Electromechanical Transients Study in an Unbalanced Active Distribution System: A Colombian Study Case

Estudio de Transitorios Electromecánicos en un Sistema Activo de Distribución Desbalanceado: Un Estudio de Caso Colombiano

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ABSTRACT

In this article the analysis of the impact of electromechanical transients caused by the aperture of a line in an unbalanced Active Distribution System using the methodology of modeling and simulation in PowerFactory DIgSILENT software is presented. The results allow to determine the voltage limits coupled to the electrical system and the considerations to be taken into account for the settlement of the event. The paper is organized in the following way, presents an introduction to the topic of electromechanical transient and Active Distribution System, followed by the description of the case study and simulations, then the analysis and interpretation of the results are presented and finally the conclusions and recommendations.

Keywords: Active Distribution System, electromechanical transients, dynamic stability, Small Hydro Power Plants.

RESUMEN

En el presente artículo se presenta el análisis del impacto que tienen los transitorios electromecánicos causados por la apertura de una línea en una Sistema Activo de Distribución desbalanceado empleando la metodología de modelado y simulación en el software DIgSILENT PowerFactory. Los resultados obtenidos permiten determinar los límites de tensión acoplados al sistema eléctrico y las consideraciones que se deben tener en cuenta para la solución del evento. El artículo se encuentra organizado de la siguiente manera, se presenta una introducción al tema de los transitorios electromecánicos y a los Sistemas Activos de Distribución, seguido la descripción del estudio de caso y simulaciones, seguidamente se presenta el análisis e interpretación de los resultados obtenidos y finalmente las conclusiones y recomendaciones.

Palabras clave: Sistema activo de distribución, transitorios electromecánicos, estabilidad dinámica, Pequeñas Centrales Hidroeléctricas.

Received: July 24th 2015
Accepted: Oct 15th 2015

INTRODUCTION

In the last years, the electric distribution networks have suffered the technology development penetration that gives origin a change in the paradigm of the planning and operation of these networks (Dias, 2014). Commonly, the distribution systems had a very defined and know characteristics: A grid connected to transmission system that satisfies with give to the final users a quality, reliable and safe service. Nevertheless, different acts like the non-conventional generation inclusion, changes in the demand behavior, energy and information flows since generators until the loads and the other way around, the rise of new necessities like the energy storage, and others that have gone taking important part in the distribution grids, have done that its composition is not simple like the last described, however it becomes in a more complex set as in construction as operation (Sioshansi, 2012).

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Currently the electric energy generation was centralized and it was far away of the consumption centers, that is to say, big generation plants, hydric or thermals (for says the most used in the world), connect them to the distribution network through extensive lines laying belong to transmission system. However, the distributed generation appearance, has allowed that the electric energy is generated a little bit more close of the final user, is a lot more controllable and start to change the network settings (Boillot, 2014).

Since the demand side had been changes related with its behavior. Now is not the passive user, that was connected in the network for satisfied its necessities for becomes an active participant in the supply process (Sioshansi, 2012). End-user are implementing generation through non-conventional resources, creating a bi-directional electrical flow and bi-directional information, these concepts is known as Producer-consumer or *"Prosumer"* (Chowdhury and Crossley, 2009).

Viewing the distribution system since its two sides (generation and demand) it can imagine a few portion of it with its own generation and its specific characteristics demand operating in particular mode in coordination with other factors intrinsic in the same network like storage device, correct protection systems and demand management programs in pro of rational energy use, giving origin a new paradigm called "*active distribution networks*" (Chowdhury and Crossley, 2009).

Due of the growing complex in the distribution network, this cannot analyze of the same way that did some years ago, where for example, the stability of voltage analysis just were in the transmission network . Now is necessary of realize in the distribution network due to distributed generation (Carvajal, 2011).

As mentioned above the complexity of the distribution network is giving, as in its planning as in its operation and in this ideas order the vulnerability to disconnections had been latent (Calderón-Guizar, 2010). The most frequent events in the electric power systems and cause the greater amount of operative difficulties in the electric distribution networks are the monophasic and three-phasic faults, which trigger transient events, which should analyze for to know its consequences and solve methods (IEEE, 2014).

Colombia is a country socially convulsed and geography diverse, presents a high vulnerability to faults in its electric system. For a side, the terrorist attempts against the electrical infrastructure and the other the nature events like lightings, fall of trees in transmission lines, and others, do the stability in the networks and continuity in the service is a permanent challenge.

In addition, in May 2014 it has been implemented in Colombia, a regulation that encourages investment in distributed generation and currently, the capacity of DG is limited rigidly by distribution network operator (DNO) to avoid the negative effects of high level penetration. Active distribution networks, is a researcher proposal based major in implementation of local and coordinated control of voltage, flows and fault levels. For control distribution networks is necessary first understand the behavior of distributed grid when occur any faults. In this paper, an analysis of electromechanical transients caused by faults in a distribution networks with small hydroelectric power plants is proposed. Considering the high embedded of this type of distributed generation in Colombia.

ACTIVE DISTRIBUTION SYSTEMS

An active distributions system is defined as an electric system that has the ability of operate connected to the transmission system and assume time can disconnecting of him and operate in islanding mode with all guarantees in the supply of service and the quality of the same (Romero, 2015). This disconnection of the transmission system can gives accidentally because of inspected event like are the faults, they can be due natural phenomenon (for example the lightings, fall of trees in lines, animals in some bay in the substation, and others) or for human faults (mistakes in electrical operations or maneuvers of grid operator). (Boillot, 2014).

Inside of the active distribution system concept, is very important to know the definition of mini-grid, being that, like can to see more forward, one of the possible consequences of the appearance of a fault in an active distribution system is the building of a mini-grid.

A mini-grid can be defined like an electric distribution network which is operating typically in values under 11 kV (DANIDA and UNEP, 2012). The electric energy that powers the mini-grid comes of different small local sources, generally implementing renewable energies. Is important to say that in a mini-grid can existing or not, storage devices (Hazelton, 2013).

In the same way, the active distribution systems different to the conventional distributions network, have a high penetration of distributed energy resources, which those are basically three: distributed generation, storage systems and participative demand (Chaulan, 2014). The central zone of the country, is rich in hydric resources and for this reason the hydraulic generation is the most used in the region and in this kind of generation the rotary machines playing a vital role for becomes the necessity of analyze events inside of them like is the case of the electromechanical transients. The hydric wealth in this zone of the country has accommodated to building of small plants of minor capacity compared to the big generators and are called *"small hydroelectric power plants SHP"*, which are those that have a capacity installed minor or equal to 20MW and in turn can be subdivided according to its power in pico-centrals (0.5-5 kW), micro-centrals (5-50 kW), mini-centrals (50-500 kW) and small centrals (500-5000 kW) (INEA, 1997). The SHP have been means of generation that have entered to a very important place in the planning of the active distribution systems.

In an unbalanced active distribution system, which have distributed generation through SHP, passive demand and addition to is operating in islanding mode, going to realize a study for determine the impact that the electromechanical transients can cause on that system when it have a single phase to ground fault.

TRANSIENT EVENTS

A transient is defined as an electric power system parameters disturbing that can presents like consequence of a high contingency like a fault in the system (Kundur, 1994). Given a transient event, the system response is called *"transient regime"* that have like main characteristic a progressive extinction in time, and this time is that the system use for recover the normal values. The last differs of the *"permanent regime"* that is the system response without disturbances (Vénikov, 1985).

Different authors have classified the disturbances that can happens in an electric power system according to various criteria. One of those criteria classification is according to the duration in time of the disturbance event. The short-term transients are called electromagnetics. The transients of median term are called electromechanicals and finally the transients that considers the long term which preserve the name of transients though some authors have been defined like thermo-energetics transients (Vénikov, 1985).

Electromagnetic Transients

An electromagnetic transient is the instantaneous response of an electric system to sudden changes of its initial state to different state, caused for maneuvers inside the same system, for faults in the network or lightings (Vénikov, 1985).

Electromechanical Transients

The electromechanical transients are those that interact between the mechanic energy storage in the rotary machine and the electric energy storage in the electric system. Is considered inside this group those events happened in t=5s and its duration can reach to presents for a few minutes (Vénikov, 1985). The study of this kind of transients, can means to future, established boundary conditions of dynamic stability of the parameters of the different machines coupled to the electric power system like are the motors in the plants and along the network (Kuiva, 2008).

The simulations that will show in this article were made implementing this last kind of transients.

STUDY CASE

The simulations made in the present study case, were made above a real model of the electric distribution system in a town called Salamina.

Salamina is a town in the north zone in the Caldas department which is in the center of west of the Andean Region of Colombia, like is shown in the Figure 1.

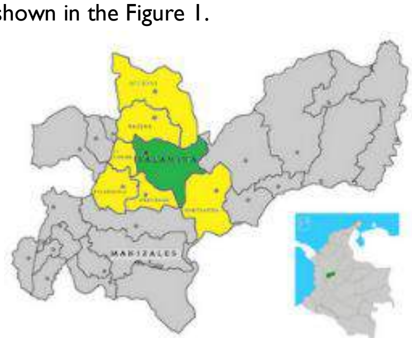

Figure 1. Location of Salamina – Caldas – Colombia [Source: www.salamina-caldas.gov.co]

There, in the Salamina substation that has a transformer 33/13.2 kV with a capacity of 4MW. The line of 33 kV that reach to Salamina substation, comes of the Interconnected National System (SIN). Of the bus bar of 13.2 kV left three powers of lines that distributed for the town (SLM12L12, SLM12L13, and SLM23L15).

"La Frisolera" is the name of the SHP that have planned put on service in the town of Salamina - Caldas and inside of its three alternatives of connection required by CREG ("*Comisión Reguladora Energía y Gas)* in the resolution CREG 025-95 (Networks code) and CREG 106-06. The alternative studied in this paper is the connection of *"La Frisolera"* in the feeder SLM23L12. In the Figure 2 can observe the single-line diagram of the network.

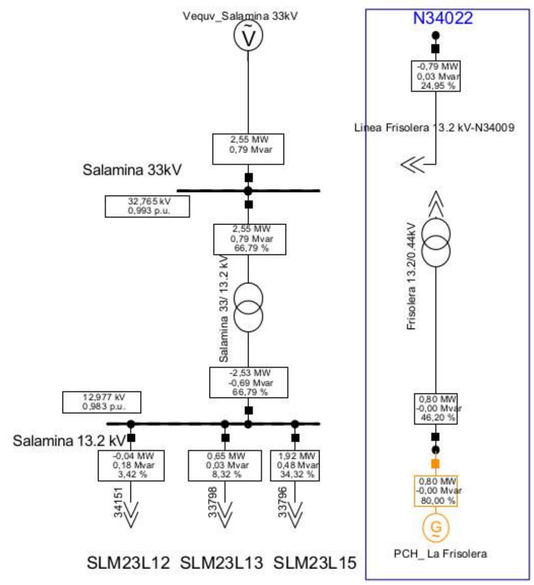

Figure 2. Single line diagram network of study

The Table 1 shows a summary of the distribution system in that will realize the simulations.

Table 1. System distribution parameters

Parameters	Values
Transformer capacity	4MW
Power size	2/0 ACSR
SHP capacity	1 MW
Generation capacity	0.8MW

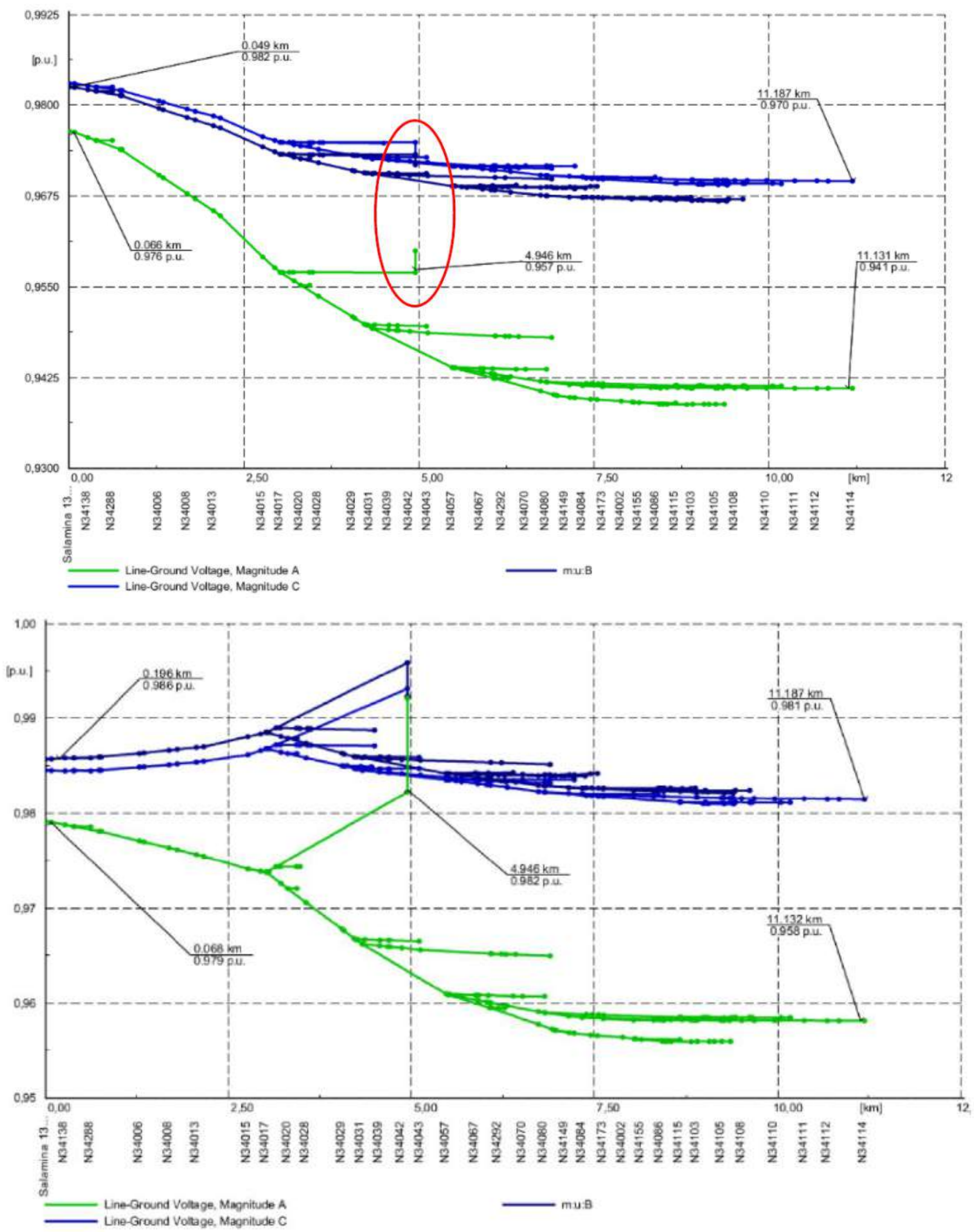

Figure 3. Unbalanced active distribution system and improve voltage profile after connection of SHP "*La Frisolera*"

The SHP "*La Frisolera*" is equipped with a synchronous machine with a capacity of 0.8 MW and the distribution network to study. The active distribution system is unbalanced; the chargeability of the three phases is different. This event can be seen in the Figure 3. This figure shows the unbalance before and after the connection of SHP *"La Frisolera"* thus allowing for the improvement in voltage profile due to the connection of the SHP.

The demand, in this case does not have self-generation, cogeneration and demand management programs, for these reason is a passive demand.

This demand is absolutely residential which it involves a behavior following the characteristic curve of electric energy consume in the residential sector in Colombia and assumes that along of the distribution line does not exist special loads such as those are commonly use in the industrial sector.

When happen a fault in the bus bar Salamina 13.2 kV, the overcurrent protection (relay 50/51) operate and the switch in the low side of the transformer Salamina 33/13.2 kV is open, and the town is disconnected of the SIN. Afterward of occurred the fault and is not clear yet, the switches of the lines SLM23L12 and the protection of transformer are open (see Figure 4) and is possible implement the operation by islands.

The SLM23L12 line, has connected in some place of its path, the SHP *"La Frisolera"* with capacity of 0.8 MW for be dispatched and both (line and generator) form and island outside of the transmission system. In the beginning the system reference machine was the voltage of the transmission system, but after the event the new reference machine is the SHP.

SIMULATIONS AND RESULTS

The simulation consists in a single phase to ground fault that occurs on feeder SLM23L12 after the island has formed. *T*he objective is to analyze the impact on active distribution system or mini-*grid* unbalanced after a single-phase fault occurs.

Simulation cases

Case 1: After two seconds the island or mini-grid in the SLM23L12 circuit is formed. Simulating a single-phase fault on phase A (phase lower voltage level) at five seconds is performed, then 100 ms (typical time set by a recloser) after the fault it is clear and the mini-grid continues its normal operation.

Figure 4 shows that during the first two seconds the feeder has a stable voltage between 13126 V and 13014 V, after two seconds the island is formed, appearing an electromagnetic transient voltage variation which is within the recommended limits +/-10% [IEEE 1547]. Once the voltage begins the process of stabilization, a failure within 5 seconds and 100 ms after it is cleared simulated, appearing a voltage drop on Phase A of 12758 V and finally the voltage establish with a value of 13824 V.

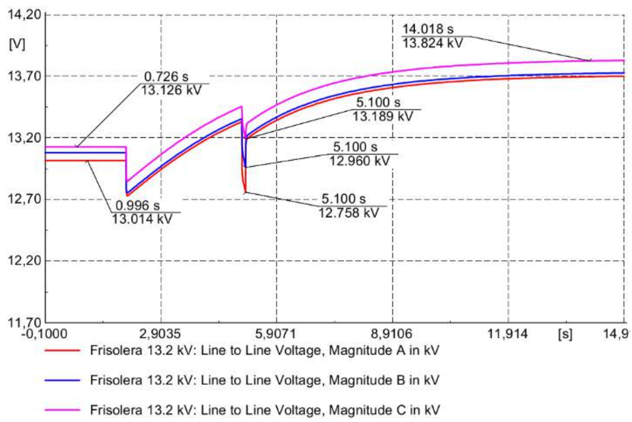

Figure 4. Case1: Answer of voltage in the substation of SHP "La Frisolera" to the single-phase fault on phase A

Case 2: After two seconds the island or mini-grid in the SLM23L12 circuit is formed. Simulating a single-phase fault on phase C (phase with higher voltage) at five seconds is performed, then 100 ms after (typical time set by a recloser) the fault it is clear and the mini-grid continues its normal operation.

Figure 5 shows that during the first two seconds the feeder has a stable voltage between 13126 V and 13014 V (values similar to Case 1), after two seconds the island is formed, appearing an electromagnetic transient voltage variation which is within the recommended limits +/-10% *[IEEE 1547]*. Once the voltage begins the process of stabilization, a failure within 5 seconds and 100 ms after it is cleared simulated, appearing a voltage drop on Phase C of 12012 V and finally the voltage *establish* with a value of 13810 V.

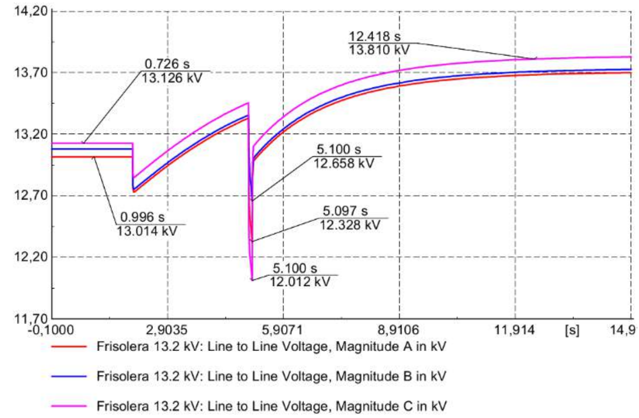

Figure 5. Case 2: Answer of voltage in the substation of SHP "La Frisolera" to the single-phase fault on phase C

After performing the simulation of the formation of the island and the simulation of single-phase fault on different phases of the circuit SLM12L12, the Mini-grid presents operating in isolation, which will have the condition until the moment the service is restored STN. In Figure 6, the final condition of the mini-grid is show.

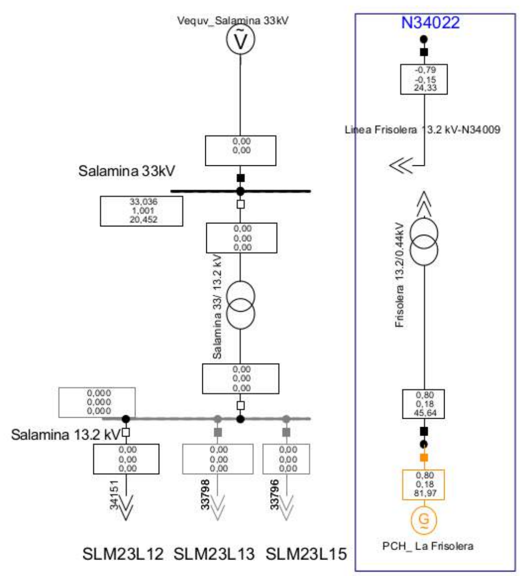

Figure 6. Single line diagram network of study after the fault

CONCLUSIONS

The probability of a single-phase fault occurrence distribution systems is around 70% (compared to other types of failure), unbalanced systems such failures can cause tripping generator protection relays, substations and bars. In this paper it is shown that the response of an active unbalanced distribution system before a disconnection event, the limits are in appropriate ranges. However, when the Active Distribution System operates in isolated mode (Mini grid forming) the system becomes more vulnerable to events of single-phase faults.

Due it is not possible to determine the place where a failure occurred, the simulation is performed in the major and minor phases loaded. The simulation shows that an active unbalanced distribution system, failures occurred on the most loaded phases may cause the protections (relay 81) of the machines operate and not allow operation by islands.

Therefore, to have a proper operation mini-grids is necessary to know the percentage of imbalance of Active Distribution System and adjust the protections against over current (relays 50/51) and against overvoltages (relay 81) in generators and substations.

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