Power quality devices improve manufacturing process stability

Peter Daehler, Markus Eichler, Osvin Gaupp, Gerhard Linhofer

If resetting the digital clock after a power blip irritates you, imagine what it feels like to have a short sag in power hit your manufacturing plant. An interruption of even a few tenths of a second can easily cost a company thousands of dollars.

One way to protect plant equipment against power grid disturbances is to install a large-scale, fast-response Uninterruptible Power Supply. However, this is tantamount to overkill for many applications; a UPS is designed to compensate for complete loss of power, but most problems arise from short blips, usually in one phase only. The answer to this dilemma is the Dynamic Voltage Restorer, or DVR. A DVR will instantly catch and compensate voltage sags, so they won't even be noticed.

ABB recently installed two DVRs which, rated at an impressive 22.5 MVA, are easily the most powerful ever built. ABB Integrated Gate Commutated Thyristor (IGCT) technology makes such devices possible and gives them their special attributes – extremely fast response (<1 ms), higher-than-usual performance and outstanding reliability.

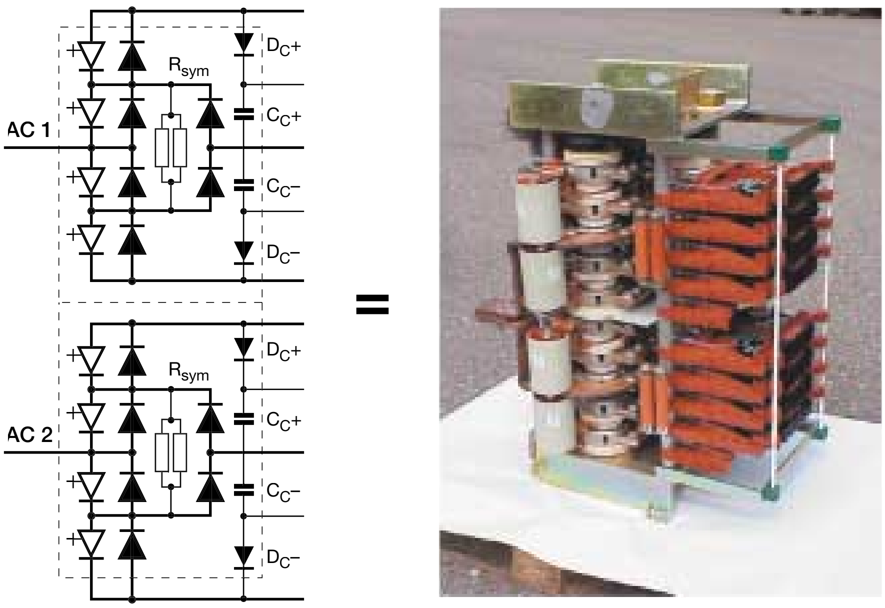
In summer 2000, just eight months after receiving the contract, ABB Industrie AG – in partnership with ABB High Voltage Technology Ltd – delivered and put into service two power quality devices which are among the largest of their kind anywhere. The main purpose of the devices – more commonly known as Dynamic Voltage Restorers (DVR) – is to compensate for temporary voltage sags caused by disturbances and faults in power grids. While such devices have been built by a variety of manufacturers in recent years, these DVRs are unique because of their rating. Designed for loads of up to 22.5 MVA each, they are by far the largest units of their kind to date.

Why voltage sag correction is important

Most of the disturbances that occur in power grids are short-time voltage sags. They can be caused by inrush currents whenever large transformers are energized, or by the starting currents of large motors. The vast majority of voltage sags, however, are the result of short-circuits or ground faults somewhere in the grid, possibly many miles away from where the voltage sag is experienced. The duration is usually quite short, about as long as it takes to disconnect the faulted line from the grid.

It might be argued that nobody cares about a voltage sag lasting a trivial 0.1 seconds. At home in the evening, reading or watching TV, you might just notice the light flicker briefly or a streak race across the TV screen. But the next moment everything will have returned to normal, and an hour later you will probably have forgotten about it altogether.

It's a completely different story if you just happen to be in an elevator when a voltage sag causes the system control to trip, and for some reason the device does not restart automatically. Alarming the service operator, who then has to restart the system manually – hopefully after just a few minutes – can be an unnerving experience, and one you will not forget so soon. Even so, nothing really serious will have happened, nothing has been damaged, and the time you have lost will have been no longer than that spent in your last traffic jam.



1 The basic building block of the Dynamic Voltage Restorer. Such modules can be combined to build different converter configurations and high-power DC-DC choppers.

For the manufacturing industries, a voltage sag takes on a quite different dimension – one which can be summed up by 'lost production, lower revenues'. The search for higher production efficiency has accelerated the trend towards automation, not only of single processes and manufacturing steps but also of continuous lines combining large numbers of individual processes and production steps. Moreover, some of these processes demand an extremely stable environment, completely absent of disturbances, to ensure the very highest quality and minimum outage. In either case, even a disturbance lasting less than 100 milliseconds could result in several hours of lost production – or as long as it takes to stabilize the process conditions.

One way to protect complete manufacturing processes or plants from power grid disturbances is to install large-scale uninterruptible power supplies capable of very fast response. However, this is a rather expensive solution in terms of up-front investment and operating costs. Since most power supply disturbances do not involve a complete loss of supply, but rather a temporary voltage drop, usually in just one phase of the supply line, simple voltage sag compensation would provide sufficient protection in about 90% of all disturbances originating in the power grid.

The conditions that called for voltage sag correction

The manufacturing facility in which the two mentioned DVRs were installed is of a complex nature and receives its electric power from two medium-voltage feeders. Under very unfavorable weather conditions the number of flashovers and line-to-ground faults in the grid can rise to more than 15 occurrences within a 24-hour period. In 1999 a total of more than 150 recorded voltage sags had a considerable impact on production, calling for an urgent remedy. It was decided that what was needed was a pair of power quality devices – one per feeder – and that they would have to be delivered in the fastest possible time. In accordance with the client's brief, they had to be up and running within 8 months of the order being placed.

The basic technical specifications were:

- 22-kV nominal feeder voltage
- 15-MVA nominal load per feeder, at a power factor of 0.9 pu
- Performance:
  - Protect the nominal load against a 3-phase voltage drop of 35% for a duration of 500 ms
  - Protect a load of 22.5 MVA against a 3-phase voltage drop of 35% for the shorter duration of 333 ms
  - Protect the same loads against 1-phase voltage drops in excess of 50% for up to 600 ms
  - Time for switching from standby to boost to be less than 1 ms

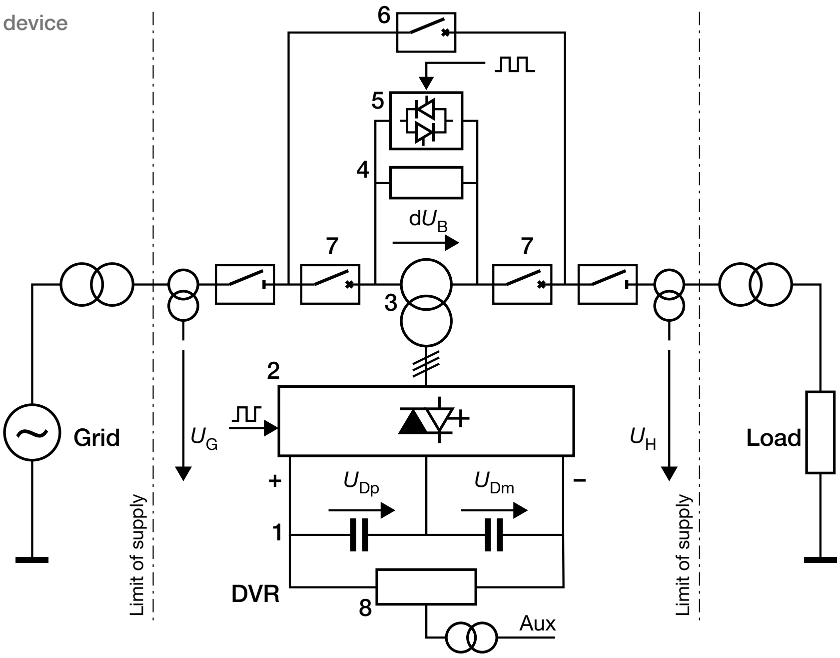
The device also had to be 'expandable' to permit uprating, should this be deemed necessary at some time in the future.

How the requirements are met

What made the short delivery time possible in the first place was the fact that a matching hardware platform

2 Single-line diagram of the power quality device

1 *DC link with capacitor bank*
2 *Voltage source converter*
3 *Booster transformer*
4 *Damped highpass filter*
5 *Crowbar*
6 *Bypass switch*
7 *Isolation switches*
8 *Charging unit*
U_G *Grid voltage*
U_H *Load voltage*
U_{Dp} *DC link voltage, positive charge relative to midpoint*
U_{Dm} *DC link voltage, negative charge relative to midpoint*
dU_B *Inserted, sag compensating voltage*



already existed. This allowed modules to be used that ABB also employs in its larger standard voltage-source frequency converters and large medium-voltage drive systems (ACS 6000). The basic module 1 is a phase leg for three-level, neutral-point-clamped converters. These modules can be combined to build different converter configurations and high-power DC-DC choppers. Such a platform, together with matching signal interfaces and a versatile, easily programmable control system, provides the very high level of flexibility and adaptability necessary to build units for a wide range of applications without having to make any basic changes to the design.

The active switching elements used are Integrated Gate Commutated Thyristors (IGCTs) – a kind of advanced Gate Turn Off Thyristor (GTO). Compared with GTOs, IGCTs have the advantage of lower conduction and switching losses, plus much better switch-off characteristics, allowing a snubberless converter design.

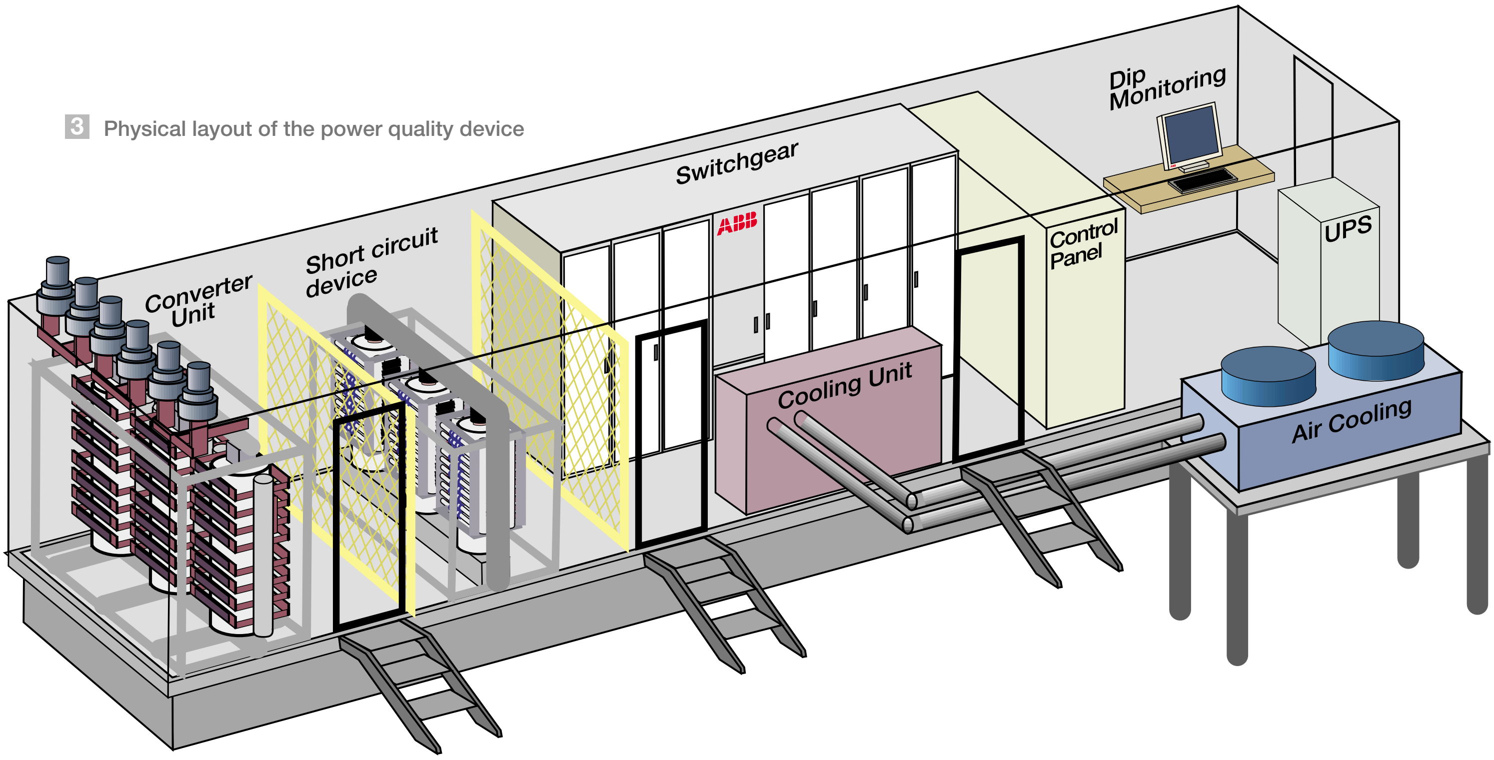
What set this contract apart from earlier ones was the amount of energy to be stored in the DC link capacitor bank, which serves as the energy storage device. The challenge here was not so much the amount of energy itself but rather the need to design the equipment such that no kind of internal fault – eg, a faulty capacitor unit, short circuit or fault in the converter – could cause any damage to it besides the failed component which had instigated the fault. This task is not at all trivial since during operation of the device (when a voltage sag has to be compensated) the current taken from the capacitor bank is not low and any current-limiting devices would have a detrimental effect if the current is too low, or even interrupted, as a result of its action. A reasonable solution was found to be to split the capacitor bank into two separate groups and to place a combination of damping resistors and fuses in strategically selected locations.

The power quality device

A single-line diagram of the PQ device is shown in 2. The main components of the power circuit and their functions are:

- *DC link with capacitor bank* (1). This also serves as the energy storage medium.
- *Voltage source converter* (2) for voltage sag compensation. It consists of two NPC phase legs per phase. The active switching elements are IGCTs.
- *Booster transformer* (3), which acts as the interface between the feeder phases and the voltage source converter.

3 Physical layout of the power quality device



■ *Damped highpass filter* (4), connected across the line-side terminals of the booster transformer. It helps to 'clean' the shape of the injected voltage by 'short-circuiting' the residual higher-frequency harmonics. Thus, the voltage that both the load and the power grid 'sees' is virtually ripple-free.

■ *Crowbar* (5), consisting of controlled thyristors that bridge (ie, short-circuit) the line-side terminals of the booster transformer in the event of an internal device fault or a fault downstream (on the load-side) of the device. The latter function, is particularly valuable as a means of avoiding interference with existing protection schemes.

■ *Bypass switch* (6). This allows the entire device to be bypassed.

■ *Isolation switches* (7), for isolating the device when the bypass switch is closed for maintenance purposes, ie without having to interrupt the feeder line.

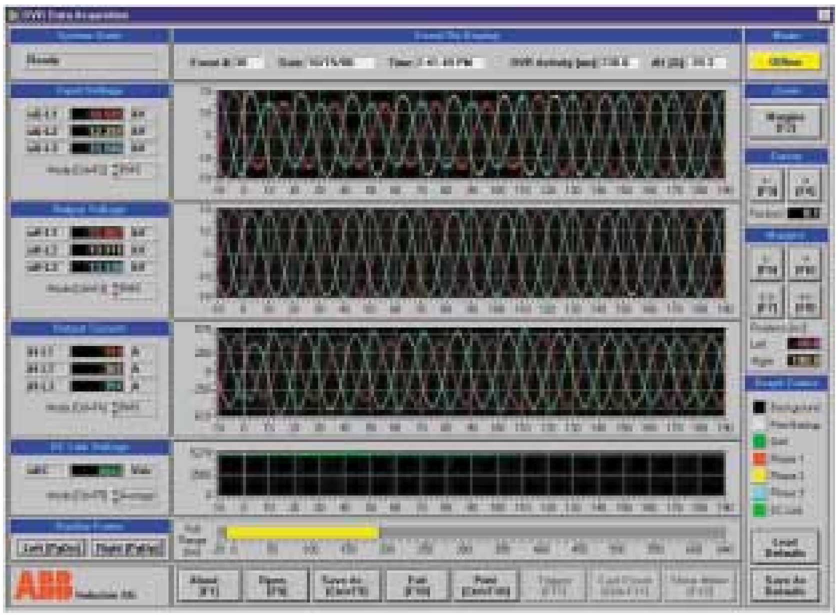
■ *Charging unit* (8), for charging the DC link capacitor bank prior to putting the device into operation and for recharging the capacitors after a voltage sag compensating operation.

An impression of the physical layout and arrangement of the DVR's main components is given in 3. By completely installing, wiring and testing the units in the factory prior to shipment, on-site installation time is reduced to a minimum and the time needed for commissioning is also significantly reduced. The container shown is 12.5 meters long, 3 meters wide and 3 meters high. Most of the energy-storing capacitor bank is housed in a second container of similar size (not shown).

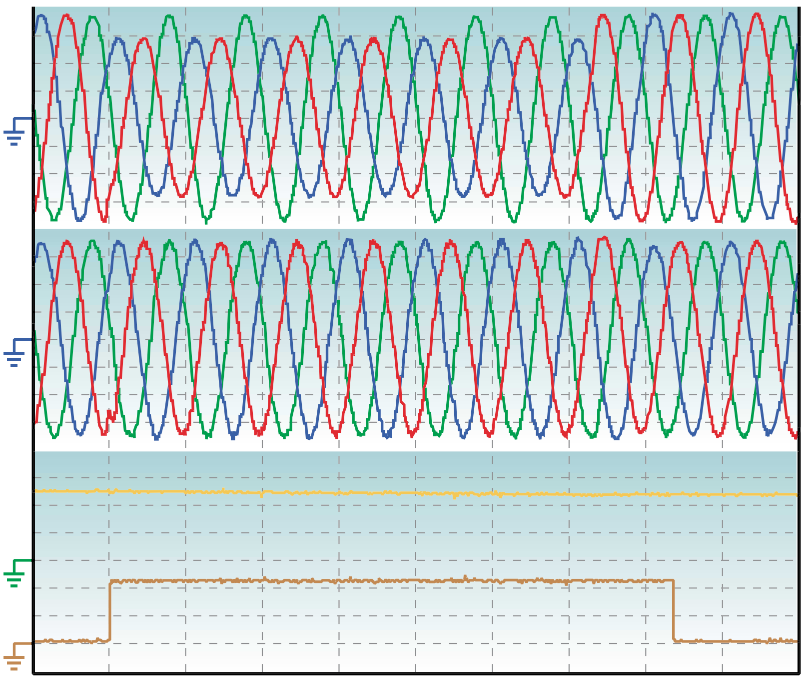
Control and monitoring

The control system – the nerve center of the DVR – has to respond extremely fast and also be very reliable.

The modulator and all converter-related interlocking and monitoring functions require a very fast processing speed (ie, very short cycle times). They are therefore implemented on a special board equipped with an EPLD (Electrical Programmable Logic Device) and several digital signal processors. Apart from some minor modifications it is the same standard board that ABB uses to control its ACS family of medium-voltage drives. The higher-level control is executed by ABB's PSR system (Programmable High Speed Controller), which ensures not only a very high degree of flexibility but also easy application-specific adaptation and modifications. A third, PC-based system serves as the operator control interface and is also used to monitor the operation and operating performance



4 Screenshot of the data acquisition function. This information can also be made available at remote locations.



5 Voltage sag compensation, viewed with the hardware simulator. Top to bottom: input voltage, corrected output voltage, DC link voltage, trigger signal

of the power quality device. Use is made of advanced communication technology. In the event of an internal disturbance within the device, an e-mail describing the problem is generated and sent to preset addresses. Personnel authorized to access the system can supervise the controls from practically any location in the world, and if necessary change parameters or modify the program. This built-in, remote trouble-shooting capability is a key system feature.

A screenshot of the voltage and current traces recorded during an actual voltage sag in the grid is shown in 4 as an example of this monitoring function.

Operating performance

The design and manufacturing phases of the project were accompanied by computer (software) simulations and by tests carried out on a hardware simulator. Software simulations were used to verify the design parameters and component specifications as well as the control algorithms and their parameter settings. The entire control system was later tested on a hardware simulator to confirm that the control software and hardware, including the I/O ports, had been correctly configured and were working properly.

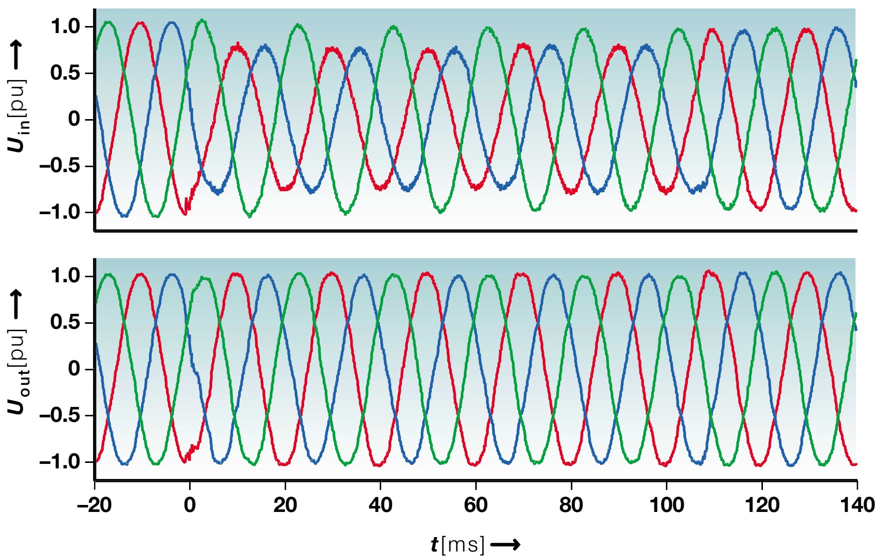
All of these efforts were seen to pay off when, in late summer 2000, both power quality devices were placed in operation after what had been a remarkably short commissioning time.

Traces of the input and output voltages recorded during simulation of the correction of a 30% voltage sag are shown in 5.

6 shows the same traces, but taken from a recording in the actual installation when a genuine voltage sag of similar magnitude took place shortly after commissioning. If the device had not been in operation, such a voltage sag would have had a negative impact on production. It can also be seen that the voltage compensation takes place extremely quickly, ie in less than one millisecond, which is faster than is actually needed or specified. This is made possible by the unique feed-forward control used for this kind of application. It almost completely does away with the delay and settling time that would be unavoidable if a more conventional control algorithm were used.

Last but not least, it has to be emphasized that the specifications were considered as guidelines and minimum requirements for the devices. The sag compensation, for example, is not limited to the specified value. If a three-phase sag happens to be larger than 35% it will still be compensated – not for 500 ms, but for as long as the energy storing capacitor bank can supply the power. And if the sag is smaller, the system provides protection for up to 600 ms, so that many consecutive voltage sags are compensated. In addition, the nominal DC link voltage is lower than its maximum permissible value, so the DC capacitor bank can also absorb a certain amount of energy. This enables not only voltage sags to be compensated but also some temporary overvoltages (voltage swells) as well.

7 shows the voltage sag versus disturbance duration capability of the system for 1-phase, 2-phase and 3-phase sags.

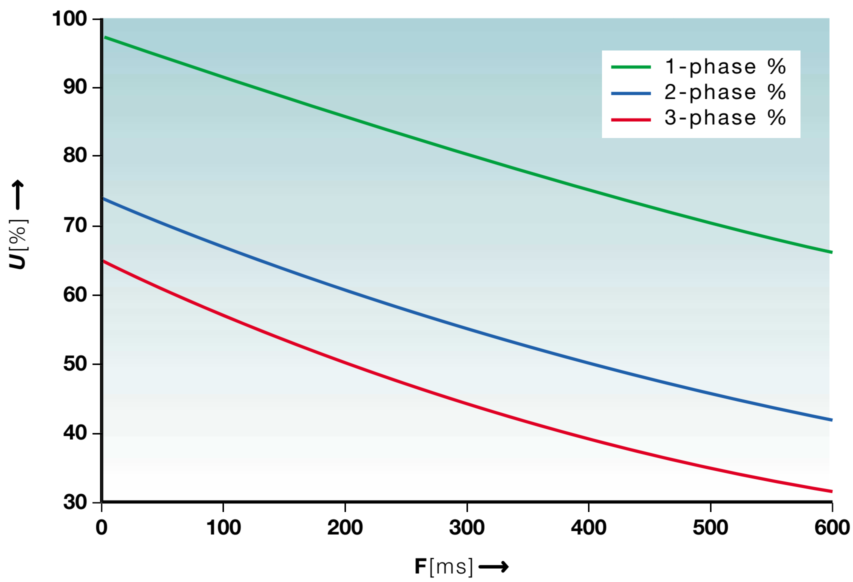


6 Voltage sag compensation in the actual installation. The top recording shows the input voltage, that below it the corrected output voltage.

U_{in} *Input voltage*

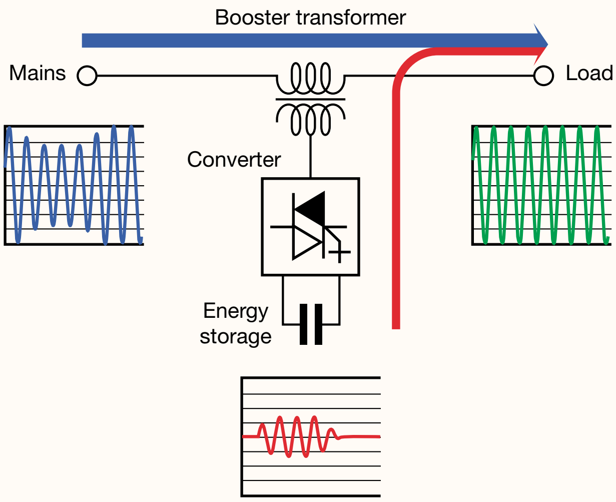
U_{out} *Output voltage*

t *Time*



7 Protection capability of the system. Voltage sag (*U*) versus fault duration (F)

Power quality systems – tools for boosting productivity



Principle of the Dynamic Voltage Restorer with a response time of less than one millisecond

A short dip in the supply voltage, unnoticed by the majority of electricity consumers, can still stop an entire production line in highly sensitive industries, such as computer chip manufacturing, oil refining and textiles. Severe climatic conditions often can cause the total interruption of an electric power supply for hours, rendering entire production lots useless. ABB has developed and successfully introduced systems to overcome such obstacles by means of advanced power electronics. These power quality systems stand out for their reliability and for their responsiveness to voltage disturbances.

The Dynamic Voltage Restorer (DVR) is the optimal solution for most customers who want protection against the bulk of these disturbances – voltage sags and swells resulting from remote system faults. A DVR compensates such voltage excursions almost immediately providing the supply grid is not disconnected entirely by upstream breaker trips.

Conclusions

Power quality devices with DVR functionality are not intended to replace uninterruptible power supplies. However, they offer excellent protection for complex manufacturing processes against most disturbances occurring in power grids. They are also very rugged and reliable, and are capable of extremely fast response, plus they require practically no maintenance. And since they can be built with relatively high ratings, they can be employed across industry - not only to protect individual production lines but also entire factories or industrial parks. Just as importantly, they do not interfere with existing protection schemes by limiting fault currents when faults occur downstream. They can therefore be installed without requiring modifications to the existing equipment.

For further information please visit http://www.abb.com/powerelectronics

Authors

Peter Daehler
Markus Eichler
Osvin Gaupp
Gerhard Linhofer
ABB Industrie AG
CH-5300 Turgi
Switzerland
Address for questions and inquiries
E-mail: pes@ch.abb.com
Fax: +41 56 299 2090

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