EXPERIENCES USING FAULT RECORDERS IN THE PERUVIAN POWER SYSTEM

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Abstract: *This paper describes the experiences got in the Peruvian power system using fault recorders, showing some records of dynamic and transient phenomena and a brief analysis of them.*

1. INTRODUCTION

Before in Peru, the fault analysis has been made using the protection relays (electro mechanicals, electronics, etc) indications and the event sequence recorded in the control centers, with that information engineers could identify the type of fault and the consequences. With the Peruvian system growth came up dynamic phenomena that originate the protection relays trip without reason apparently.

The needed to explain the relays operations, obliged some utilities to install basic fault recorders in substations and lines, to get grater information, allow identify: the type of fault, its location, magnitude, and duration.

Nowadays with the technology development and modernization of the Peruvian power system, the control centers of some utilities have SCADA systems, and remote access to digital fault recorders which are synchronized with GPS system, giving more information with time synchronization. With this information is possible rebuilt the disturbances, analyze the electric system behavior in order to determine the origin of such and raising the solutions that are necessary. Also, this information allow to verify the performance of the protection relays and another equipment of the power system.

The present Peruvian law imposes compensations in case of loads interruption to the originator utilities of the disturbance. With the purpose of determining the responsibility of each utility, an analysis of each interruption is made reconstructing the event and determining the degree of participation of each utlity in the event. The fault records and chronological sequence of events, play a very important role in this analysis.

For this reason the utilities have increased the implementation of digital fault recorders, in order to demonstrate its degree of participation in the event, being this fact very beneficial to know depth the behavior of our electrical system.

2. THE PERUVIAN POWER SYSTEM

The Peruvian power system has a radial configuration fundamentally, with a transmission system in 220kV and 138kV, with a 2950 MW peak demand in the year 2003.

The main load is concentrated in the center of the system (Lima) with predominantly hydraulic power plants of generation very separated from the load, and interconnected by very long lines.

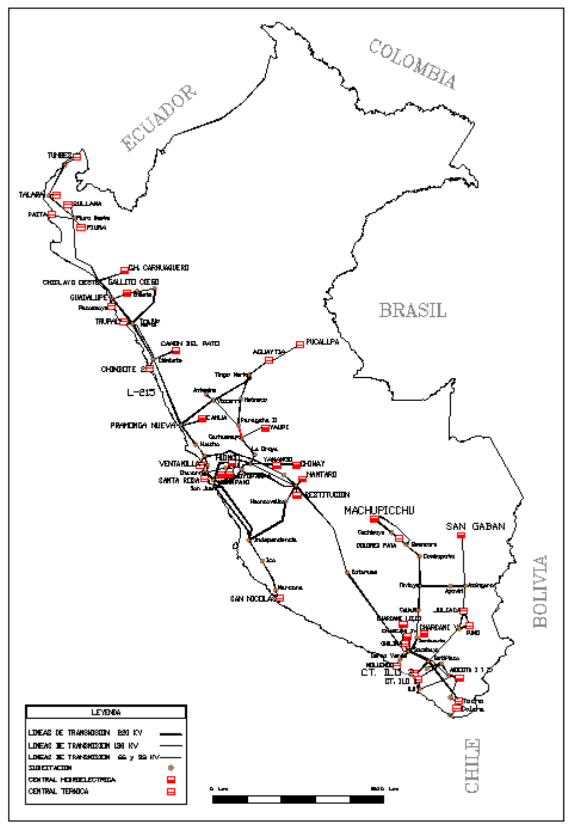

Figure Nº 1. The Peruvian power system

These power plants present equivalent impedances in terminal of the generators between 0,3 to 0,6 pu, for that reason during dynamic conditions they have unstable behaviors.

In the minimum load condition, the system presents deficit of reactive inductive compensation, in the north and south areas, become manifest with overvoltages.

Consequently, the Peruvian power system has critical zones in which evidences dynamic and transitory problems, being this The South Area, The North Area and the Tingo Maria ring in the Center area.

3. FAULT RECORDS

In Peru at beginnings of years 80, were installed the first electromechanical fault recorders in few substations of the system, in order to register the behavior of the main parameters of the power system during a disturbance and later to be able to make the respective analyses to determine the causes of the disturbance. These equipments were denominated Electromechanical Oscillograph, which printed the record in special sheets with color fountain pen, as is showed in the figure 2.

Figure Nº2. Electromechanical Oscillograph.

With those equipments and the signalings that gave the electromechanical relays, It could be determined the type of fault (single-phase, two phase or tree phase), magnitude of the fault (Peak values) and from them the analysis engineer calculated the phasor and plotted the phasors diagrams.

They were very useful equipment however during its operation they presented some problems, such as

- In severe events, they left the scale or the pen remained joined

- The equipment was unfit.

- In summer the ink of the pen was spilled and in winter it was congealed.

- High maintenance cost.

- Go to the place to gather the records.

The radial growth of the electrical system, the interconnections with the North and South areas of the country complicated the operation, appeared new dynamic and transitory phenomena that no longer could be registered with the electromechanical equipment, being without explanation many of these events.

With the advance of the technology, nowadays exist in the market digital fault recorders, that have additional characteristics like: recording of data to variable frequencies, capacity to record transitory events, storage and reproduction of registered data, with the advantage of the local and remote communication by means of a personal computer. This characteristic allows to access in few minutes and from remote places to the event data and to extract the record, saving displacements of specialized personnel to make this work.

In Peru, at the present time are installing in the main lines of the system, digital fault recorders and digital relays that have the function of oscillographic fault record, with the purpose of identifying the origin of the fault , to verify the performance of the protective equipment, to locate the fault point and to take decisions in real time.

The Figure Nº3, show the installation scheme which is implementing. After happened a disturbance the information stored in the memory of the digital fault recorder, is transferred to a master station installed in the control centers of the utilities, being this information used by the operators to take decisions in real time. Later, all the companies that have registered the event in the diverse points of their facilities, analyze this information and send it to the Committee of Economic Operation of the System (COES), so that it makes the respective analysis.

With the fault records got of the fault recorders or protection relays, is come to make a fault analysis observing the dynamic and transitory performance of the electrical system, evaluating the frequency records, digital records of the signals of the protection systems, voltage profiles, magnitudes of currents and power.

From the analyses made, it has been possible to identify dynamic phenomena like: Power swing, out-of-step, voltage collapse; and transient electromagnetic phenomena like: Resonance, ferroresonance, inrush and troubles synchronizing power systems, some of these cases are describe in this paper.

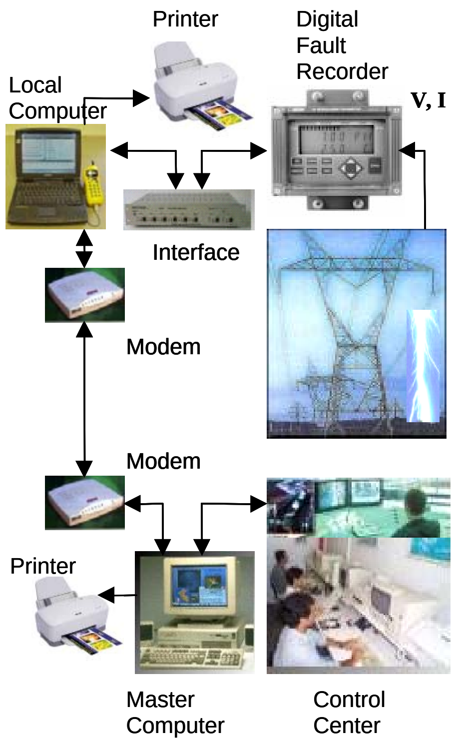

Figure Nº3. System of digital fault recorder

3.1. Blackout produced by a small signal unstability phenomena.

The 25 of July 2002 at 18:10 hours, oscillations of Low frequency took place originated by the increase of generation in the North area

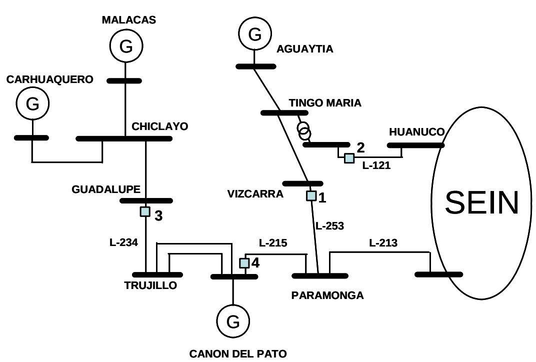

Figure Nº4. North area, Peruvian power system.

The increase of generation in the North area, is appraised in the increase of the flow in the lines L-215 (Chimbote – Paramonga) and L-213 (Paramonga – Huacho), being observed in the frequency that, as the flow in these lines was increased began the phenomenon of small signal power oscillation, as it is appraised in figure 5.

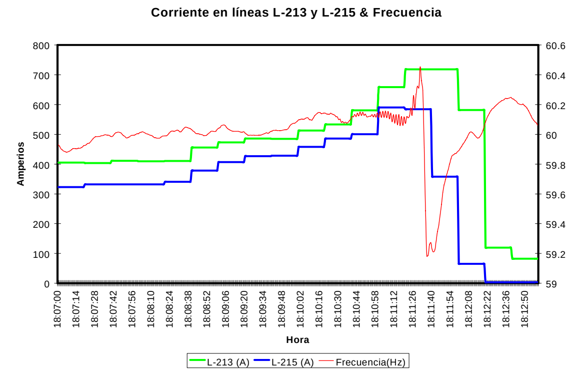

Figure Nº5. Flow in the lines L-213 y L-215 & frequency of SEIN

(1) The increase of the electromechanical oscillations and the low damping that have the North area, originated the disconnection of sensible loads to the voltage variation, increasing the flow in the lines aggravating the problem of power oscillations, that they took to this area to a lost of synchronism, which is appraised in the record of the L-253 line.

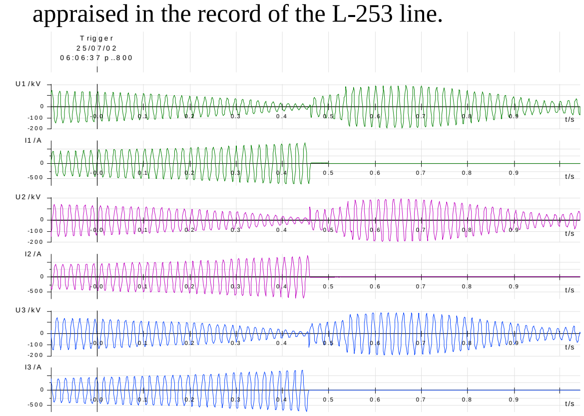

Figure Nº6. Record of line L-253, Vizcarra Substation

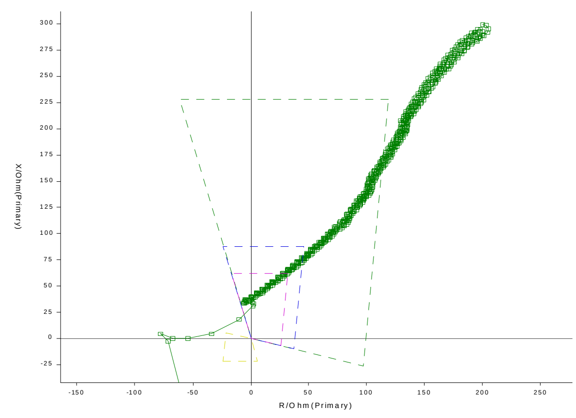

Figure Nº7. Impedance seen for the relay in the Vizcarra Substation

(2) The disconnection of the line L-253, caused the disconnection of the line L-121 in the Tingo Maria substation (figures Nº8 y 9) for out-of-step, due the

Aguaytía power plant stayed connected to the system through a weak connection.

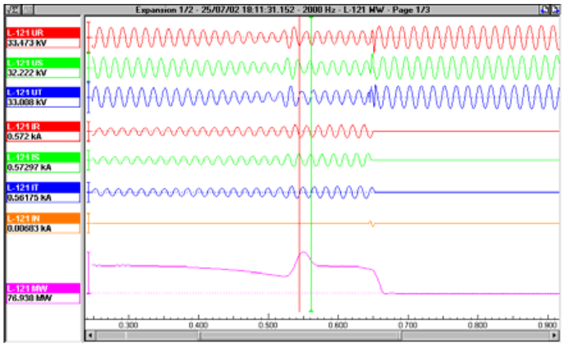

Figure Nº8. Record of the line L-121, Tingo María Substation

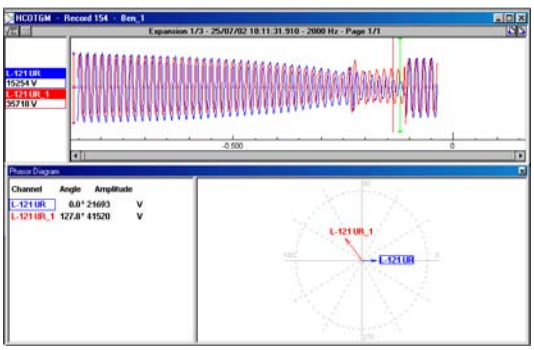

Figure Nº9. Voltage angle between Tingo Maria and Huanuco Substations.

(3) In the North area, different combined modes oscillation took place, identifying the local modes and interarea modes, being this last one which produced an out-of-step of this area in the Guadalupe substation, which is why a line disconnected.

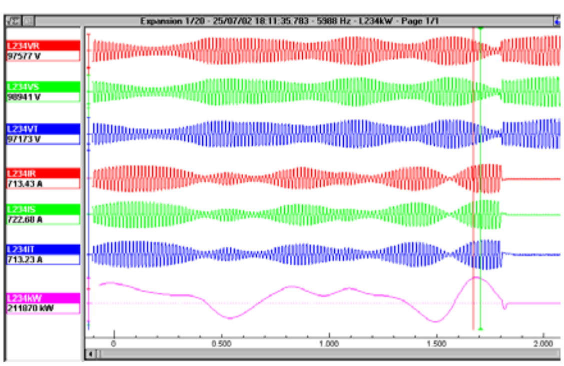

Figure Nº10. Record of the line L-234, Guadalupe Substation

During this event, disconnected the L-234 line (Guadalupe – Trujillo) in the Guadalupe substation because the distance relay saw an out-of-step, disconnecting the line.

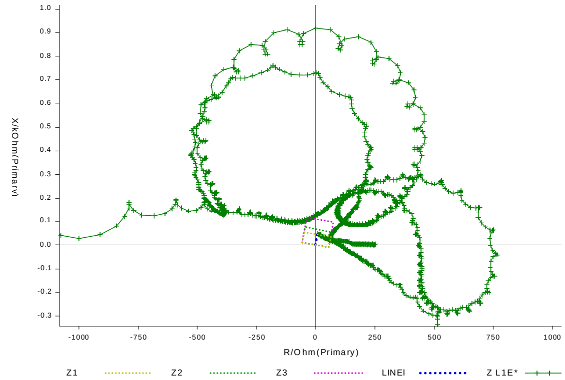

Figure Nº11. Impedance seen for the line L-234 relay, Guadalupe substation.

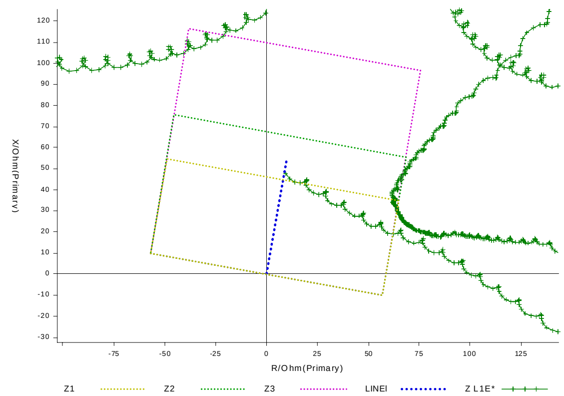

Figure Nº12. Zoom to the figure 11, Impedance in the operation zones for the relay line L-234, Guadalupe substation.

(4) Finally the L-215 line disconnected by overvoltage, producing a blackout in the north area.

3.2. A Voltage collapse phenomena

This event happened in the ElectroAndes area in august 14 of 2001, at 01:57 hours. In this event disconnected a power autotransformer of 220/50kV in the Oroya substation originating dynamic problems in that area because the postfault configuration, producing a voltage collapse.

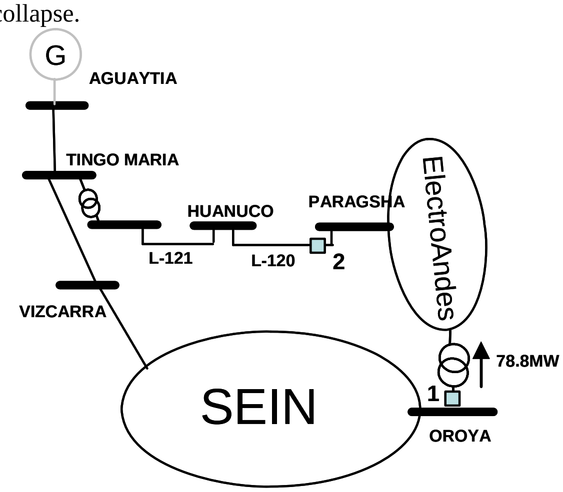

Figure Nº13. Area in which the voltage collapse was produce.

After the Oroya autotransformer disconnection, the flow was increased in the Tingo Maria ring, and more over due the connection is weak without reactive compensation a great fall of tension was produced.

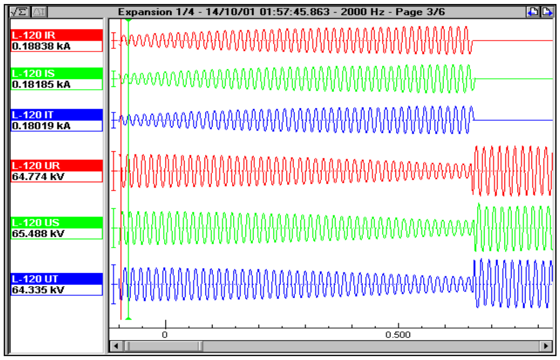

Figure N°14. Record of L-120 line (Paragsha – Huanuco), in Paragsha substation.

When the records where analyzed, it was observed that it did not correspond to a loss of synchronism, reason why from the voltage and current obtained from the record, the active power was calculed for this line, according to the figure 15.

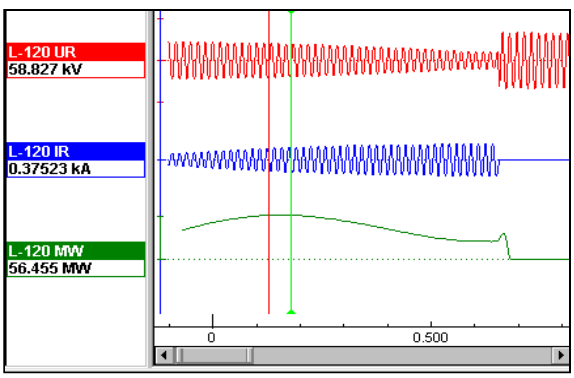

Figure N°15: Voltage, current and active power, L-120 line.

From the previous record, some points of voltage and active power were taken, those points were plotted in the plane P-V, getting as a result a characteristic voltage collapse, the line disconnection occurred just at the lowest voltage point

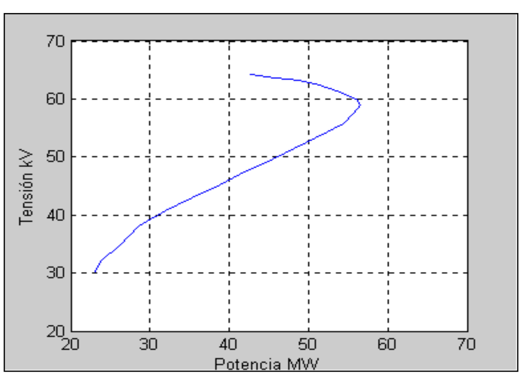

Figure N°16: Voltage, current and active power, L-120 line.

The L-120 line disconnection was produced by the distance protection tripped, because the dynamic impedance of the system entered to the operation zone of the relay.

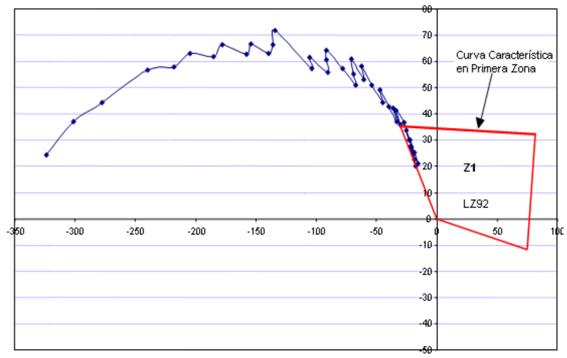

Figure N°17: Impedance and relay zone of the L-120 line, paragsha substation, plotted from the fault record.

3.3. A Resonance phenomena

The resonance event happened in December 23 of 2001 at 09:04 hours and occurred in the Tingo Maria ring, which was in radial configuration, the 220kV lines were with low load. That configuration was produced because a line link of the ring was on maintenance, The L-253 (Vizcarra – Paramonga) and the SVC (+90/-45 MVAr) of the Vizcarra substation, as is shown in the figure N°18.

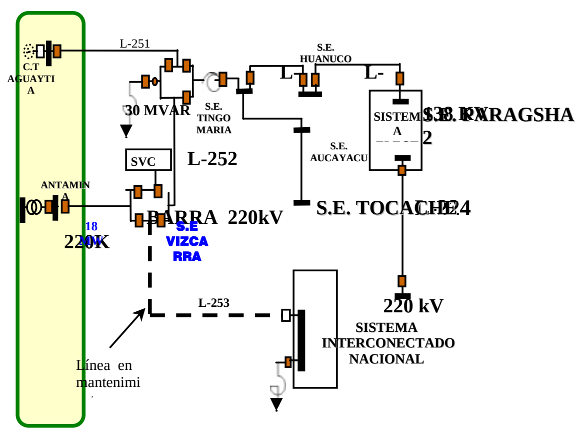

Figure N° 18. Pre-fault configuration.

During the equipment maintenance, the bus bars of this area were operating with a voltage in the range of 242kV because there were not enough reactive control elements. The SVC maintenance in the Vizcarra substation had finalized before the line, in order to manage voltage and take load in Antamina, the SVC entered in service, taking place oscillations of voltage and current because of this operation, choosing the operator to disconnect the SVC immediately.

The System Coordinator after verified the stable conditions of the system and didn't have clear evidences of the oscillations source, ordered the SVC connection, taking place again oscillations of voltage and current (Figure Nº19), the operator of the Vizcarra substation disconnected the SVC immediately, stopping therefore the oscillations.

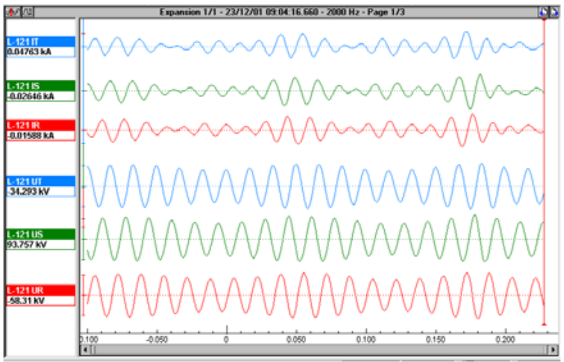

Figure Nº 19. Oscilografic record of a Ferroresonance at industrial frequency in the Tingo Maria ring.

A third attempt was made, with the same previous results, that is why the system coordinator of the System arranged that the SVC stayed out of service until the L-253 line enter in operation.

Later, the oscillographic records were analyzed and it was observed that those records had a characteristic of maximum current and maximum voltage, but in other time both variables were minimum. This characteristic gave us the idea of a resistive load, but that only happen in resonance, that resonance should give us a high voltage without oscillations. However, the oscillatory characteristic took to us to analyze in detail the components of the network, reaching the following conclusions:

* The topology that presents the Tingo Maria ring for the L-253 disconnection (open ring) and operating with low load, takes this area of the system to an operation point near the condition of resonance at industrial frequency (60Hz).

* The voltage in this area without compensation elements, is not controllable and reach to have high values (1.1 Pu), conditioning it to the appearance of electromagnetic phenomena.

* The SVC connection in the Vizcarra substation under that conditions contributes to the resonant component of the network, and later when give more reactive inductive component removes it from that condition. Therefore, the oscillating resonant behaviors was produced by the interaction of the SVC under the high voltages that appeared.

It was possible to determine the cause of the strange behavior of this area, aided by the oscillographics records, which show us the behavior of the system variables and the analysis elements to understand the phenomena.

3.4. Synchronization problems.

The synchronization problems in Peru have appeared when carrying out maneuvers in manual form and by fault in the synchronism equipment, causing a strong disturbance in the system and giving as result the immediate disconnection or stay in service with oscillations

One of this events happened on Monday, December 23 of 2001 at 10:54:55 hours in the Tingo Maria ring, when a line of this ring was on maintenance. The event began with the breaker opening in the autotransformer of 50MVA and 220/138kV in the Tingo Maria substation, because the overvoltage protection tripped, in that condition the Aguaytia area were separated of the system (figure 20).

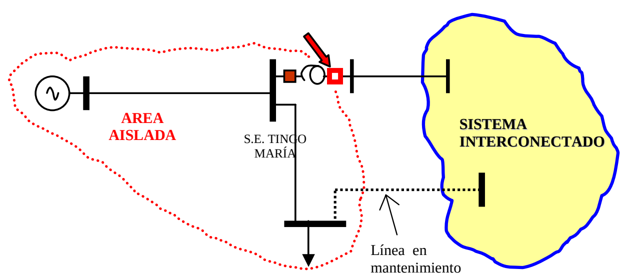

Figure Nº 20 Diagram of the false synchronization.

In that condition, the operator thought that the Aguaytia system was connected to the system trought the L-253 line which was on maintenance, closing the breaker without synchronism check, originating a strong disturbance with an oscillation of 1.5 seconds, that ended with the Aguaytia Power plant disconnection, the loads of this area finally, remained connected to the system.

The strong disturbance, was caused by the closing of the breaker with a great angular difference (60°), appearing suddenly a great current with a continuous component, like a three phase short circuit, followed by a slow oscillation when the aguaytia power plant tried to resynchronized to the system, disappearing when the aguaytia power plant tripped by the loss of synchronism.

The synchronizing equipment sent the signal to close the breaker, when being with inadequate settings because in that point synchronization maneuvers were not made. Using the oscillographic record shown in the figure N°21, got in the L-121 line en the Tingo Maria substation, it was possible determinate what happened in this event.

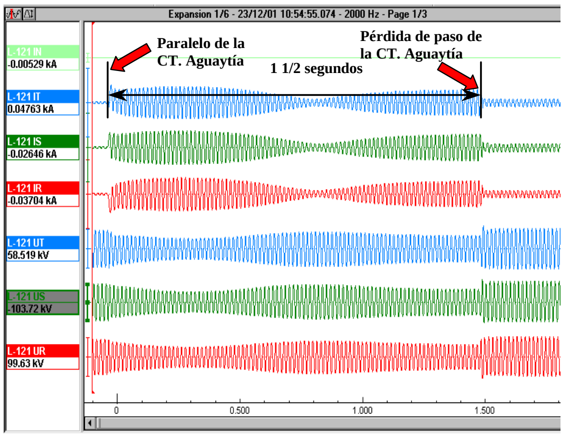

Figure Nº 21. Oscillography of the synchronization between Aguaytia area with the SEIN.

Another event happened on January 24 of 2004, at 03:39:10 hours, when were synchronized two areas the South area with the Center-north area after a fault in the interconnection line which separated the system.

After the fault in the L-2054 line, this line was energized in the Cotaruse substation in order to synchronize automatically in the Socabaya substation. However, when variations of frequency appearing in the South area, the synchronism relay did not allow the closing of the breaker. That is why the synchronism was made in manual mode.

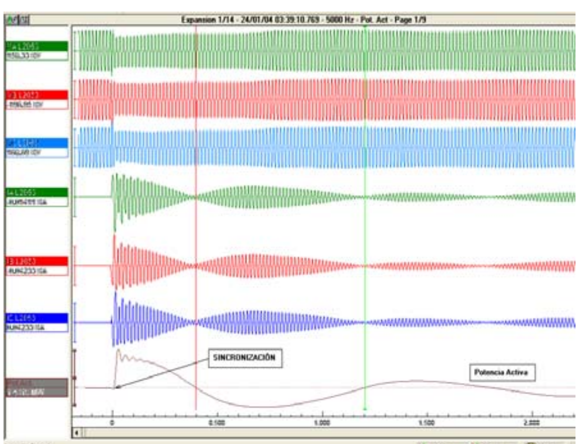

Figure Nº 22. Oscillography of the effects of a forced synchronism between the south and the Center-North area in the Socabaya substation.

The operator saw that the conditions were very variable and wait until he saw conditions to close the breaker, causing a disturbance with power oscillations with a frequency of 1.25 Hz in the power system, which were attenuated in 5 seconds according to the figure N°22.

The disturbance caused a voltage drop of 20% in the busbars near the socabaya substation during 600ms approximately, after that it recovered (figure Nº23), but that voltage drop tripped some industrial loads by under voltage protection.

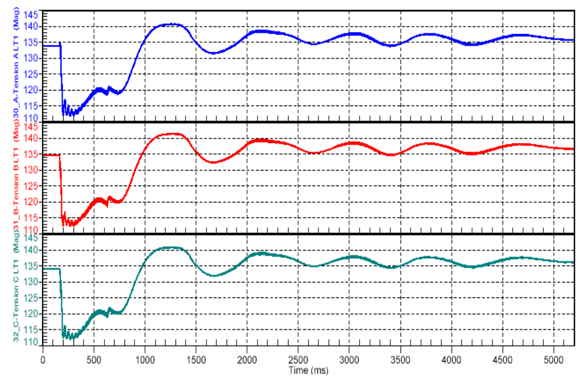

Figure Nº 23. Voltage oscillography in the 220kV busbar, Ilo2 substation.

The disturbance was caused when the synchronization was made with inadequate parameters. With the oscillography shown in the figure 24, it could be determinate the parameters in the synchronization between both systems, been this values the following: $\Delta f = 0.2$ Hz; $\Delta V = 2.49$ kV y $\Delta\delta = 91°$.

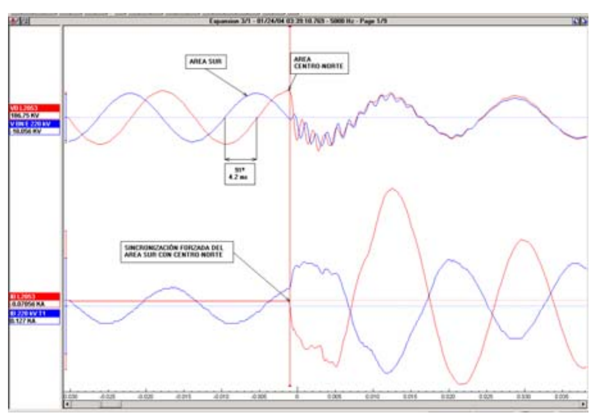

Figure Nº 24. Analysis of the synchronization of the South operative area to the center-north using oscillographic records.

From these values, we can conclude that the angle between power systems in the synchronization was too big, for that reason during the closing, appeared a high current with a voltage drop, for the power system it was as a three-phase short circuit, but the system recover the stable condition after 5 seconds, without generation shedding.

As it was shown, using oscillographic records and software available for the analysis it is possible to determinate the origin of the problems and the effects in the power system.

4. CONCLUSION

The oscillographic records nowadays are a tool of extreme importance for the electrical power system analysis; the application of these recorders in Peru has allowed detecting dynamic and electromagnetic transient's phenomena, determining its origin and raising the remedial actions that allow to control or to eliminate the effects of these phenomena.

In this paper, we showed some cases in which oscillographic records were obtained that allowed us to make the analyses of the faults and events in the electrical system.

Another application that has in Peru is to evaluate the performance of the protection relays, sending to the relays the digital signals that are analyzed in the performance during faults. Also, the oscillographic records obtained in the events, are used to verify and to improve the protection relays settings. This verification of settings is made in the protection laboratory, using relay testers, the record is save in Comtrade format and then is injected into the relay observing the performance, and varying the settings according to the requirement of the case.

Finally, we comment that at these moments in the Peruvian power system are being implemented in stages, digital fault recorders in the lines of 138 and 220 kV and important power plants of generation, with the purpose of being able to observe the dynamic and transitory behavior of all the components in the electrical system.

5. REFERENCES

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Gratefulness

We thank for to the "Comite de Operacion Economica del sistema" (COES) and the utilities members of this by the support and facilities offered for the development of the present article.