Electrical Resynchronization in the Peruvian Power System.

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Abstract*:* This paper describes the analysis of a fault in the Peruvian Power System, and an Out-of-Step and resynchronization events after it between the Southern-Western Region and The National Grid. The paper describes theoretically the phenomenon, and shows the analysis made using digital transient recorders, with that was possible to demonstrate the electrical separation between two regions of the Peruvian Power system and the resynchronization of them after some generation shedding.

1- Introduction

The connection of two power systems between a transmission line which has a capacity under (10% - 15%)[2] of the small power system, is called a "Weak connection"

In power systems with "weak connections" is necessarily to have enough reserve in order to maintain stability. The operation of this connections near the stability limits can originate frequency or power oscillations

If each one of the interconnected systems could regulate its power momentarily in such a way that the generation is exactly the load of the system for a frequency of 60 Hertz, then the frequency in the systems would stay constant. Any variation of the frequency in each one of the systems immediately would be compensated by its respective variation of the generation. Unfortunately, this regulation cannot be made

Any difference between the power and load means a change in the frequency, which also causes the action of the primary regulators that gradually change the generation.

From the analysis of the interchanged power variations and the oscillations that appear, these oscillations are divided in the following types[3]

1.- Control modes;
2.- Interarea modes;
3.- Local modes;
4.- Unstable modes;
5.- Torsional modes.

The investigation and experience show that the irregular oscillations of power only can be evaluated considering the smallest of the interconnected systems.

The loss of synchronism in the weak connections frequently is caused by the disconnection of one line or power unbalance between the interconnected systems. The short circuits events, even the most severe, would not cause the loss of the stability, if the faults are cleared quickly by the protections in a time smaller than the critical time.

The analyses of real events like the ones described previously, are made from the data obtained in the SCADA systems, the protective relays and the transient recorders. The transient recorders, capture many parameters of the event such as voltage and current with high resolution. The Transient recorders nowadays have multiple capacities such as register waveform, digital signals, rms values, frequency, etc, and the samples intervals are configurable and can go from the milliseconds to the hours

In The Peruvian Power System using the transient recorders, which are installed in different points from the electrical system, an interesting phenomenon originated by the disconnection of a line was recorded. This disconnection produced a loss of synchronism of the Southeastern region.

This loss of synchronism was not detected by the separation of areas scheme, for that reason the Southeastern region did not separate of the national grid; staying connected with a overfrequency. This phenomenon is known as a loss of frequency stability.

2. Power System Stability

The stability is a condition of balance between opposite forces. The mechanism by which the synchronous machines interconnected maintain synchronism is by forces which tend to accelerate or decelerate the machines with respect to a reference. Under stable conditions, there are an equilibrium in a machine between the mechanical torque and the electrical torque considering a constant speed. If the system has a perturbation, this balance finishes, and an acceleration or deceleration of the generator's rotors take place. If a generator temporarily is accelerated over another one, the angular position of its rotor is increased. The angular difference transfers part of the load of the slowest machine to fastest, depending on its relation power-angle

The relation power-angle is nonlinear. Over a certain limit (90°) an increase in the angular separation is accompanied by a decrement in the transferred power and causes more instability. In some situations, the stability of the system depends of the angular position on the rotor.

When a Synchronous generator loses synchronism (an out-of-the-step condition), the rotor is accelerated. This originate fluctuations in power, voltage and current in the machine; so that the protection relays trip and isolate the machine of the system.

The loss of synchronism can happen between a machine and the system or among groups of machines. Its possible to recover stability in the system insolating the machine that caused this condition.

In electrical power systems, the change in the electrical torque of a synchronous machine followed a disturbance has two components:

$$\Delta Te = T_S.\,\Delta\delta + T_D.\Delta\omega$$

where:

$T_S.\,\Delta\delta$; Is known as the Synchronizing torque.

$T_D.\Delta\omega$; Is know as the dumping torque.

The system stability depends on the existence of synchronizing and dumping torque in each synchronous machine. The lack of synchronizing torque result in an angular instability, and the lack of dumping torque result in oscillating instability.

3. The Power swing and the out-of-step phenomena

The active power transmitted through an ideal transmission line (without losses), that connects interconnected systems as it is shown in the figure 3.1, is determined using the state variables and the parameters of the system, according to the following relation:

$$P = P_S = P_R = \frac{E_S E_R}{X_T}\, Sen\delta \qquad (3.1)$$

In which, it is observed that the maximum transferable power depends on:

- the voltages of the equivalent sources
- the total impedance of connection
- the angle between the voltage of the two equivalent sources.

Considering that both systems are strong, it would be possible to be assumed that the voltages would stay constants; for that reason when the angular difference between the equivalent sources is increased, the power has describe a change as it is shown in the figure 3.2.
As we increased the flow through the transmitssion lines, the angle between the two sources is increased, when the angular difference is 90º this point is known as the Point of maximum transference, also known as the limit of static stability.

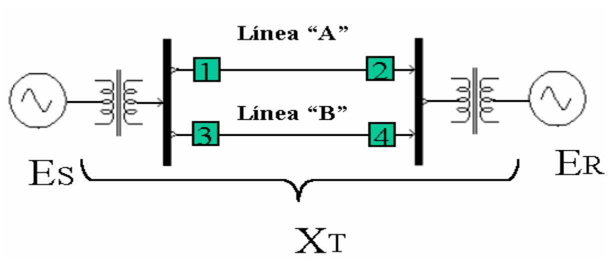


Figure 3.1 Power system with two generators.

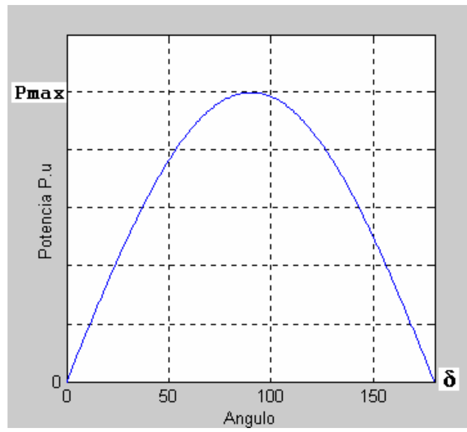


Figure 3.2 Active power & angle between sources.

The power swing can be produced by load changes, generation changes or faults. In order to analyze the behavior of the power oscillations in a interconnection line between two systems, we will analyze a fault in one interconnection line.

When a fault in the line "B" in the figure 3.1 happened, the power transmitted by the line "A" describe different states, the three states are:

- Pre-fault
- Fault (Short circuit in the line "B")
- Post-fault (The fault is cleared)

We will have a different maximum power for each one of these states, the most critical case is during the fault, because in that condition the power transmission capacity is the lowest

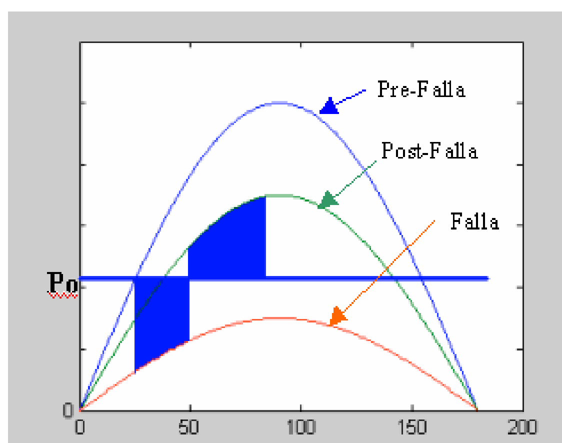


Figure 3.3 Equal-area Criterion

Depending on the fault duration and the type of fault (single-phase, bi-phase or three-phase), we can draw the curves Power(P) & angle (δ) for each state and analyze using the Equal-area criterion if the oscillation is going to be stable or unstable.

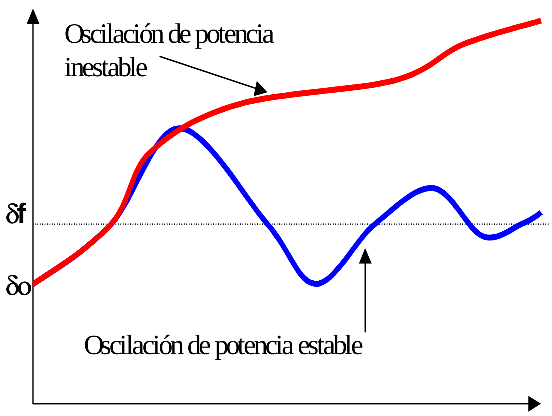


Figure 3.4 Stable and unstable oscillations

We also can draw the behaviors of the angle & the time, for stable and unstable oscillations, as it is shown in the figure 3.4.

Every power swing appears between two generators or groups of generators, which try to look for a new point of balance after a change in the parameters of the system or variables of state.

These oscillations are present in all the system, the severe oscillations are in the electrical center of oscillation, in this point the voltage can arrive at values near "0". The location of this electrical center depends on the generators location (sources) and the impedances among them (such as lines, transformers, etc).

Assuming that the electrical center of figure 3,1 after the disconnection of line "B", is in the line "A". When the angle "δ" is increased, the voltage in the electrical center diminish as is in figure 3.5. This diminution of the voltage originates that the impedance seen by the distance relays near the electrical center enters to the operation zones of them.

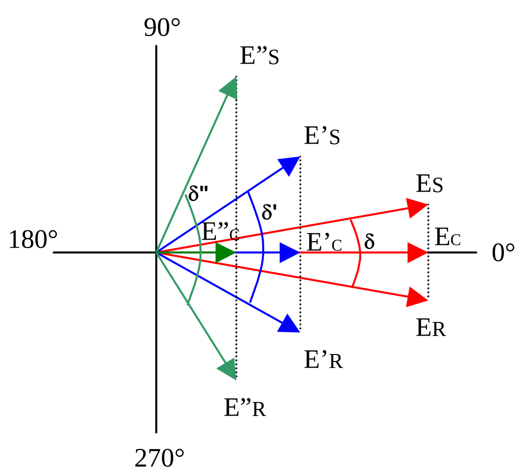


Figure 3.5 Phasors diagram of voltages in the system

The nearest distance relays to the electrical center are most susceptible to the power swing. There are many ways to block the relays during these power swings.

One way to determinate if a power swing is stable or unstable is using the measurements done by the distance relays, using the characteristic of impedance of the distance relays it is possible to determined the state of the power swing, in the figure 3.6 is shown the impedance seen by a distance relays in three stages

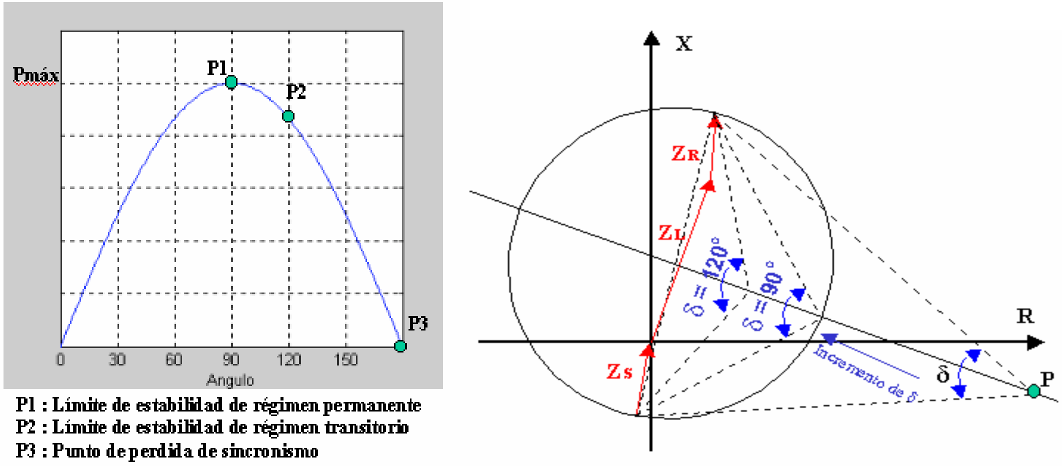


Figure 3.6 Power and impedance during a power swing

Point 1, is known as the limit of steady-state stability.
Point 2, is known as the limit of transient stability,
Point3, is known as the point of loss of synchronism.
The power systems would be separated before the point of loss of synchronism, for that reason there some schemes of area separation as it is shown in the figure.

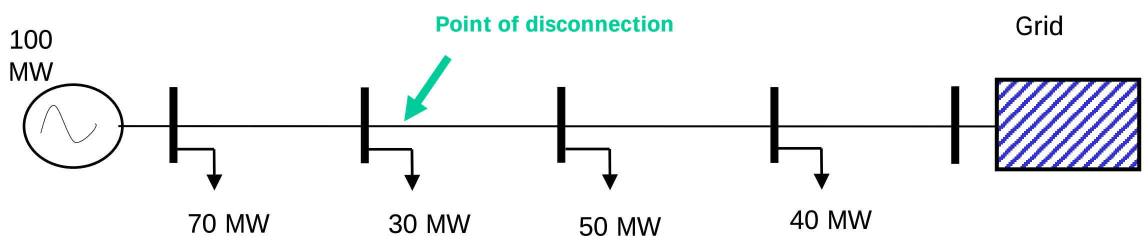


Figure 3.7 An area separation scheme.

What happen if we have an out-of-step, and we do not separate the areas?

The Out-of-Step (loss of synchronism) means that both systems are electrically separated but physically connected. The electrical separation, means that the frequency in both systems are different, in the time the frequency in the subsystem that lost synchronism is increased gradually, whereas in the other subsystem the frequency tends to diminish.

In the figure is shown an out-of-step condition originated by a fault in a line, is observed that in the system that loses synchronism the frequency is increased.

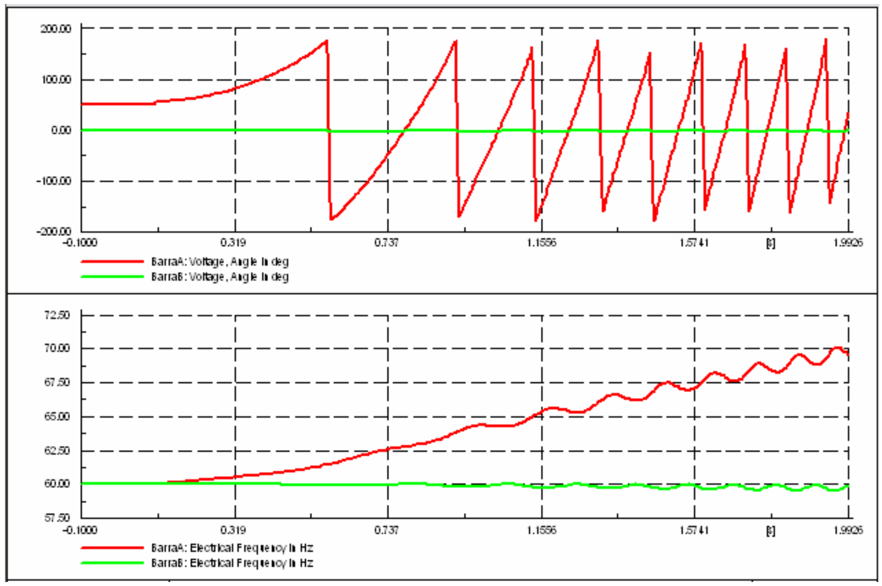


Figure 3.8 Frequency and angle during an out-of-step condition.

In the Peruvian Power system there some area separation under out-of-step conditions, but it happened an event in which the conditions of the system originated that the electrical center of oscillation was in a power autotransformer, and the distance relays did not detect the out-of-step condition, this event clearly was identified with the use of the transient recorders.

4. An Out-of Step-Condition and the Electrical Resynchronization in the Peruvian Power System.)

The Southeastern region of the Peruvian power system is shown in the figure

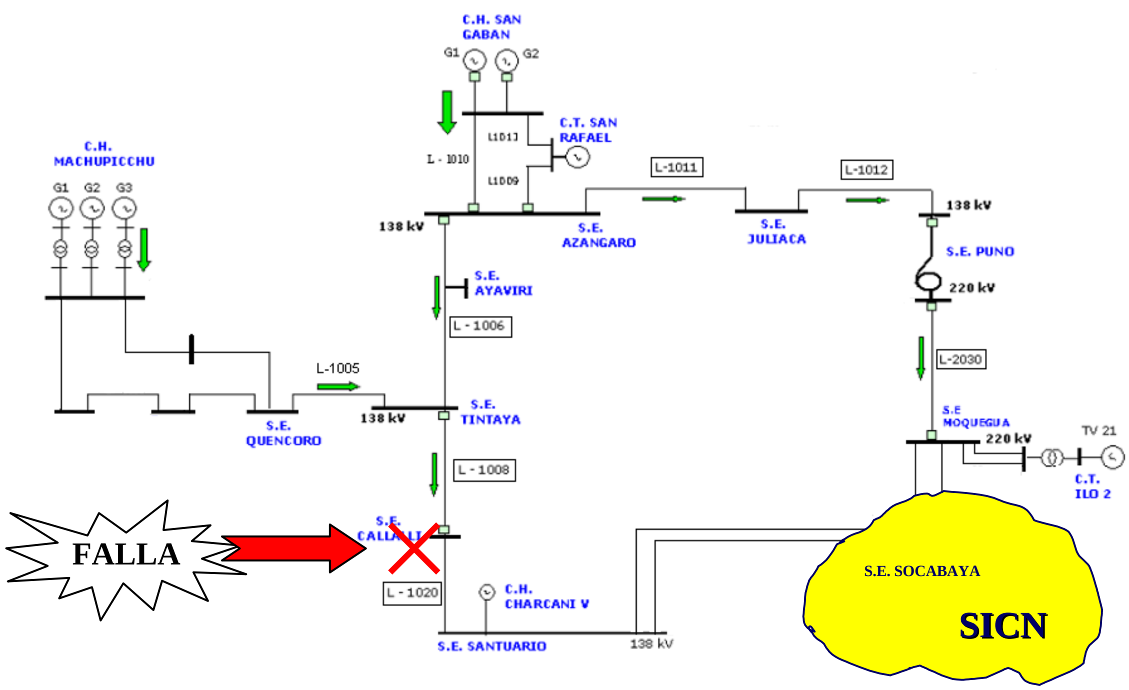
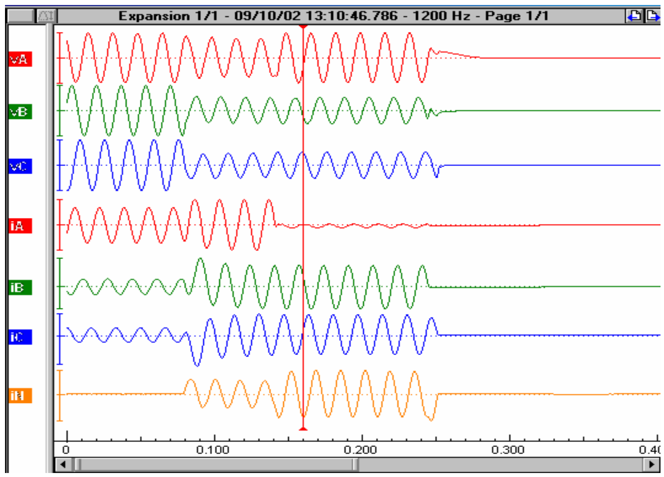


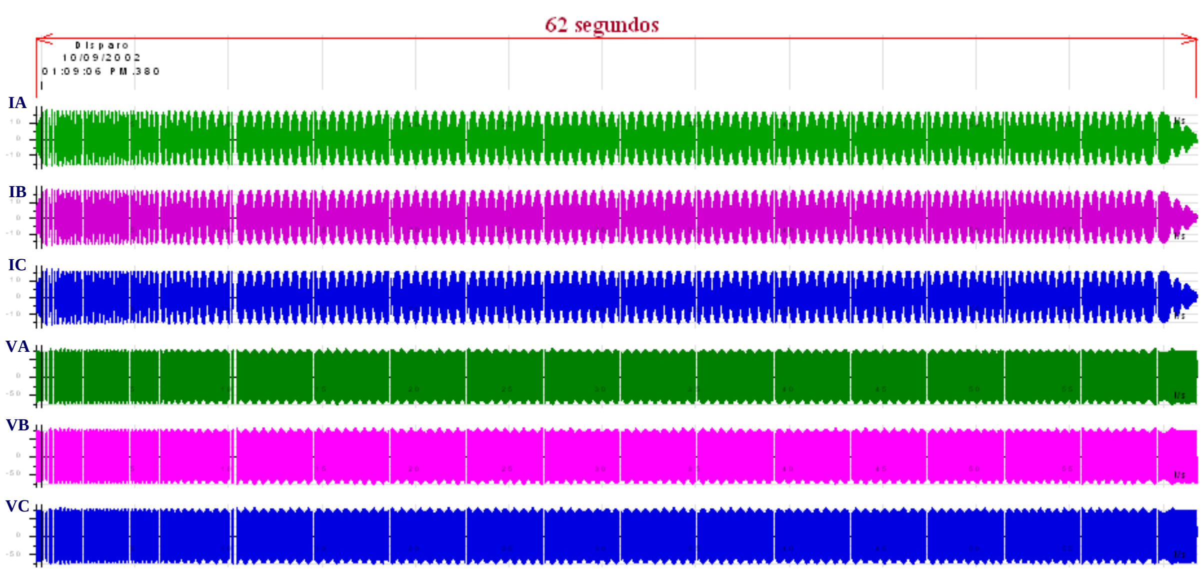
Figure 4.1 The Southeastern region of the Peruvian power system

This region is interconnected to the national grid through two connections, the lines L-1008/1020 (Quencoro-Socabaya) and L-1011/1012 (Azangaro-Puno). In these connections the lines have power swing blocking, and trip under out-of-step condition; in addition the San Gabán Hydroelectric has implemented schemes of tripping generation in case of lost of synchronism.

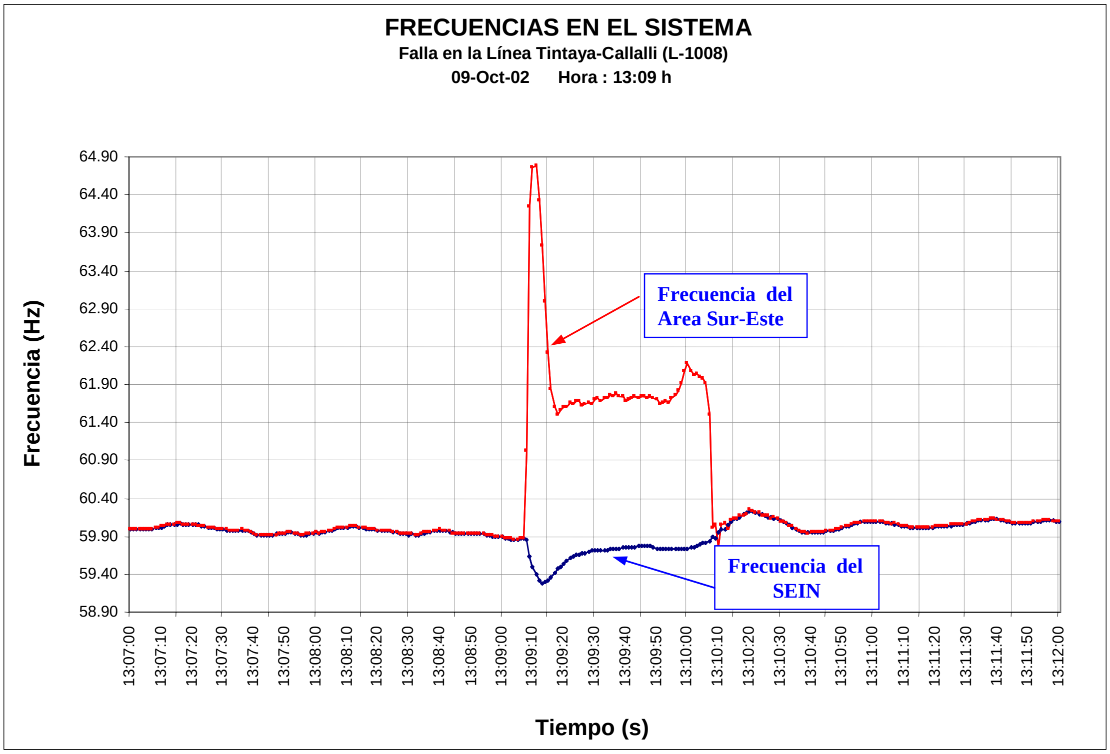
This event happened in October of 2002, In this event the line L-1008 tripped by a fault originated by lightnings, in the figure 4.2 is show the record of the tripping, After the tripping, San Gabán and Machupicchu tried to be evacuated the power through the connection Azángaro - Puno (L-1011/1012), producing an out-of-step-condition.



The electrical center of the power swing was in the Puno´s autotransformer, for that reason the distance relays implemented for the area separation scheme did not detect the out-of-step-condition

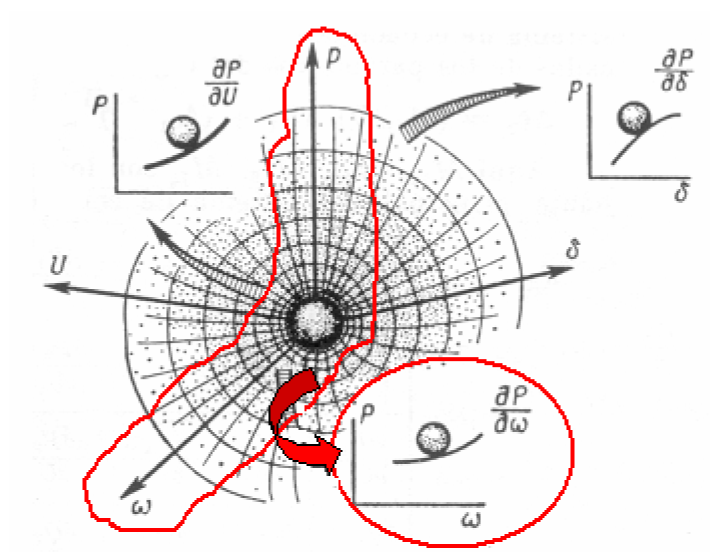


When the out-of-step condition was not detected, the frequency of the isolated System increased, whereas the frequency of the SEIN diminished as is shown the figure where the frequency in both systems are superposed.



From the superposition of frequencies it is observed that the frequency in the Southeastern region reached a value of 64,87 Hz, whereas in the SEIN a frequency reached a value of 59,28 Hertz; behaving like two separated regions.

The generation shedding during the out-of-step condition originate a resynchronization after 62 seconds. During this time the Southeastern region was physically connected but electrically disconnected.



This phenomenon, shows the use of the transient recorders to analyze a fault and some power system events of seconds, minutes and hours, becoming an important tool in power system analysis.

5. CONCLUSIONS

5.1 The weak connections are exposed to loss of synchronism conditions, for that reason the transfer limits must be calculated

5.2 When an out-of-step happen, the system must be separated in order to protect the power system. The point of separation must be evaluated using stability programs.

5.3 It is Possible to recover stability after an out-of-step condition (resynchronization), but this operative condition is dangerous.

5.4 The transient recorders an useful tool for power system analysis

6. REFERENCES

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