The distributed generation semi-rigid connection as a tool for the Smart Grids

S.M. Nesci[(1)] L.D. Sanchez[(1)] J.C. Gómez[(1)]

(1) National University of Rio Cuarto, Rio Cuarto, ARGENTINA

***Abstract* —** Smart Grids arise as a solution to the big contemporary problems of the energy distribution. The short circuit currents are modified by the presence of the distributed resources, requiring of particular analysis methodologies. Customers´ equipment (appliances), are highly sensitive to the apartments of Power Quality. The use of the distributed resources presents the high risk to the unintentional island operation. The semi-rigid connection, that instead of disconnecting the resource of the grid in the event of perturbations, it maintains it connected through a limiting impedance Zv, presents several advantages. The design of the interconnection impedance is proposed from the results obtained by experimental and Simulink-Matlab modeled studies, from which the optimum impedance value can be determined. It is concluded that the semi-rigid connection of the distributed resources in an environment of Smart Grids gives a series of advantages that widely justify its application.

Keywords: Distributed generation, semi-rigid connection, Smart Grids.

I. INTRODUCTION

Smart Grids arise as a solution to the big contemporary problems of the energy distribution such as the lack of new energy resources to answer to the growing demand, the saturation of the present-day distribution systems, the opposition to the construction of new grids, the increase of the ecological conscience, etc. The introduction of these smart grids is broadly favored for the availability of new technologies of telecommunications and teleoperation, but it is also limited firstly for the capabilities of the already installed equipment and in second place for the requirements of the modern equipment (appliances) that the users connect in these grids, those that are highly sensitive to the apartments of the Power Quality [1, 2, 3].

The first aspect is related fundamentally with the capacities to cope with the short circuit currents that are modified by the presence of the distributed resources (generators and storage equipment). Also, the characteristics of these fault currents are very particular, for what requires of analysis methodologies different to the traditional ones [4, 5].

The second aspect is the high sensibility of the customers´ equipment (appliances), denominated Sensitive Equipment (SE), to almost all the apartments of Power Quality, of those which here only the short-interruptions and voltage sags will be analyzed [3]. Understanding for short-interruptions to all interruption with duration shorter than a minute. It is considered a voltage sag the voltage reduction of rms value between 90% and 10% of the rated value, with duration between half cycle and one minute.

II. DISTRIBUTED RESOURCES CHARACTERISTICS

The distributed resources (DR), being generators or storage devices, supply energy to the distribution system, with some particularities, such as:

- Supply alternating current at 50 Hz (or 60 Hz), by having been generated this way or after having been converted by an inverter.
- For the most part the energy source is non-dispatchable, therefore their readiness is of considerable randomness.
- Frequent changes are presented in the circulation direction of the energy, along the day.
- Their short-circuit powers are strongly variable.
- To require of parallel devices or synchronization equipment.

These characteristics, impact strongly to the short-circuit currents contribution to the distribution system, requiring of a special analysis [4].

III. FAULT CURRENT CONTRIBUTION

The currents that now contribute to the distribution system the distributed resources should be considered from several points of view, studying here the current magnitude (to be compared with the circuit breakers breaking capacity) and the wave forms (amplitude and their attenuation).

The first aspect is to verify that the maximum currents that will be forced to interrupt the circuit breakers and to withstand the passive devices (switches, bars, transformers, etc.) it is not bigger to those of design. It should be remembered that the thermal effect determination is based on rms values, on the other hand the electro-dynamic effect is proportional to the squared instantaneous maximum values of current. If this is not the case, that is to say they are not thermally or electrodynamicaly verified, it should be appealed to two solutions, to cut the currents before they reach instantaneous values higher than those allowed (limitation for cut) or to control the rms current values (inserting limiting impedances). Both solutions have their pros and cons that require of a careful study.

The second factor to keep in mind is the particular wave form, strongly variable of the fault current. This current is composed of the one contributed by the distribution system plus the ones that come from the distributed resources.

The one contributed by the system at the distribution system level, possesses the form of traditional wave of two components, the transient one or the d.c. component, plus the permanent one or the a.c. component. Now other components should be added that depend of the type of distributed resource. If the energy is coming from synchronous or induction generators, it will have necessary to consider the presence of the subtransient and transient components. If it is through inverter, the devices usually possess overcurrent protection, limiting the current to adjustable values of the order of 150% of the inverter rated current. The result is that the distribution systems have now fault current wave forms as which is shown in Fig. 1 [4].

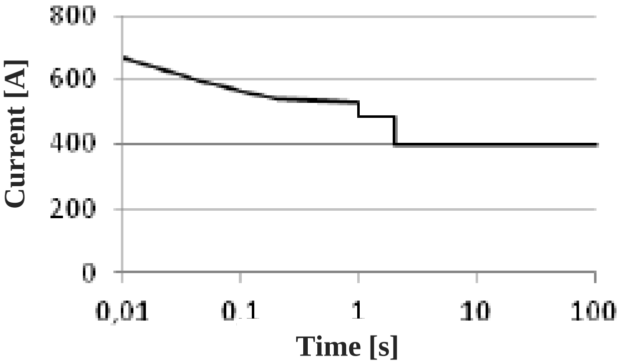

Fig.1, Short-circuit current given by the grid and two other sources (synchronous generator and photovoltaic cell).

The calculation of the total short-circuit current is based on adding instant to instant the component currents of each one of the resources, for the more unfavorable initial angle. For it can be used any suitable commercial software or a simplified method that considers the exponential attenuation of some of the component currents based on a known or experimentally determined time constant, such as the grid transient component, the subtransient and transient of the synchronous generator or just the subtransient of the induction generator. In the event of using inverters protected against overcurrent, the simplified method allows to introduce the instant of time of the current drop from the no-limited one to the limited one. This simplified method can be assembled in a sheet of calculation software type, allowing to obtain the maximum instantaneous values (electrodynamical effect) and the variables in the time rms values (thermal solicitations and required breaking capacity of the involved switches). As will be shown later on, this methodology is necessary for the protection coordination work among protective device and protected equipment as time function [4].

IV. SEMI-RIGID CONNECTION

The use of the distributed resources presents a risk that is the unintentional island operation. To avoid this risk extreme measures are taken, such as the requirement of disconnecting the distributed resource of the system immediately, in the event of perturbations with origin in the system. When the perturbation has been resolved, the distribution system is broken in parts (without islands but with generation loss). The system has weakened and could possibly be not in conditions of continuing feeding the pre-existent load, besides the restoration of the system also forces to the new synchronization of the sources and its later connection, what can demand an extensive time.

The resources usually possess the equipment required for the synchronization task with the grid, when the source previously is outside of the grid, for what the resynchronization operation of this source in intended island is not possible, unless it possesses double synchronization equipment, with its corresponding over-cost.

To solve this problem, the semi-rigid connection has been presented that instead of disconnecting the resource of the grid in the event of perturbations, it maintains it connected through a limiting impedance Zv, as it is shown in Fig. 2 that presents the following advantages:

- It controls the contribution of fault current to the system and the depth of the voltage sag.
- It improves the power quality at the terminals of the connected equipment on the DR circuit breaker side.
- It avoids the necessity to re-synchronize after the perturbation.
- In special cases the necessity of synchronizing for the connection can be obviated.
- It allows maintaining in use the reclosing of the protection systems.

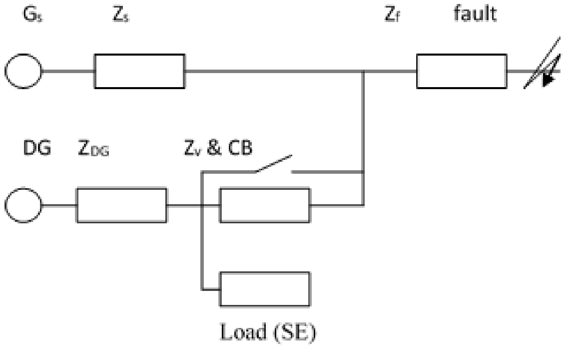

Fig. 2, Simplified distribution system with a distributed generator.

Fig. 3 shows the experimental result, voltage on the generator terminals and current contributed by the generator, of a study carried out on a synchronous machine of the Electric Machines Teaching Laboratory of Río Cuarto National University. It is a 2 kVA machine (without squirrel cage), interconnected through a 29 ohms resistance to the laboratory distribution system, the time of opening of the circuit breaker connected in parallel with the resistance was of 280 ms, opening up the fault 420 ms later. It can be seen that the relative values, make that the voltage drops even more in presence of the resistance.

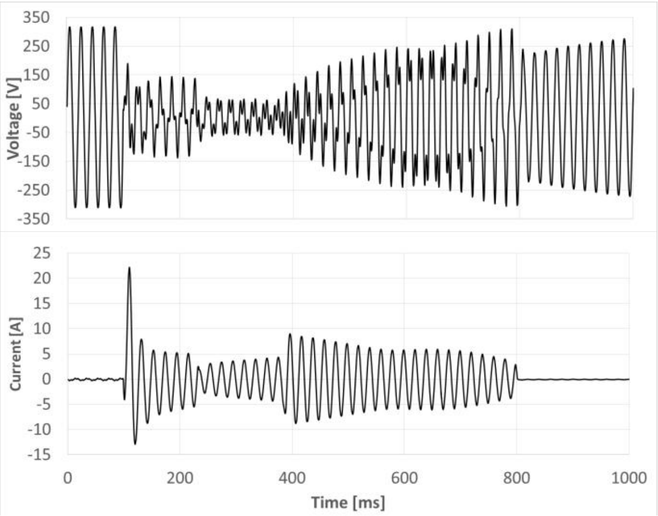

Fig. 3, Voltage and current of the synchronous generator, with a resistance of connection of 29 ohms.

On the other hand, in Fig. 4, with interconnection resistance of 45 ohms, it is shown that the voltage is increased during the semi-rigid connection. In both situations, (with 29 ohms and 45 ohms resistance), the direct reconnection to the grid (short circuit of the interconnection resistance) took place without any difficulty.

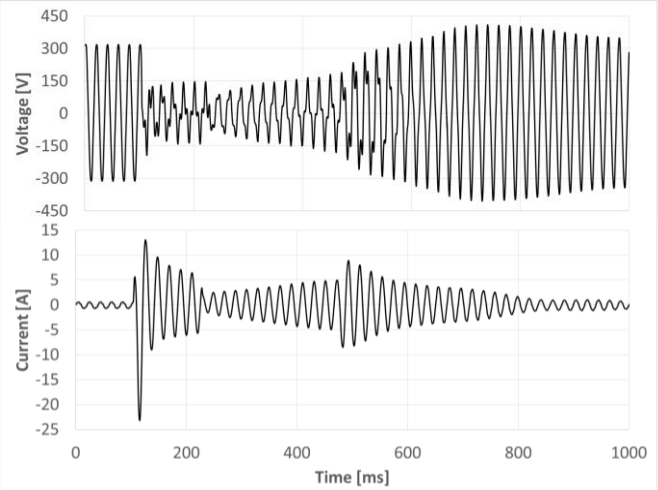

Fig. 4, Voltage and current of the synchronous generator, with a resistance of connection of 45 ohms.

If the interconnection resistance is higher, for instance of 70 ohms, resynchronization problems rouse when disappearing the perturbation, being presented oscillations of the type " hunting ", with duration of such an extension that forces to the final disconnection of the synchronous machine, phenomenon that is shown in Fig. 5.

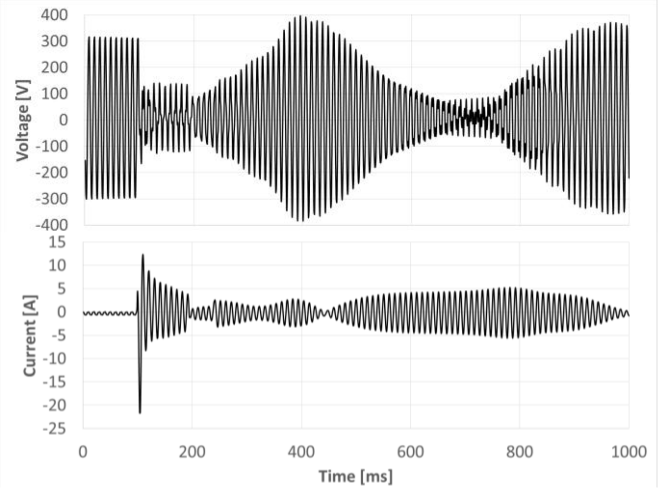

Fig. 5, Voltage and current of the synchronous generator, with resistance of connection of 70 ohms.

In order to facilitate the design of the interconnection impedance, the experimental circuit was modeled in Simulink-Matlab, circuit that is shown in the Fig. 6, where the optimum value of the mentioned impedance can be determined. Also it can be studied on it the effect of the grid direct connection, without previous synchronization.

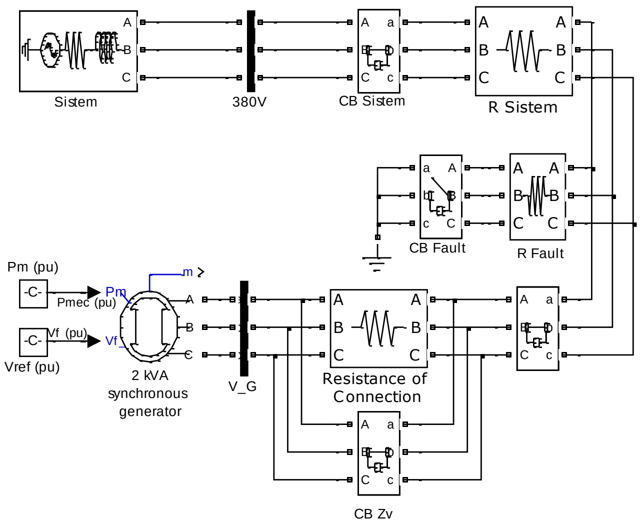

Fig. 6, Simulink scheme for interconnection modeling.

Fig. 7 shown the curves of voltage and current obtained by means of the use of the model, for their comparison with the experimental results of Fig. 3.

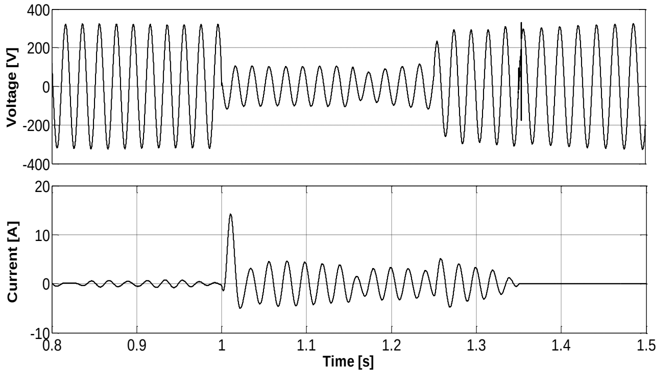

Fig. 7, Modelled voltage and current of the synchronous generator, with resistance of connection of 29 ohms.

The use of the modelled circuit, allows determining the recommended typical values of the interconnection inductance, as also its effect on the fault currents contributed to the system and the energy deficit suffered by the connected sensitive equipment on the side of the DR. These results shall be compared with the breaking capacities, let-through currents and with the sensitive equipment immunities in presence of short interruptions and voltage sags.

V. PROTECTION AND ITS COORDINATION

The Smart Grids, except for systems pilots created especially, in their great majority are mounted gradually on systems already built, for what should be considered the coexistence of new technologies with the pre-existents. For it, the grid will have smart or intelligent protection that should be coordinated with the traditional protection; for that coordination methodologies different to the usual ones are applied, reaching bigger importance the concept of specific energy in reason that the fault current is now strongly variable.

The concept of specific energy (of current) it is a tool broadly used in the studies of protection. On the task to protect equipment against overcurrents, by means of a overcurrent protective device connected in series with the protected, the thermal energy liberated in the protected one is given by $\int ri^2dt$. If the protective device is sensitive to the heating (as a fuse), the energy that is liberated inside it, responds to the same equation but now the resistance is its own value. If a micro-processed circuit breaker is used or one with temperature analogical emulation, the same concept of liberated energy is applied. Therefore the protector's resistance and of the protected one cannot be of the same value and besides its variation in time can be different. This leads to the consideration that of the mentioned equation, the part common to both devices is just $\int i^2dt$ that it is denominated specific energy (I^2t) and it is expressed in A^2s. The way to use this term, is determining the value withstood by the protected equipment that should not be allowed to go through by the protector. This value is usually used for adiabatic processes (without heat exchange) for which it is constant. Nothing prevents to extend this concept to longer durations, provided that the exchange of heat is kept in mind.

Thus the traditional time-current graphs are not of direct application due to the non-constancy of the current, and now the short-circuit current has several different paths and several dissimilar components, for that that the protective devices and those protected are not more “strictly” in series.

Fig. 8 shows the new graph to be used, giving the specific energy in function of the time, where can be seen the energy developed by the fault current and the energy allowed to let-through by the protective devices, both in function of the time [4]. In the figure it is shown that due to the determined fault current, the protective device represented by the thick full line operates in 0.05 seconds, on the other hand the device represented by the thick broken line operates in 0.11 seconds. These graphs also allow to determine the moment in which a protective device stops to protect the protected equipment, that is to say if the specific energy that generates the fault current overcomes the one withstood by the protected one; or the protective device interrupts the overcurrent some time before.

The equipment overcurrent protection, follows similar concepts. The elements and equipment circulated by this new type of fault currents, should be protected using the specific energy versus time. This information or data form has been used in the protection of transformers and capacitors, for several years, but with the purpose of eliminating the case explosion risk [6]. These curves, for the protective devices, are obtained starting from the traditional time-current graphs, by means of the determination of the current value for each time that is squared and multiplied for such a time, obtaining I^2t for each instant of time, being the " translation " of these curve to the field of the non-constant currents and of the not-strictly in series paths. It is necessary to have that information for the remaining equipment, such as cables, transformers, etc.; information that can also be extracted from the time-current curves applying some simple expressions, like it was explained above.

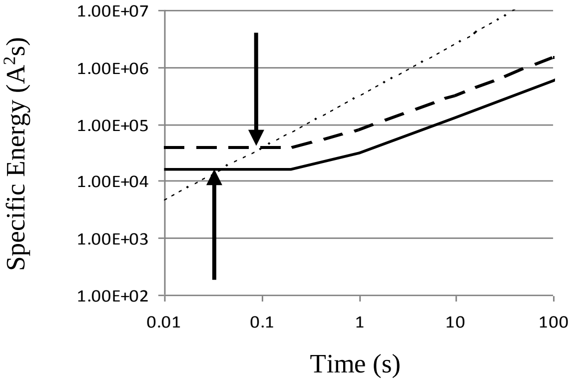

Fig. 8, Comparison among specific energy of the current (thin line of points) and the one allowed by the protective devices (thick lines).

VI. OVERCURRENT-UNDERVOLTAGE COORDINATION

The availability of the semi-rigid connection and the knowledge of the waveform of the fault current, together with the circuit data (resistances and reactances) allow to calculate the waveform of the voltage that is applied to the sensitive equipment (SE) terminals. This enables the study of the coordination for undervoltage, using the corresponding graph of immunity V-t (CBEMA or the one that corresponds) with the duration and depth of the short-interruption or voltage sag [3, 4].

The analysis is carried out using a elsewhere presented graphical study (shown in Fig. 9), where the curves of specific energy of current as time function are superimposed with the homologous of specific energy of voltage on time. The specific energy of voltage is derived of the current homologous that being based on the energy stored in a capacitor (that of the d.c link of the commuted source), it allows enunciating it as $\int v^2t$ [7].

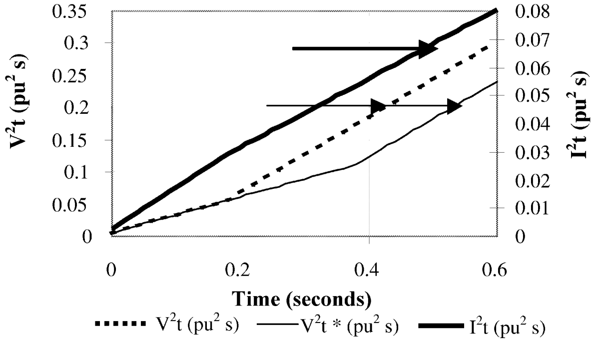

Fig. 9, Comparison of overcurrent and SE Specific Energies.

The combined use of the specific energy of current and voltage, allow selecting the protection and the control of the fault current (through the interconnection inductance) for not overcoming the capacities of the equipment sensitive to overcurrents and undervoltages [8].

VII. CONCLUSIONS

The semi-rigid connection of the distributed resources in an environment of Smart Grids gives a series of advantages that widely justify its application. To select the value of the interconnection inductance the analysis of overcurrent-undervoltage coordination should be carried out on the equipment interconnected or involved in the circuit.

REFERENCES

[1] A. M. Borbely J. F. Kreide, Distributed Generation, The Power Paradigm for the New Millennium, CRC Press, Boca Raton, FL, 2001.

[2] J. C. Gómez, M. M., Morcos, Power Quality: Mitigation Technologies in a Distributed Environment, Chapter 10, Springer-Verlag, London, 2007.

[3] M. H. J. Bollen, Understanding Power Quality Problems, IEEE Press, New York, 2000.

[4] J. C. Gómez, M. M. Morcos, “Overcurrent Coordination in Systems with Distributed Generation”, Electric Power Components and Systems, Vol. 39, n° 6, pp. 576 – 589, 2011.

[5] *IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems*, IEEE Standard 1547, 2003.

[6] B. Lageman, E. W. Schmunk, C. E. Shaw, Fundamentals of Fusing to Minimize Case Rupture in Distribution Capacitor Banks, *IEEE Transactions on Power Apparatus and Systems*, vol. PAS-98, n°3, pp. 963-971, May/June 1979.

[7] J. C. Gomez, G. N. Campetelli, Voltage sag mitigation by current limiting fuses, IEEE IAS 2000 Annual Meeting, Roma, Italy, October 8 – 12, 2000, vol. 5, pp 3202-3207.

[8] J. C. Gómez, M. M. Morcos, Coordination Analysis of Voltage Sag and Overcurrent Protection in Electrical Systems with Distributed Generation, IEEE Transactions on Power Delivery, Vol. 20, No. 1, January 2005, pp. 214-218.