Custom power equipment to facilitate the penetration of embedded generation in distribution networks

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Abstract

This work explains the use of power electronics devices connected to medium and low tension networks, which contribute to mitigate or compensate the influence of electrical disturbances of the net on installations connected to the distribution network, which are susceptible to them.

The inclusion in the electrical system of the distributed generation, associated to the diversification of the energy sources, modify the topology of the power system. This new generation system, either because of its nature, or because of the frequent incorporation of power electronic converters as element of connection to the net, make necessary an extra survey of the quality of the nets where they are connected. There are a double reason for it: on the one hand they are very sensitive, and in the other they generate perturbations, which can occasion stability problems in the system, not individually but as a whole.

The incorporation of the classical devices, such as D-Statcom (Distribution Static Synchronous Compensator), DVR (Dynamic Voltage Restorer), and UPQC (Unified Power Quality Conditioner), means a continuous control, with a very fast response time, and they allow and assure an improvement in the wave quality of the power supply.

Key words

Custom Power, Embedded generation, Renewable Sources, DGfacts, Power Quality

1. Introduction

The European challenge to produce 20% of primary energy from renewable sources before 2020 implies the need to facilitate the integration of embedded generation on the grid in order to achieve and even exceed this goal. The rapid development of wind energy is a clear example of the benefits of integrating embedded generation into the grid. With an installed power in Spain above 16GW, the record of providing 26% of daily production has been achieved.

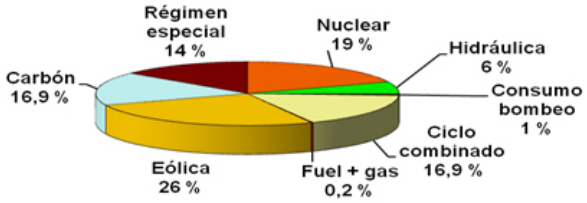

Fig.1 Electricity generation sources in Spain 22/01/09

The boom in the integration of the international energetic markets offers the possibility of the technological development in Distributed Energy Resources (DER), such as: microturbines, fuel cells, wind power systems, small hydroelectric power stations, gas or diesel combined heat and power plants (CHP), solar photovoltaics, hybrid-mininets systems, and energy storage systems.

Energy systems tend to present the following characteristics: short scale sized, easy to build (and dismantling), decentralized, localized, and small. To achieve this objectives, two key areas have to be developed:

- The type of generators, based basically on:
  - Micro-cogeneration. Especially the so-called trigeneration, which combines heat, cold and power.
  - Fuel cells: solid oxide fuel cells (SOFC) and molten carbonate fuel cells (MCFC)
  - Decentralized renewable energy sources

- Custom Power equipment to facilitate and control the integration of diverse distributed energy sources

This new approach of the energy systems is opening new opportunities for consumers, energy suppliers, and energy generators. The possible combinations allow a wide range of consumers (including homes) to install plants that satisfy their needs of heating, cooling, and electricity in most cases (if not all of them).

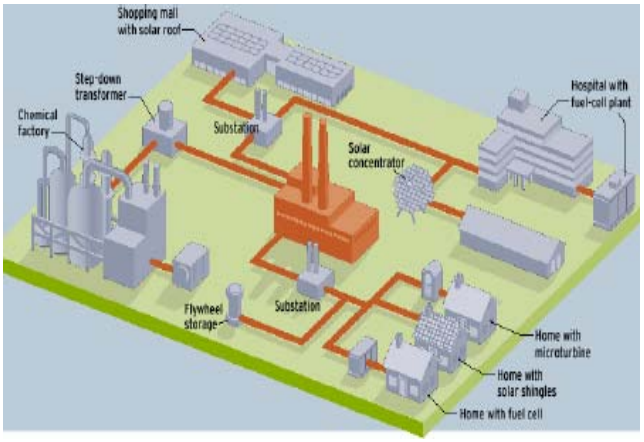

Figure 2. Distributed energy resources (DERs)

The technological development in the two areas discussed above, should carry a profound change in the energy market and the industry competitiveness, with impact on the demand technology and the environment. While in the short term it is difficult to compete with technologies based on oil and gas, in the medium term it is likely that decentralized renewable energy find their own complementary market. This is a first step to an economy based on a combination of electricity and hydrogen as main energy carriers to replace the traditional energy model based on fossil fuels.

In the area of equipment enabling the integration of small-scale energy systems, progress in emerging technologies should facilitate a remote control of the flows of electricity, ensuring the quality of the system in all its aspects (quality of supply and waveform quality), and giving security and independence to the systems. Under this premise, the implementation of Custom Power devices in distribution networks of medium and low voltaje is considered, adapted to the most demanding requirements of network sensitive to disturbances, which ensure high quality provision and coordination among devices, and integrate without much problems this new energy system [1].

2. Distributed energy resources

Literature on electrical systems includes terms such as Distributed generation (DG), Distributed energy resources (DER), Embedded generation, Distributed power, Decentralized production, Distributed production, Integrated production, Dispersed Generation. Among them, DG is the most internationally recognized term for the connections of the non centralized power generation plants. Some of these definitions are shown in Table 1.

Organisation	Definition of "Distributed Generation"
European Commission	Distributed Generation means generation plants connected to the distribution systems
DPCA Distributed Power Coalition of America	Distributed power generation is any small -scale po wer generation technology that provides electric power at a site closer to customers than central station generation. A distributed power can be connected directly to the consumer or to a utility's transmission or distribution system.
CIGRE	Distributed Generation is not centrally planned, today not centrally dispatched, usually connected to the distribution network and smaller than 50 or 100MW
IEA International Energy Agency	Distributed Generation is a generating plant serving a customer on site or providing support to a distribution network, connected to the grid at distribution -level voltages. It generally excludes wind power, since that is mostly produced on wind farms rather than for on -site power requirements.
US-DOE Department of Energy	Dist ributed Generation – small and modular electricity generators sited close to the customer load – can enable utilities to deter or eliminate costly investments in transmission and distribution systems upgrades, and provide customers with better quality, mor e reliable energy supplies and a cleaner environment.
California Energy Commission	DG is electric generation connected to the distribution level of the transmission and distribution usually located at or near the intended place of use

Table 1. Definitions of "Distributed generation"

Most of the experts and the documentation on the subject agree that the concept of DG does not includes all the electric generators connected to the network. Distributed Generation in fact corresponds to the generators that satisfy certain conditions. Generally, the critical parameters used in the definitions of distributed generation are:

- The location of the generation system. It must be placed in the customer installations, or just outside them.
- The point of connection to the network. Only energy sources connected to the grid (distribution network), and not to the transport network, constitute DG.

Based on the definitions described above and taking into account not only the systems based on renewable energy, but also systems for cogeneration of heat / cold and fuel cells, which incorporate some of these "devices", and which add aditional benefits, we can conclude the definitions concerning RES, DG and DER

Renewable Energy Sources (RES). Designates renewable non-fossil energy sources (wind, solar, geothermal, wave, tidal, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases)

Distributed Generation (DG). Is the integrated or stand-alone use of small, modular electricity generation sources, installed within the distribution system or a customer's site by utilities, customers or any other third parties to meet specific capacity and reliability needs in applications that benefit the electricity system, specific end-use customers, or both.

Distributed Energy Resources (DER). Are Distributed Generation and demand-side measures that provide electricity, thermal and/or mechanical energy. These resources can be located on-site or nearby to users. They can be used to meet base load power, peaking power,

backup power, remote power, power quality, cooling, and heating needs. DER include Distributed Generation devices and storage and interconnection equipment needed to interconnect with customers and/or the utility grid.

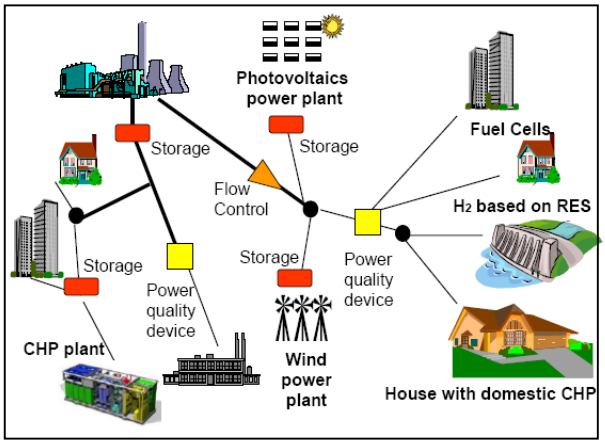

Figure 3. Integration of DER into future networks

What does seem clear, and is assumed by everyone, is that all these concepts introduce, totally or partially, some benefits, such as:

- To reduce losses in electrical transmission systems (estimated at 7% in OECD countries).
- To help reduce congestion on transport networks.
- To allow the use of waste heat through cogeneration, improving overall system efficiency.
- To improve the quality and reliability of power system
- From the viewpoint of investment, easier to match the increased capacity with the growth of local demand with low capital risk.

3. Contribution of Custom Power devices

Custom Power devices involve the use of power electronic controllers in distribution systems for medium and low voltage, in order to provide a level of reliability and quality in the energy needed to power consumers that are sensitive to changes in power quality. In other words, Custom Power devices are designed to protect the customers from the interruptions and tension dips originated in the system, as well as those transferred to the customers originated by other customers, or even disturbances caused internally. Custom Power Static devices include switches, active filters, DVRs, coupling transformers, and energy storage modules for maintaining uninterrupted current and to regulate voltage in a distribution system to improve reliability and quality of the electrical system [4, 5, 6].

In a Custom Power system the customer receives customized power quality from the service provider or device, or from the equipment installed by that customer in coordination with the device, which includes an acceptable combination of the following characteristics:

• No power cuts
• The magnitude and duration of voltage reduction are bounded inside determined limits.
• The magnitude and duration of overvoltages are also within the defined boundaries.
• Low level of harmonic tension.
• Low phase imbalance.

This can be applied to individual customers, a major customer, from industry or business, or a technology park for high technology [2, 3].

A. Aplications

Custom Power equipment arises from the need to address:

- Interruptions and voltage cuts provided by the system and produced by lightning, faults in transmission and distribution lines, low-frequency oscillations in the transport system, tree falls in power lines, damage to the equipment, disconnections, or as a result of variation of great loads that affect their own equipment or others equipment through the network.

- Pulses and overvoltages affecting insulation, due to lightning and sudden changes in loads on the transmission and distribution system.

- Transitory overvoltages, of several cycles or several seconds, usually as a result of large load changes, changes in capacitor, switching transformer, excessive VAR with light loads, etc.

- Voltage unbalance in one of the supply phases, because of the connection of large loads in unbalanced distribution lines, and because of large lines with unbalanced impedances per phase.

- Harmonics due to the type of load of the customer, or produced because of saturation of the transformers that can be amplified by resonance in the network and / or in the installation of the customer.

B. Custom power devices

Power electronic controllers, as Custom Power, used to provide custom solutions to clients, can be divided into two types:

- Network reconfiguration devices
- Compensation devices

- Network reconfiguration devices. They are based on the Solid State Breaker (SSB), with series connection, which permit to transfer, to cut, or to limit the electric current in an interval shorter than a frequency cycle. The present running contact breakers or switches have been designed

based on the GTO and IGCT thyristors. These devices are the following ones:

- *Static Current Limiter (SCL)* limits a fault limits a fault current by quickly inserting a series current by quickly inserting a series inductance in the fault path.
- *Static Circuit Breaker (SCB)* breaks a breaks a faulted circuit much faster than a faulted circuit much faster than a mechanical circuit breaker.
- *Static Transfer Switch (STS)* is connected in the bus tie position when a sensitive load is supplied by two feeders. It protects the load by quickly transferring it from the load faulty feeder to the healthy feeder.

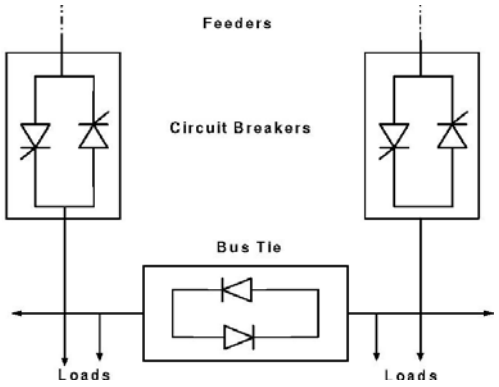

Figure 4 Basic structure of STS.

- Compensation devices. They are used for load compensation, improving the power factor, the imbalance, and the voltage supply quality. These devices are series or parallel connected, or a combination of both [7]. The different devices are:

- *Distribution Static Synchronous Compensator (DSTATCOM)* is a parallel connected device that can operate in two modes; Current Control. The DSTATCOM acts as an active filter, power factor corrector, load balancer etc. These functions are called the load compensation. In the Voltage Control can regulate a bus voltage against any distortion, sag/swell, unbalance and even short duration interruptions.
  When coupled with the Solid-State Breaker (installed on the line side of the D-STATCOM) and energy storage, the D-STATCOM can be used to provide full voltage support to a critical load during operation of the feeder breaker that protects the distribution feeder on which the D-STATCOM is installed.
- *Dynamic Voltage Restorer (DVR)* is a series compensating device. It is used for protecting a sensitive load that is connected downstream from sag/swell etc. It can also regulate the bus voltage at the load terminal. By injecting voltages of controllable amplitude, phase angle and frequency into the distribution feeder in instantaneous real time via a series injection transformer, the DVR can "restore" the quality of voltage at its load-side terminals when the quality of the source-side terminal voltage is significantly out of specification for sensitive load equipment.
- *Unified Power Quality Conditioner (UPQC)* consists of two three phase inverters connected in cascade. In this arrangement, the shunt connected Converter can supply and absorb reactive power in order to support the bus voltage, supply and absorb the real power to support the series connected converter, and act as an active current filter. The series-connected converter on the other hand, supports the customer voltage for any deviation, dips and interruptions. The storage comes into play when the shunt connected converter can not supply the power during large dips and interruptions. The main purpose of a UPQC is to compensate for supply voltage, flicker/imbalance, reactive power, negative-sequence current, and harmonics. In other words, the UPQC has the capability of improving power quality at the point of installation on power distribution systems or industrial power systems..

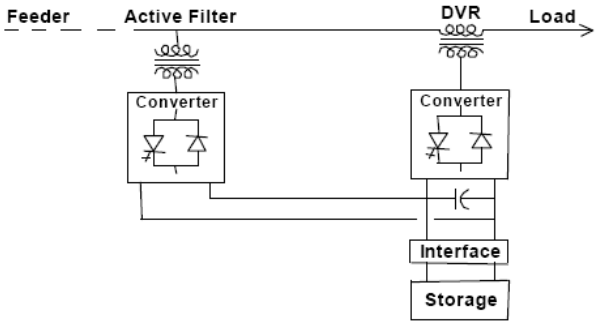

Figure 3. Custom Power based on two Voltage Source Converters and Storage

4. Action global strategy. Custom Power Park (CPP)

As a new custom power concept of improving power quality, attention has been paid to Custom Power Park, which is able to offer customers high quality of power and to meet the needs of sensitive loads with an industrial/commercial business park. The concept requires integration within the park of multiple Custom Power devices, which have previously been deployed independently. These devices compensate for power quality disturbances to protect sensitive process loads as well as improve service reliability. By integrating multiple power quality technologies and utilizing a communications network between the devices, this concept is actually distinguished from previous technologies that only stand-alone pieces of equipment.
As mentioned in the previous sections, STS, Dstatcom, Active Filters, DVR, and UPQC so forth are state-of the-art technologies installed to coordinate with each other and monitor the power supply so as to mitigate disturbances. The CCP combines power quality controllers with engineering services to develop and maintain integrated high-quality electric service.

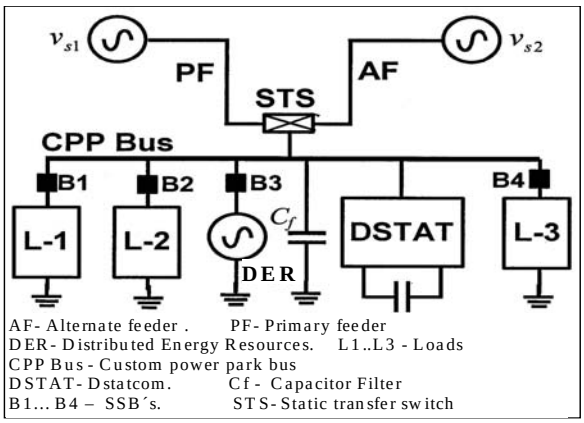

Fig. 4. Example of the Custom Power Park (CPP)

A tenant in the CCP may be able to dispense with specialized equipment to condition incoming electric power, and experience improved power quality. Functions such as power factor correction and power conditioning would become the responsibility of the Custom Power Park operators and would be achieved by proper application of power quality controllers.

The Park operations center receives power from multiple distribution feeders and can even combine it with distribution sources or energy storage systems, and then distribute power to its tenants in the park. Another possible CCP design includes a utility corridor with multiple electric circuits. Electric power with different power quality specifications could be provided to tenants with different needs. Tenants would be able to connect portions of their load to appropriate classes of service. If a tenant's load characteristics later change (as detected by the monitoring system), the tenant may be switched to a different power quality rate and service level as appropriate.

In a Custom Power Park all customers will benefit from a basic supply which is a cut above the normal power supply from a utility, but there are three different grades of power that can be supplied to the park´s customers, or three grades of qualities:

Grade A. This is the basic value-added power at the Park. Its higher quality, compared to the regular power and may be characterized as follows:

- 60-80 percent reductions in voltage sags.
- Rare occurrence of interruptions.
- Active harmonic filters.

Grade AA. Over and above grade CP-A, grade CP-AA receives the benefit of a standby generator which can come up to speed in about 10-20 seconds in case of a power loss.

Grade AAA. This includes all the features of Grade, In addition, receives the benefit of a custom power like DVR or UPQC, which precisely adds the right amount of voltage including harmonics to the feeder voltage to ensure virtually sag free, interruption free, and harmonic free voltage to the customer. It is assumed that under emergency conditions, loads classified as Grade AAA may degrade to Grade AA. For unavailability of backup power, it would still receive superior quality power and priority customer service attention.

Though the custom power park it is possible to supply power to different types of sensitive loads ranging from shopping malls and hospitals to semiconductor manufacturing. For example, a Biotech Corporations needs Grade AAA supply since a sudden voltage dip can cause the loss of a few hours of production. With modern and life support equipment, a hospital on the other hand, requires both Grade AA and Grade AAA supplies.

5. Conclusions

Integration of DERs in electrical power networks may need some measures to be used for maintaining the required power quality in the grid. Custom power equipment used to protect end-users from effects of disturbances, which in modern electrical network cause many technical and economical problems.

The interest in the industries to have devices that guarantee an adequate supply quality can be understood taking into account that, according to estimates made by the Leonardo Power Quality Initiative (LPQI) organization, quality problems of electric power to industry and commerce in the European Union around 10,000 million euros a year, while expenditure on preventative measures is less than 5% of this amount. This highlights the importance of accelerating the introduction of Custom Power devices in distribution networks.

Number of installations of Custom Power Devices is increasing in the world. Increasing competitiveness and new utility regulations force the industrial consumers towards installation of Custom Power Devices and make possible the implementation of a Custom Power Park that would provide a guaranteed improvement in the quality of electrical service to the tenants of the park.

The state of art equipment allows the development of FRIENDS and Custom Power Park concepts. FRIENDS (Flexible, Reliable and Intelligent Electrical Energy Delivery Systems) and Custom Power Park are the advanced technologies that provide the means by which the electric utility may add value incrementally via additions to its infrastructure. As a future work a Custom Power Park model should be implemented and performance of the Park and device interactions and coordination should be studied during different fault scenarios.

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