 1 (MD-VHA, variable 41.1 in Figure 12) implied command to open the LT 500kV AYO-VHA and the equivalent 220kV AYO-GUA.
- After opening the LT 500kV MD-VHA 1, the angle difference between the SE-MD and the ES-AYO can exceed 80 degrees, but the angle logic does not trip because of the interlock condition by checking the 500kV circuit breakers.
- When a logic acts, the first part of the interconnected system verification logic is reset, but the time shifter keeps the other logics active for 700ms (see Figure 8).

All evaluated conditions were as expected, illustrating the good performance ECCANDE presented in the RTDS test.

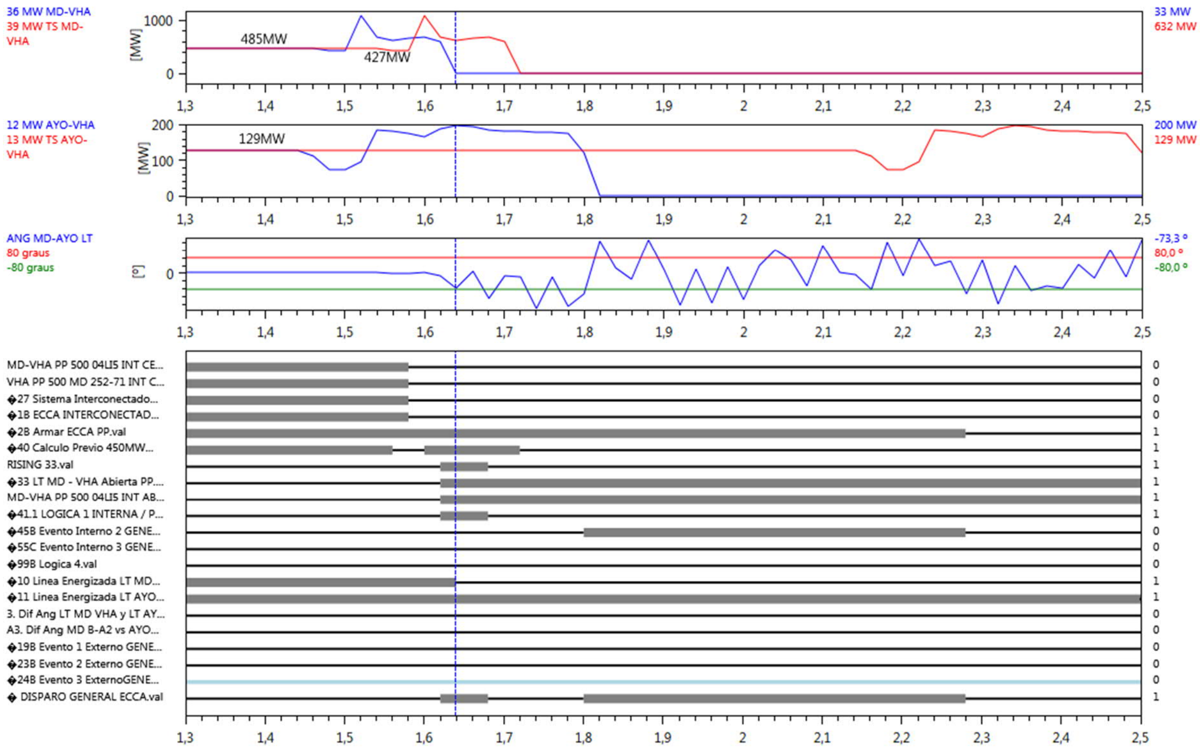

Fig. 12 – Actuation of internal logic 1.

Due to COVID-19 situation the participants couldn't meet at the laboratory in Germany, this challenge was tackled by doing the tests via remote connections and virtual meetings (showing the lab facility, racks with hardware devices, RTDS, and so on). The engineers from Colombia were connected to the devices and the data processor via remote access with virtual machines. The calls to Paraguay were also done by video calls to discuss the test results with ANDE, ITAIPU and YACYRETA. The time difference between South America and Germany was used to share the workload, tests were done in Germany and were then sent to Paraguay, so that the experts there could analyze and give comments. The outcomes were discussed together with the experts in Germany in the next session, which then could prepare the next tests or to do some adjustments. So, each day an alignment and discussion meeting took place in the morning in South America and the afternoon in Europe.

Our experience shows that the realization of such Hardware-in-the-Loop tests by remote participation is possible if it is well organized.

5.3 Field Commissioning in Paraguay

Fifty-four (54) days for the commissioning were necessary to guarantee the correct operation of ECCANDE scheme, live tests with the power system were carried out with good results. ECCANDE is currently online, safeguarding the whole system.

In the commissioning process it was necessary to test 16 substations in a short period of time, which led to testing 2 substations at the same time on some days. For example, testing at the same time one substation in Ayolas in southern Paraguay (about 250 km from Asuncion) with another substation in Ciudad del Este in eastern Paraguay (about 300 km from Asuncion), and correctly receiving all the information in Asuncion in the control center of ECCANDE (Villa Hayes substation).

One of the biggest challenges in the commissioning of the WAMPAC system, was to configure, to test, to debug and to send the WAMPAC system information to three different control centers: ANDE (Paraguay), ITAIPU (Paraguay-Brasil) and EBY (Paraguay-Argentina). The RTUs had to receive all the information from the PDC servers and to manage the sending of this information to the different control centers. It was necessary to use different IEC 60870-5-104 addressing and even deal with signal type changes because each control center had different IEC 60870-5-104 profiles.

The simultaneous use of up to 4 secondary injection equipment was necessary to test the different logics (internal and external) with GPS time synchronization to ensure the accuracy of the measurements and reaction times. In total, around 150 cases were executed ensuring the full functionality of all schemes, external, internal, over voltage and under voltage logics.

The following Figure 13 shows the HMI for the ECCANDE system which is implemented in the control center of Asuncion. All relevant PMU and RTU measurements are depicted as well as the status of the important circuit breakers.

In Figure 14, a detailed view on the synchronism-check condition of the ECCANDE system is shown. The condition is mainly observed in substation VHA. The depicted angle difference is between the line side voltages of the 500kV transmission lines to MD and AYO. In this case, the system is separated because the angle difference is not equal to zero (ideally) and the frequencies between VHA and AYO are different.

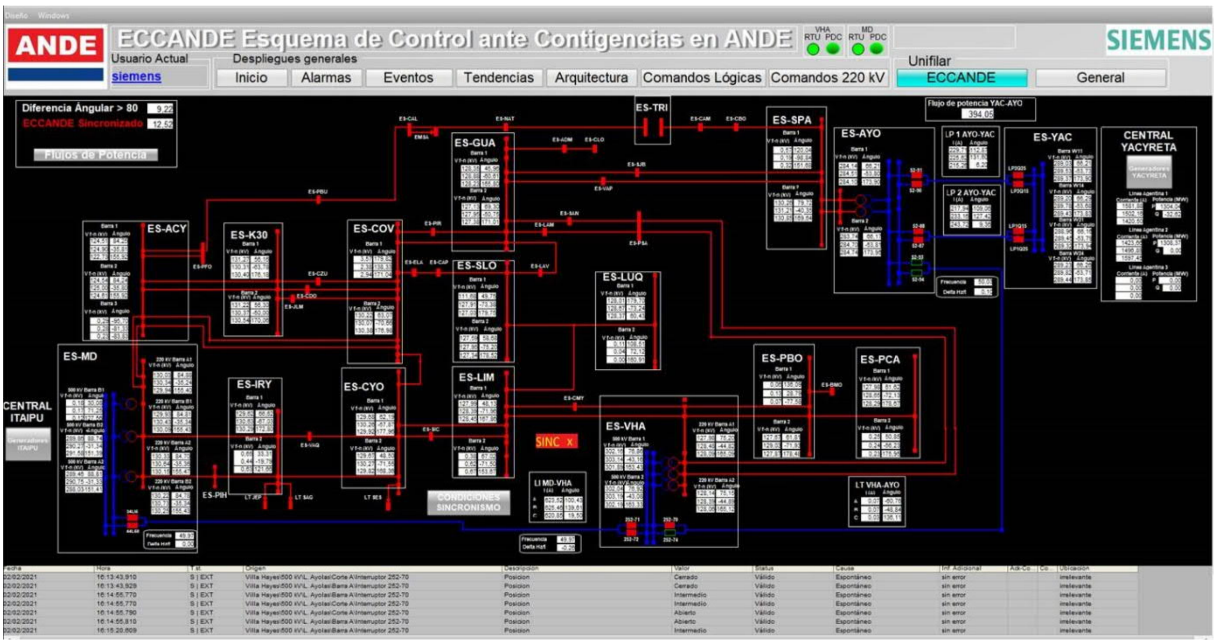

Fig. 13 – ECCANDE system in HMI and SCADA ANDE.

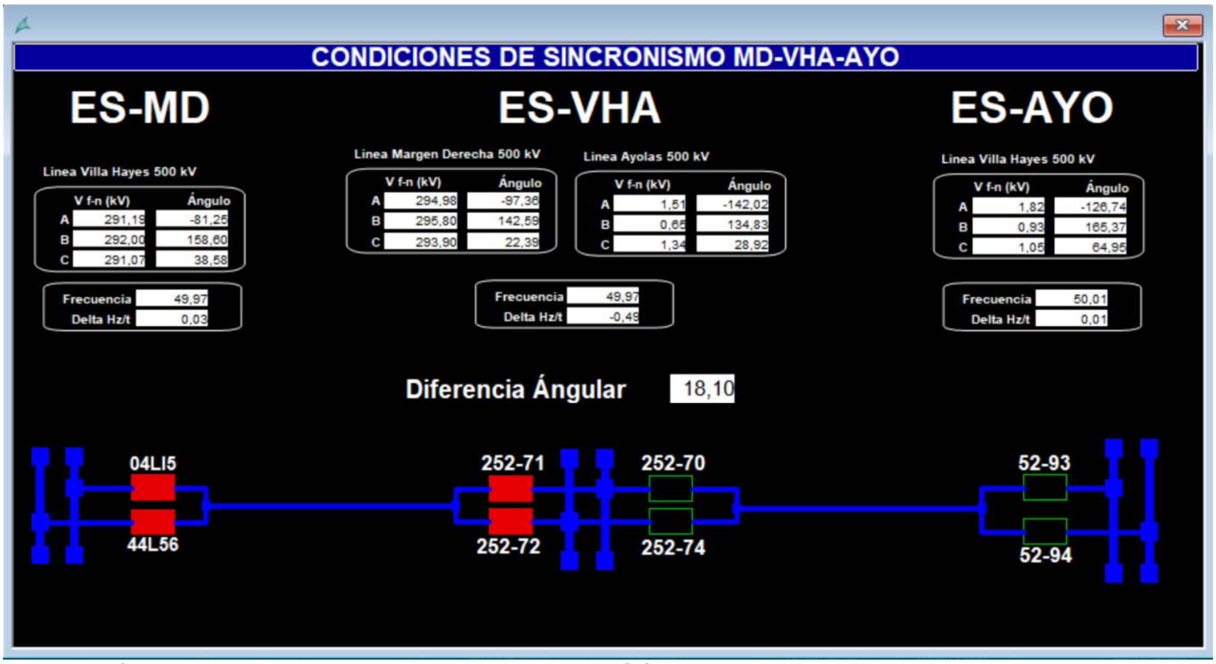

Fig. 14 – Synchronism-check conditions in HMI and SCADA ANDE.

After rigorous tests in the factory in Colombia, in the RTDS laboratory in Germany and finally in Paraguay, the ECCANDE was connected to the national transmission system. To perform this task, prior preparation of the transmission, generation and dispatch agents was required, since it would be the first time that both electrical systems would be interconnected (Brazil, Argentina and Paraguay). Once the necessary conditions were achieved, a power switch opening maneuver was executed. This simulated a failure case, and the expected reaction of the scheme was to achieve the separation of the systems with the effective opening of the circuit breakers in the necessary substations, this was a total success.

6 Conclusion

Different aspects make the ECCANDE system unique, especially the fact that three different utilities were involved to realize this WAMPAC system. All three parties participated in each step of the project. The goal was to interconnect the two hydro power plants to secure the power supply in South America between Paraguay, Brazil, and Argentina and to utilize the full capacity of the power plants. A detailed power systems study showed that a WAMPAC system was needed to fulfill all requirements regarding stability problems. Therefore, the ECCANDE WAMPAC system constitutes an essential set of logics to ensure the stability of the Paraguayan power system in the face of critical contingencies, after the interconnection of the Itaipu and Yacyretá plants. Its conception is based on synchronized phasor measurement technology, presenting itself as a pioneer project in the electric power systems industry.

Several teams collaborated in activities from its conception, implementation, and tests, which were carried out in the hardware-in-the-loop format and in the field, meeting the proposed requirements and demonstrating the excellent performance of the functionalities.

The ECCANDE system was successfully designed, tested, implemented, and commissioned in the field. It is running and ensuring the overall system security since end of 2020.

Acknowledgements

Due to COVID-19 situation a lot of experts worked together remotely, and it was very challenging to gather always all the necessary information. But all the discussions during the virtual meetings helped to make it happen and the project could be managed very well.

But COVID-19 showed us also a different perspective on life as one of our authors the expert from ANDE Paraguay Mr. Jose Maria Barua Godoy passed away due to COVID-19 infection. We want to state here our deepest condolences to his family, loved ones and colleagues.

All Authors are writing this paper in memory of Mr. Jose Maria Barua Godoy, a great expert and friendly colleague. It was a great pleasure for us to work and discuss with him either in the same company or during this project.

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