Digital Algorithm for the Protection of the Interconnection, Utility-Industry, Operating in Co-generation Systems

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ABSTRACT

This paper aims at developing a digital algorithm for the implementation of a protection in the interconnection "Utility-Industry", operating with co-generation systems. The disconnection of the two systems is always something difficult to be done, because it implies in technical and economical risks, for both: the utility and the industry. A multi-function protection with a systemic view of the main operative conditions is proposed, with special attention to: the automatic reclosing caused by a short-circuit at the utility; the power swing followed by the energy deficit between the two systems; and the islanding – "a condition of part of the utility load to be fed by the industry in case of partial or total loss of its own feeding process. Under a mathematical point of view, the impossibility of the use of just one observation window for these phenomena due, mainly to their frequency characteristics (high and low frequencies), motivated the search of new mathematical tools, such as the wavelet transform for the classification of the events, obtaining satisfactory results. Through specific algorithms for the location, type of fault duration, measurement of point "E" at the stability curve for the power swing, and the measurement of the 5^{th} harmonic for the islanding, the COGERA algorithm for the protection of the interconnection is obtained.

Key Words: Co-generation, Wavelet Transform, Reclosing, Islanding, Power Swing.

I. INTRODUCTION

The increasing demand of energy at various industrial plants, together with the recent policy of privatization, has made industries generate part, or a great part of their electrical needs, aiming at a low cost. Despite its rapid popularity, the operation of electric connection between the utility and the industry present problems still to be solved.

Concerning protection, it is a great challenge to introduce an integrated solution for the problems caused by this interconnection, once, for some of these industries, a deficit in the consumption means economic loss, which they can not take.

Item 2 discusses the inherent phenomenon of a co-generation system and their operative aspects. The protection systems, where conventional rearguard protection for generators is applied with a longer coordination time, currently in use, is also discussed.

Items 3 and 4 propose a digital algorithm to implement the protection of the interconnection utility-industry. This algorithm named – COGERA – first classifies the various events at the interconnection, such as: short circuit at line (type of fault, transitory or permanent); short circuit at industry; loss of synchronism and islanding. After this classification the algorithm identifies the situations that might imply in damage risks for the co-generation plant or for the utility's consumers. It also promotes the disconnection of the interconnection with a consequent break between the two systems. In order to have the classifying function implemented, new methods, to observe the current and voltage signs, were studied: clusters analysis, use of Fast Fourier Transform, use of Wavelet Transform and use of energy concepts contained in these signs. Obtained results are discussed in item 3.

In item 4, the COGERA algorithm development is presented with results, conclusions, suggestions and approaches that can be used as basis for future researches on the subject.

II. CO-GENERATION SYSTEMS

A. Basic Concepts

Figure 1 presents a typical configuration of an industrial plant with its own generation connected to the utility in high-voltage, which operates in parallel or isolated, to supply part of its electric energy consumption.

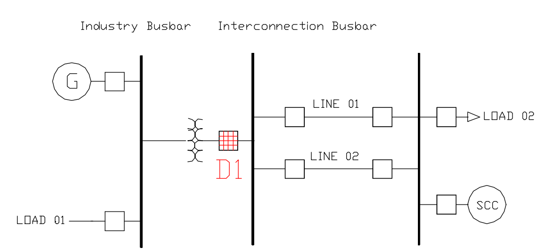

FIGURE 01 – UNIFILAR DIAGRAM

In Brazil this generation is basically done with gas, (petrochemical industries); with steam (cellulose and paper industries); or with sugar cane bagasse (refused matter of crushed sugar cane) at sugar and alcohol industries, where power generators vary from 10% to 40% of plant nominal power. It is important to notice that lines 1 and 2 of the utility operate under normal/reserve conditions, and that this configuration is presented as the most common one in the electric system – therefore assumed along this work.

Nevertheless, some aspects still need a more careful analysis, such as:

- the connection point between the 2 systems;
- the grounding system;
- the protection device.

At the connection point, the interconnected systems – specially the high voltage ones- represent the most favorable condition, taking into consideration the aspect of interconnection protection because the transformer impedance decreases the effects for the utility, in case of a short circuit. For the generator grounding system, the resistance limits the faults value to ground and attenuates, significantly, the current of third harmonics generated by the engine. At the transformer, the delta connection in high voltage limits the contribution of the generator for a phase-to-ground short circuit of the utility and enables the detection of phase-to-ground faults. The most used functions for the protection of generators are:

- 50/51 - overcurrent;
- 67 - directional overcurrent;
- 27/47 -under voltage and lack/sequence of phases;
- 81- absolute frequency;
- 25- synchronism;
- 32- power reversion;
- 40- loss of excitation.

Among above-mentioned functions, there are some, which can be applied to protect the interconnection. This sort of solution has the function $\delta F/\delta T$ added to function 81; and function 59 to functions 27/47, that complemented by the vector surge function, and power variation index at generator ($\delta P/\delta T$), are the available protections in the market for the protection of the interconnection. Relevant to mention, that these protections depend on the active power flow interchanged between the systems, to make its measurements more effective.

In fact, when some of the mentioned functions are proposed as protections for the interconnection, their coordination demands some time, with specific protection of other equipment. This, therefore, makes the time between decision and separation of the two systems excessively long, propitiating the damage of the generator of the industry.

On the other hand, the adequate use of the complementary functions as the vector surge and the power variation of the generator ($\delta P/\delta T$) originate adjusting criteria that are very sensitive and difficult to be calculated, demanding a rigid criterion for a correct use.

The main research line of this paper is to focus on a systematic view of the mentioned events that might propitiate a rapid and accurate decision for opening the interconnection between these two systems, aiming, at the integrity of the industry generator.

B. Requirements for a multi-function protection of interconnection

The utility never takes any responsibility for the protection of consumers' generators and equipment of the industry (Norm CPFL/ref2). The consumer has to be responsible for an efficient protection of all installation, as well as for all the equipment, in such a way that faults or disturbances in the utility system will not damage the equipment. The industry, on the other hand, cannot energize deenergized circuits of the utility.

Due to these norms, there are 4 operative conditions that should be avoided:

a) reclosing of utility's circuit breakers without having the voltage of the two systems perfectly synchronized. This situation may occur after the opening and reconnecting of circuit breakers 1 and 2 – figure 1 – due to a fault in line 1. In case the 2 systems are not really synchronized, this reclosing may produce mechanical demands at the axe of the industry generator.

b) Islanding of industry generation feeding some utility's consumers, where such condition may occur after a loss of generation at the utility through an opening of its equivalence. (See figure 1).

c) Electromechanical oscillation provoked by an unbalance between generation and load in the utility's system, causing mechanical demands at the axe of industry generator. Depending on the magnitude of this oscillation, the protection of the interconnection should open the connection between the two systems.

d) For the condition of short-circuit, the proposed algorithm will check the type of fault (phase-to-ground, phase-to-phase and three-phase) and will only allow for the reclosing after checking the synchronism of D1 circuit breaker if the short-circuit is phase-to-ground and transitory. This measure aims at protecting, effectively, the generator of the industry against reclosings originated from more severe faults in the utility system, as well as phase-to-phase faults and three-phase faults, not only at the interconnection lines, but also in other equipment that need a more careful inspection after the occurrence of the faults, as in the substation transformer of the utility, for example.

III. CLASSIFICATION OF SIGNALS

A. Introduction

One of the most important aspects of the COGERA algorithm is the possibility of classifying accurately the three main events under the systemic point of view for the interconnection, that is: the short circuit, the electromechanical oscillation and the islanding.

A tool is under research to have this classification done fast and efficiently.

Figure 2 shows the simulation of a short-circuit condition at the instant 96.6ms or at sample 600, where: the presence of a component of 60Hz is noticed; the deadening exponential component is seen, as well as the variation in module of current signal.

The aspects of high frequencies can also be observed in some cases of monophasic short-circuits with electric arc at the voltage signals of faulty phase.

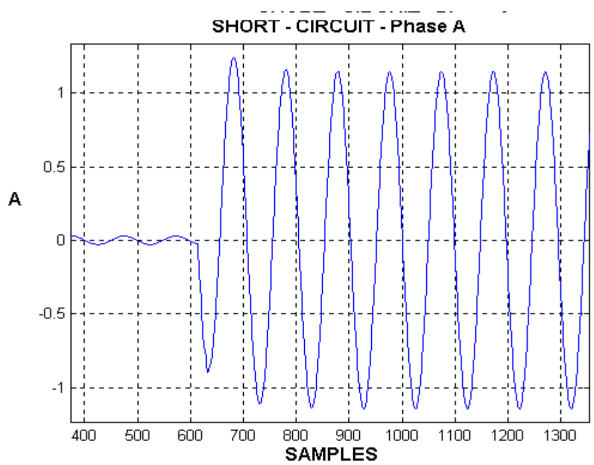

FIGURE 02 – SHORT CIRCUIT WAVEFORM

Considering the condition of electromechanical oscillation shown in Figure 3, at the same point of previous simulation, the insertion of big blocks of load in the interconnection line was mathematically modeled, between the utility and the industry, obtaining the modulation for low frequencies (0.5 to 4 Hz) at current signs and voltage.

The islanding has the following operative condition: before opening the circuit breaker of the utility generation, there is no active/reactive power flow exchanged between the two systems. It means that the current, which circulates through the interconnection line has, as its main purpose, to energize the high voltage transformer at the industry substation, presenting, therefore, juxtaposed harmonics to the fundamental component of 60 Hz before the opening of the utility's circuit breaker – fact that also happens at the instant 96.6ms or at sample 600.

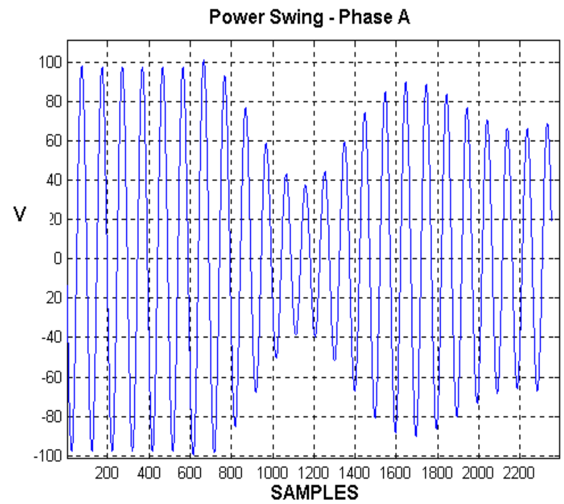

FIGURE 03 – POWER SWING WAVEFORM

After the opening of this circuit breaker the low value load of the utility will then be fed by the industry generator that will energize the high voltage transformer by the low voltage side (13.8kV). The high voltage has a typical 60 Hz component that feeds utility's loads.

Respective waveform is shown, as follows:

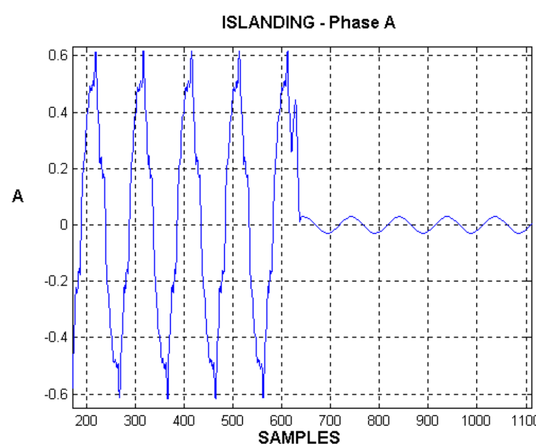

FIGURE 04 – ISLANDING WAVEFORM

B. Wavelet transform and standard deviation of their coefficients

Following the concepts shown in the bibliography, the wavelet transform presents a possibility of detecting, simultaneously, high and low frequencies, contained in the signals due to the characteristics of "a" and "b" parameters, and Salama et al (ref.1) applies this concept, so that through the standard deviation of the coefficients of each level, it enables visualizing better the events and after defining more clearly which of these levels should be better analyzed. This analysis is just another representation of the signal energy and, besides the obtained juxtaposition in the cluster analysis in the development of the project, a move of the position in the plan can be seen, when the window is juxtaposed to the subjected phenomena. There is a variation of signs energy that may be useful later. The proposal consists on the following:

Energy calculation of each level given by Parsevals's theorem:

$$\int [\Im(t)]^2 \cdot dt = \sum_{k=-\infty} [c(k)]^2 + \sum_{j=0}^{\infty} \sum_{k=-\infty}^{\infty} [d_j(k)]^2 \qquad (01)$$

where, according to Mallat's algorithm (see reference in attached 2), c(k) is an approximation of the original signal and d (k), its detailed version. Both correspond to Wavelets coefficients.

The calculus of the detailed version of standard deviation (coefficient d (k)) of each level, through the formula below:

$$s_x = \sqrt{Variância(X)} = \sqrt{E\left[(X-m)^2\right]} \qquad (02)$$

where μ is the mean coefficient of each level contained in each window.

The central frequencies of each level are described in table 1 following Mallat's theorem for the sampling frequency of 5760 Hz (96 samples/cycles), where the first frequency of level 1 is the Nyquist's required frequency. After that, a graphic with standard deviations for all levels, for the current signs to be analyzed, was prepared.

Table 1 below, together with above comments, indicate that level 10 with range from 2.81Hz to 5.62 Hz, is the most appropriate one for the power swing phenomena analysis. Level 6 with a range between 45 to 90Hz for the short, as this phenomenon is typical of fundamental frequency. Lastly, level 4 for the islanding, because its range of 180 to 360 Hz comprehends mainly the fifth harmonic, that is, the 300Hz.

	2880 Hz		90 Hz
Nível 01 ?		Nível 06 ?	
	1440 Hz		45 Hz
Nível 02 ?		Nível 07 ?	
	720 Hz		22,5 Hz
Nível 03 ?		Nível 08 ?	
	360 Hz		11,25 Hz
Nível 04 ?		Nível 09 ?	
	180 hz		5,625 Hz
Nível 05 ?		Nível 10 ?	
	90 Hz		2,81 Hz

TABLE 01

The following adjustments are suggested for obtaining this graphic:

a) Power Swing: a window of 20 cycles at level 10 moving on the sign with a juxtaposition of 50% between them was used, aiming at obtaining the widest energy variation range in order to detect the low frequencies of a more effective form.

b) Short circuit: a four-cycled window for level 6 with juxtaposition of 50% was also used.

c) Islanding: Level 4 (same procedure as above)

The appliance of these windows over signs under observation propitiates obtaining the variation of the respective standard deviation coefficients of the levels, as shown in figure 5 for a short-circuit case, e.g.

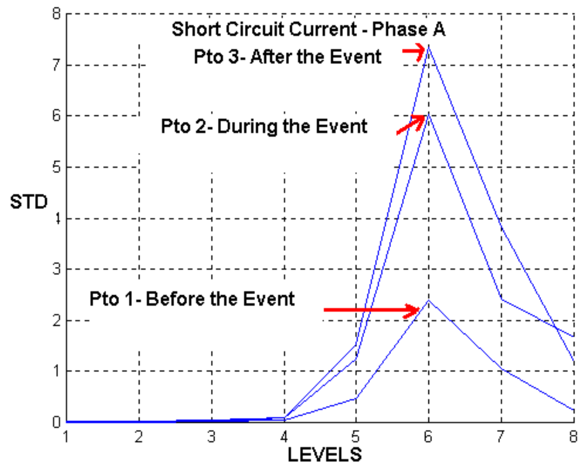

FIGURE 05 – STANDARD DEVIATION SHORT CIRCUIT

After that, the maximum and minimum value ranges can be obtained, which through software enables an accurate classification of the three mentioned operative conditions.

This procedure obtained 95% rightness in the 300 simulated cases, where the performance can be bettered for phase-to-ground faults with the introduction of a logic negative sequence.

IV. THE COGERA ALGORITHM

Once the phenomena are classified, a systemic vision of the connection between the industry and the utility is learnt. For the short circuit cases the Prakash's algorithm based on signs ΔI and ΔV to determine the fault location. This process has proved to be fast and efficient, independently from the connection system of the transformer, mainly for phase-to-ground shorts. When location is defined, if it is at the utility, the type of fault is to be determined and an angle between the positive and negative sequences is used, so that the phase-to-ground faults will be zero or next to zero.

To determine if the fault is permanent or not, the measurement concept of the current arc is simulated by a kind of square wave in phase with the short current generating harmonics at the terminals of voltage wave forms. The main aim in this case is to allow for the reclosing of the utility if the fault is monophase and transitory.

Figures 6 and 7 show the block diagrams of the fault analysis process and the simulation of the measurement between the sequence angles.

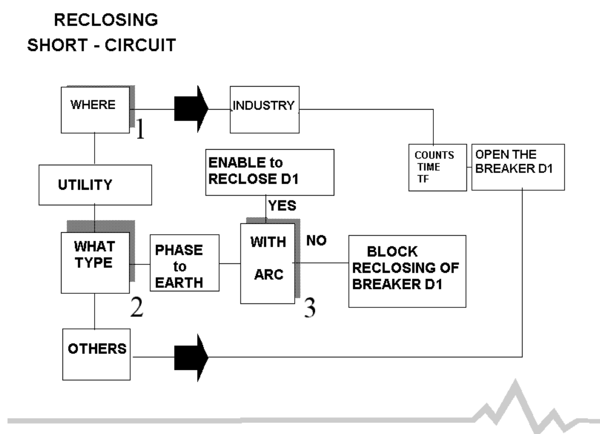

FIGURE 06 – BLOCK DIAGRAM FOR SHORT CIRCUIT

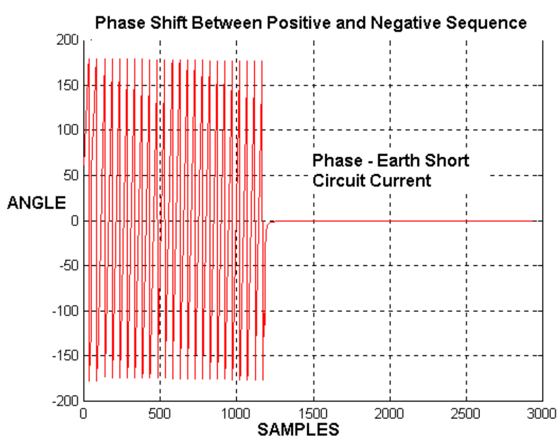

FIGURE 07 – ANGLE BETWEEN POSITIVE AND NEGATIVE SEQUENCE.

In the following general block diagram of Figure 8, all main steps of COGERA algorithm can be observed, highlighting the beginning of the process due to energy variation and the aspects of mentioned classification. The short-circuit algorithms, the power swing algorithm and the islanding algorithms are not detailed due to their length

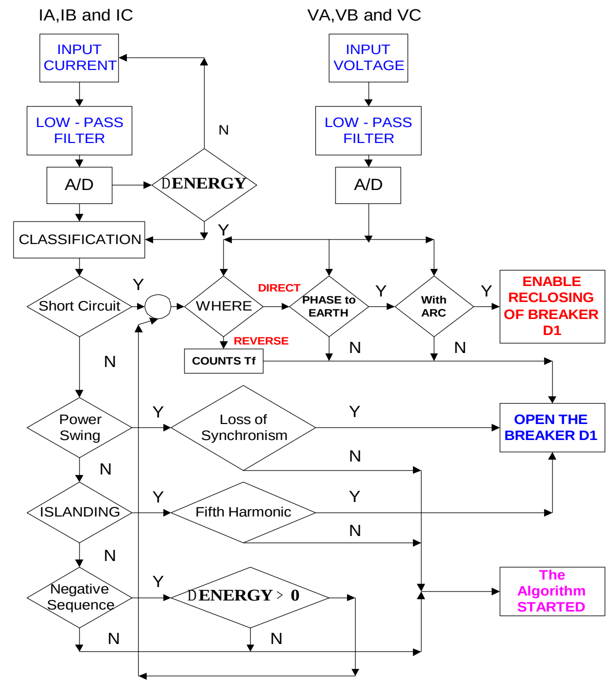

FIGURE 08 – BLOCK DIAGRAM COGERA ALGORITHM

V - CONCLUSIONS

The use of a new mathematical tool to classify the events has proved to be efficient and fast. The fact that a one-sized window can not be used due to the low frequency aspects (power swing), and due to the high frequencies in cases of short and islanding, enabled the algorithm scales of wavelet transforms to be a reasonable alternative solution for the problem. Another relevant aspect to be discussed is that a more careful simulation is needed, applying specific software such as MATLAB in order to obtain values that define the standard deviation ranges for later classification.

At last, it is important to mention that this paper is a summary of a PhD's theses for POLI/USP – "The Polytechnic School of Sao Paulo University" to be concluded in December 2001. The COGERA algorithm is being implemented for both, MATLAB, and C, C++ programming languages.

V. BIBLIOGRAPHY

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VI. BIOGRAPHY

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