The electricity distribution scenario around the world is undergoing fast change due to the privatisation and deregulation process. The wide spread use of microprocessor based electronic controllers, sensitive to disturbances in power quality, and high level of competition in the energy supply business are promoting higher consciousness of industrial and commercial end users to Power Quality (PQ) issues and, obviously, its economic value. A deeper understanding of PQ problems and their mutual impact on the power system and on the end-users facilities will lead to better system planning and lay-out. The objective is to build and operate a safer, more reliable and, at the end, more profitable energy supply system. This paper will discuss 3 products which, embedded in the power system, will provide significant and low cost PQ enhancement.

The PQ can be improved by means of mitigation or prevention. Simultaneously, the sensitive equipment is becoming increasingly robust. Power electronics, with short and controllable response time, are from a technical perspective suitable components for PQ applications. Despite a continuous reduction of cost, power electronics based solutions are, presently, difficult to justify economically. However, there are low cost solutions using improved conventional technology available now.

In this paper, a general description of new functions integrated in the medium voltage switchboard to meet the PQ challenge is provided. The solutions are based on circuit breakers using the magnetic actuators. The magnetic drives were introduced 1997 and has now paved the way for a range of new PQ related low cost applications. This technology combined with intelligent control systems have made it possible to integrate PQ solutions into normal sized MV panels. They are factory assembled and tested, providing for short installation and commissioning times.

**HSTS – High Speed Transfer System** Transfer solution to momentary/sustained interruptions and, due to fast transfer, voltage sags for critical users. Load transfer to an emergency feeder in less than two cycles, simultaneously providing full short circuit protection.

**PFC –Power Factor Controller** - Compact design, turnkey integrated shunt capacitor bank with an intelligent control unit, state-of-the-art and anti-resonance protection.

**SCB – Synchronous Circuit Breaker** - Three individually driven poles enable complex synchronous switching strategies, adaptable to various loads and network configurations. It eliminates switching transient effects, ranging from poor PQ to protection untimely tripping, to overvoltages and premature failure.

The paper discusses some practical examples in industrial applications of the effectiveness of the above Power Quality solutions.
INTEGRATED POWER QUALITY IN DISTRIBUTION EQUIPMENT

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ABSTRACT

The electricity distribution scenario around the world is undergoing fast change due to the privatisation and deregulation process. The wide spread use of microprocessor based electronic controllers, sensitive to power quality disturbances, and high level of competition in the energy supply business are promoting higher consciousness of industrial and commercial end users to Power Quality (PQ) issues and, obviously, its economic value.

The PQ can be improved by means of mitigation or prevention. On the other hand, the sensitive equipment is becoming increasingly robust. These are the driving forces for shifting the focus, from expensive power electronic based PQ devices to adequate, low cost, PQ solutions which can be economically justified.

A better understanding of PQ problems and their mutual impact on the power system and on the end-users facilities can lead to build and operate a safer, more reliable and, at the end, more profitable energy supply system.

In this paper a general description of new functions integrated in the medium voltage switchboard to meet the PQ challenge is provided.

INTRODUCTION

Since 1997 a new series of medium-voltage circuit-breakers with a magnetic drive instead of a spring-based operating mechanism has been introduced, Dullni et al. (1). The magnetic actuator, based on limited number of parts, very simple cinematic chain and more compact design, allows a higher number of mechanical operations. A power electronic controller supervises and operates the magnetic drive from one to the other of the two stable positions by injecting a current pulse in the actuating coil. This solution soon proved to be much more reliable than its predecessor.

By implementing new power electronic actuating devices, based on magnetic actuators and taking advantage from the controllability of the coil current, enabling dynamic performances, a new generation of intelligent switching device with high performances allows improved functionality:

- High Speed Transfer System (HSTS), based on a fast CB, to drastically reduce the operating time, enables to transfer the load to an undisturbed power supply and to enhance the distribution node Power Quality;

- Synchronous Circuit Breaker (SCB), with independent single phase real-time controlled operation, to reduce network switching transients and CB wear both in closing and opening operation;

- Power Factor Controller (PFC), integrating the Power Factor improvement function in MV switchgear, with state of the art and resonant protection.

HIGH SPEED TRANSFER SYSTEM

The diffusion of electronic controllers and other sensitive equipment can, even in case of temporary voltage disturbances, lead to complete loss of production and long process downtime.

The new ITI (CBEMA) curves show that electronic equipment is becoming increasingly robust. The vast majority of applications have a capability to ride-through voltage sags disturbances with a duration up to 2-3 cycles. A HSTS consist of two or three fast acting, full rating, circuit-breakers using a magnetic drive operating mechanism. The fast vacuum circuit-breaker, enable this high speed transfer system to commutate the supply to an alternative feeder realising extremely short operating times. The minimum number of moving parts and the simple magnetic latching principle enable minimum opening times of 10ms and closing times of 16ms.

The High Speed Transfer System, HSTS, offers a low cost solution to momentary/sustained interruptions and voltage sags, Heinemeyer et al. (2). The automatic load transfer to an emergency feeder in less than two cycles eliminate expensive downtime. The total transfer time of about 25 ms include time for reliable detection, circuit breaker operating as well as arcing time.

The fast magnetic, CB has a lifetime of more than 20,000 C-O operations, ensuring the same ratings and reliability of the standard CB version. The HSTS has the full short-circuit rating of up to 40 kA breaking current, 100kA making current and a rated current of up to 2500 A. Thus, the circuit-breakers of the HSTS can be used for standard applications as well as for the transfer system.

System Configuration

There are two typical installation configurations:

2-breakers configuration. One main feeder normally feeds the bus (one breaker closed, the other open). In case of a voltage drop/loss causing a disturbance of
feeder 1 the transfer system transfers the load to a standby-feeder.

**3-breakers configuration.** For reasons of redundancy the load is split into 2 busbar sections, the bus-tie normally is open and both feeders are closed. In case of a disturbances in one of the two feeders the transfer takes place between the circuit breaker of the disturbed feeder and the bus-tie.

**HSTS advantages**

The main advantage of the HSTS is the extremely short total transfer time (25 ms). In case of a fault, the phase angle between main and stand-by network may change rapidly.

Normally, conventional transfer systems have an operating time of approximately 100 ms calculated from fault, to completed transfer when stand-by breaker is closed. During this time, the phase angle between UBusbar and UStand-by increase significantly. Typically, after approximately 30-40 ms the phase angle difference is already too high and therefore, fast transfer is not allowed due to the risk of damage of e.g. shafts in machines. However, as a direct result of the very fast circuit breakers with a total transfer time of 25 ms for the HSTS, fast transfer mode is practically always possible. Other transfer systems, using conventional circuit breakers, will have to wait until first phase coincidence occurs, which typically takes 500ms. I.e. conventional MV breakers are not suitable for PQ transfer applications. The HSTS is suitable for a range of applications where safety and security is important, e.g. hospitals, military installations, auxiliary power for power plants and hazardous processes. Other applications, where economy of operation is the main driving force, include industrial plants with continuous processes and a high degree of automation, petrochemical and chemical plants as well as precision machining in manufacturing plants etc.

**HSTS - an application**

A mail order company, with a highly automated package centre, processing 40 000 deliveries per hour had one incoming 15 kV supply line. Due to the old supply system, the power quality was poor with frequent ground faults and short circuits. This caused outages in the process and automated storage computers with high associated costs.

Two alternatives, both based on a new alternative incoming supply line, were considered.

One alternative was to build a second ring down to low voltage level direct to the loads. Differential protection would trip faulty supply in about 40-50 ms at low voltage level. This alternative would basically mean a complete duplication of existing supply equipment including MV switchgear, extensive cabling and civil works. Installation of the HSTS directly at the medium voltage level was found cheaper and faster. The building of the new ring would not be necessary and, additionally, the response time would be much shorter. The HSTS was delivered in 3 normal MV panels.

**SCB – SYNCHRONOUS CIRCUIT BREAKER-**

The synchronous circuit breaker has each pole individually driven by a controlled magnetic actuator (fig.3), enabling complex synchronous switching strategies, adaptable to various loads and network configurations. It carries out operations that are synchronous with the network signals, voltage or current, disregarding when the starting signal is given, either manually or by a remote control, Cereda et al.(3).

It enables the reduction of switching transients, causes of a variety of disturbances on distribution power systems, ranging from poor PQ through untimely tripping of protection to unacceptable overvoltages, leading to severe damages and premature failures, CIGRE', (4).
In the following two installations, in operation from mid 2000, are described, with the results in reduction of the switching transients due to capacitor banks and transformers energisation. The two examples reported, as significant for inductive/capacitive loads, can be used to evaluate the impact of synchronous CB operation on the power system.

**Capacitor banks switching**

In the deregulated energy market the capability to offer a higher availability and Power Quality of the energy supply will be one of the parameters used by the Regulator for fare definition and licence allocation. The liberalisation process in act in Italy foresee the transfer of part of Enel distribution network and clients to local municipalities. One of this multi-utility municipalities, with about 30 thousand low voltage users supplied yearly, has installed a SCB on one of the two existing 1.2 Mvar, 15kV PFC cubicles at the main substation coupling the city MV network to the Enel grid.

In this case the SCB installation enables to significantly lower the transients at bank energisation, thus assuring a higher availability and better PQ to MV and LV customers that must relay on the local distribution network for PQ parameters critical to their process.

In a comparison between the standard CB, closing the three phases together, and the synchronous closing of each phase at the best timing, the inrush current for single bank energisation is reduced from several tens to few times the rated current (Fig. 4). When back to back operations with the first bank already energised are considered, both high I/peak/In ratio and high peak inrush are experienced and normally a limiting reactance has to be installed. The SCB achieves the best results, with reduction of the current by a factor 10. At the same time the voltage transient due to synchronous operation is strongly reduced when compared with values due to standard CB closing operation. Due to the fact the controlled closing maximum error is around 0.5ms, overvoltage is always kept under 1.2 p.u. (as shown in Fig.4, 5).

**Transformers switching**

The inrush current has a certain statistical probability to occur at transformer energization. Such occurrence frequency and the inrush amplitude depend on the switching-on instant and on the transformer residual magnetization. The resulting inrush current can be very high (up to ten times the rated current, i.e. several hundreds times the steady state magnetizing (no-load) current). Such transients are quite long, with decay to the rated current value from hundreds of milliseconds to seconds.
In a major Italian Utility a SCB has been installed on one of the two 6.25 MVA, 23/15kV YY transformers used to supply the metropolitan area MV network.

The transformers are frequently switched as the 15kV MV network is reconfigured during maintenance and operation.

In this case the SCB installation enables to greatly reduce the inrush current when the transformer is energized, thus avoiding problems related to the high inrush currents, as the statistical occurrence of untimely protection tripping and resonance or capacitor overload due to the heavy harmonic content of inrush currents.

In the following figures are reported the inrush waveform recorded at the CB commissioning: the synchronous peak current (fig.6) is lower than the peak current, obtained with a standard operation (fig. 8) by closing the three poles together. By using the residual flux strategy it is possible to achieve a even more significant reduction of the inrush peak current down to the rated current (fig. 7).

While current transients are restricted to the switch location, transient overvoltages travel to remote locations, possibly affecting other users and propagating to different voltage levels.

Installing an SCB greatly reduces the stresses, overcurrents as well as overvoltages, that the network components experience at switching, achieving significant advantages in terms of higher power quality and increased system reliability.

**PFC – POWER FACTOR CONTROLLER**

The Power Factor Controller (PFC), is a turnkey device that provides a compact design shunt capacitor bank, integrated in the MV switchgear with an intelligent control unit, state-of-the-art protections and operation logic.

The PFC built-in measurements and control facilities allow to implement an active resonance to prevent dangerous resonance conditions. By sensing the increase in harmonic content, the PFC can take a reverse action and de-tune the circuit if a new resonance condition arises, due to the capacitor switching or changes to the network, Cereda et al.(5).

In the version equipped with synchronous circuit breaker (CB) the “point on the wave” switching operation enables a strong reduction of transients, with an improvement of the electrical life of capacitors, a reduced CB wear and a higher network power quality.

The integration of capacitors and switching equipment in the same cubicle allows space and cost reduction and offers a system solution, relieving the end user from the need of engineering the PF installation, choosing switching and protective equipment, reactive power control system and assembling and testing on site.

The integration offers an overall cost reduction and a higher reliability due to the factory quality tests of the whole system. The PFC solution enables to reduce engineering, interface problems, installation and total deployment time.
PFC - an application

A water Distribution Company has scheduled the installation of a new pumping site, providing water to the southern region of Puglia, in Italy, delivering up to 6500m³/h.

Due to the importance of the pumping site a high reliability and redundancy of the system has been devised. A further requirement is the improvement of the Power Factor to fulfill the local utility billing policy and avoid poor power factor penalties.

The high reactive demand of the pumping site three water pumps (3 MVA, 6kV), due to MV motors load levels operation, causes high PF penalties to be applied. The new PFC switchboards have been installed to compensate for the reactive demand of the three MV motors, enabling to save space by integrating the capacitors and to reduce the plant deployment time.

This scheme (fig. 8) enables to supply the required reactive power acting as single motor compensation. Depending of the PFC control setting the step could be used as group compensation for the main busbar the PFC switchboards are connected to when one motor is off or, depending on its load, not all the steps are required. This way a higher availability of the installed reactive power is achieved.

CONCLUSIONS

The use of the magnetic actuator has opened capabilities, which previously were only possible by using power electronics. The precision and operational speed of the circuit breakers with magnetic drives is now effectively filling the gap between the sub-cycle power electronics and conventional circuit breakers. The technical benefits of power electronics are indisputable, but the main problem is the decreasing, but still high, investment cost. The described applications, using circuit breakers with magnetic actuators are easy to justify economically. Thus, they are low cost PQ solutions.

For the HSTS there are many applications, such as protecting the auxiliary power for power plants, where one single eliminated outage would pay back the HSTS investment cost.

SCB appears as the most effective way to reduce switching overvoltages and overcurrents. A synchronous circuit-breaker offers a simpler, more cost-effective solution than, for example, fixed or pre-insertion inductors or pre-insertion resistors.

The PFC enable to build a cost-effective, fast deployable PF improvement system, comprising all the needed P&C functions, to directly address PF Utility penalties with a fast Return of Investment.

PQ is becoming for the industrial and commercial end users an index to evaluate the supplier and his capability and readiness to satisfy his energy supply demands in the competitive deregulated market.

The low cost PQ solutions integrated in the MV system presented in the paper enable to adequately address the PQ problems to build and operate a safer, more reliable and, at the end, more profitable energy supply system.

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