ELSEVIER

Journal of Power Sources 67 (1997) 173–177

JOURNAL OF POWER SOURCES

Voltage quality and reliability from electrical energy-storage systems

B. Ratering-Schnitzler [a], R. Harke [b], M. Schroeder [b], T. Stephanblome [b,*], U. Kriegler [c]

[a] RWE Energie AG, Kruppstrasse 5, 45128 Essen, Germany
[b] EUS GmbH, Munscheidstrasse 14, 45886 Gelsenkirchen, Germany
[c] Piller GmbH, Abgunst 24, 37620 Osterode am Harz, Germany

Received 11 September 1996; accepted 27 December 1996

Abstract

Due to the increasing use of sensitive equipment for process control, the requirements for the voltage shape are growing. Voltage irregularities often cause the process control to fail, while the process at high performance is insensitive. Thus, the use of uninterruptible power systems (UPS) is indispensable. To improve voltage quality a new system is presented using the energy storage of a UPS for active compensation. © 1997 Elsevier Science S.A.

Keywords: Energy storage systems; Reliability; Voltage quality

1. Introduction

Within most operational systems, processes are today insensitive to disturbances (arc furnace, welding machines, etc.) and high-capacity processes (production streets, assembly line production, chemistry, etc.) are operated with very low or moderate requirements to the voltage waveshape. Voltage distortions and short-term voltage dips, that are caused especially by switching operations and pulsating loads that appear in running production processes, rarely result in a production stoppage.

With industrial modernization, more and more up-to-date equipment for process control and monitoring (e.g., computers) is used with very high requirements for the voltage waveshape. Voltage distortions and short-term voltage dips, that have not caused any problems in the past, are increasingly resulting in production disturbances with the control at low performance or the process monitoring normally losing conscience. The failure of these 'chainlinks' at low performance often causes an expensive, long-time production stop. In order to guarantee these sensitive 'chainlinks' with an optimal voltage quality at any time, they are increasingly becoming separated more and more by uninterruptible power systems (UPS).

2. Causes and effects of voltage irregularities

Certain factors may reduce the voltage quality. This has a main effect on two characteristics of voltage: (i) the amplitude can change very quickly once or regularly (voltage dips, flicker, etc.), and (ii) the voltage waveshape can differ slightly from the sinusoidal shape (harmonics, commutation notches, etc.).

The quality level, as it is characterized by the given features, results from the influence of different factors. Here, it concerns the external effects on the system, the operational processes within the system, the failure of operational equipment, and the disturbances of the devices and systems of the companies.

Utilities try to use high-capacity operational equipment by automatic transformer control and to achieve sufficient voltage quality for normal equipment by costly protection techniques. It is unjustifiable, however, regarding technique and economy to build up a public supply system that, at the same time, fulfils the requirements of a small

* Corresponding author.

0378-7753/97/$17.00
PII S0378-7753(97)02510-X

amount of very sensitive devices. Here, it is much more effective and less expensive for the public to install the necessary protection measures (e.g., UPS) directly at the location of the sensitive devices.

3. Remedial measures in case of irregularities in voltage

As already mentioned, measures that a utility could take with respect to a system that fulfils special requirements of some very sensitive devices are economically unjustifiable. Remedial measures directly at the location of the sensitive devices are much more effective and cheaper; these include: (i) grading of the transformer; (ii) symmetrical power distribution; (iii) compensation systems; (iv) passive harmonic filters; (v) additional induction of power converter; (vi) surge voltage protector; (vii) separate system connection, and (viii) UPS.

The use of UPS is an effective and cheap measure to protect some very sensitive devices (e.g., control systems, computers). They guarantee the operation, independent of the grid, of the devices they feed. Disturbances caused by the grid cannot affect the devices that are protected by the UPS. The system is used mainly in computer centres, hospitals, airports and telecommunications systems. Only in very rare cases, do these UPS have to fulfil their function as an emergency power supply in the case of power failure. Within the remaining period ($\sim$ 99.999%), they are connected to the grid as stand-by operation. During this time, such a UPS could fulfil further performance characteristics for the operation grid in addition to the emergency power supply, which will be described more detailed in Section 4.

4. Presentation of the idea of a unified power conditioning (UPC) system (UPS with voltage quality improvement)

The idea of the UPC system is that UPS are connected to the operation grid with $\sim$ 99.999% of their time in stand-by operation and during this time they can be used for other performance characteristics.

For this purpose, RWE Energie AG, PILLER GmbH and the EUS GmbH have started a common project with the following aims:

1. Extensive use of the matured hardware of the actual UPS from PILLER while keeping the UPS function (emergency power supply).
2. Additional performance characteristics for the operation grid such as: reduction of commutation notches; reduction of harmonics; reduction of voltage fluctuations (flicker), and loading of reactive power.

The above-mentioned requirements with respect to the UPC system are shown in principle in Fig. 1. In order to basically use all possible improvements in voltage and supply quality with a UPS a connection according to Fig. 2 should be considered.

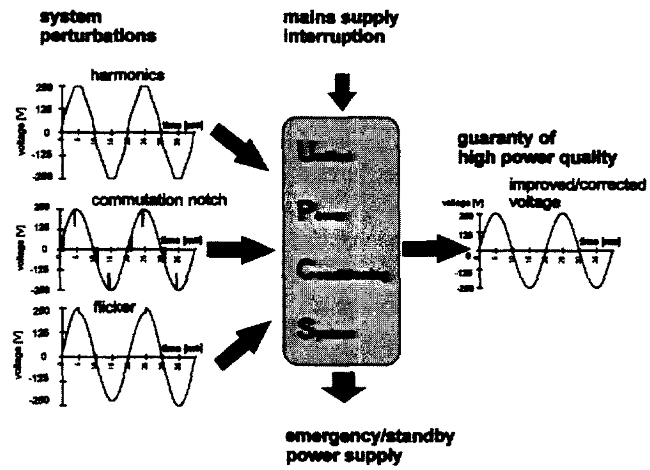

Fig. 1. Requirements of the UPC system.

In normal use with closed electronic switches, the controlling power range of the converter of the UPC system is available for the whole operation system. Depending on the required improvement of the voltage quality, this power is sufficient for operation systems with a multiple of the UPC system power, as the deviation of the voltage from its ideal value is only in the range of a few percent. Also, for the loading of reactive power, only a fraction of the whole clients' load is sufficient.

The control algorithm of the UPS operates in real time. The result is that every present voltage change can be compensated in a split milliseconds, while a control algorithm operating in the frequency range requires a few milliseconds to analyse the disturbing phenomenon and, accordingly, gives delayed control orders for its correction.

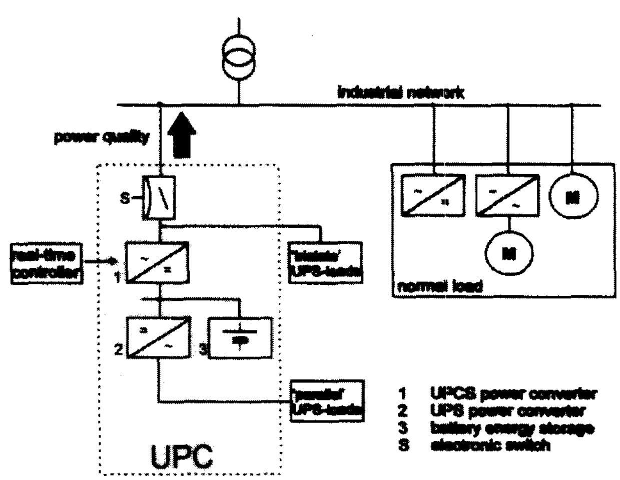

Fig. 2. Block diagram of the UPC system.

5. Presentation of first results of the UPC system (voltage quality and reliability)

First simulation calculations made by EUS in co-operation with RWE Energie showed that these performance features can be obtained by a suitable control process. A new control strategy was developed and optimized by EUS to achieve a maximum of the desired performance (Fig. 3). Technical constraints as far as the existing hardware is concerned were taken accommodated.

As a further step, the existing hardware of a UPS could be modified in such a way that, after implementing the new control strategy, the desired performance of the UPC system could be achieved. This prototype (Fig. 4) was recently tested in an operation system under real conditions (Fig. 5).

During the first test, harmonic currents as well as harmonic voltages were produced which naturally could be found in the whole system. Fig. 6 shows the irregular bus voltage of the operation grid without a UPC system and the much more regular bus voltage in the presence of active UPC. The individual harmonic voltages are clearly reduced by the harmonics compensation performance of the UPC system, see Fig. 7.

In another test, the reaction of the system was examined while in the operation grid a 75 kW asynchronous motor in delta starting was switched, see Fig. 8.

6. Perspectives for the use of the UPC system

In summary, there are two main areas of application for the UPC system introduced in this paper.

6.1. Area 1: the production process of the plant causes failures within its clients' system

The plant has to isolate its sensitive consumer (administration office, light, PC, etc.) from the production process that is causing the disturbances (e.g., welding machine) in order not to disturb itself. Usually, this is realized by the construction of a 'clean' and 'dirty' electrical power system. As a consequence, there is almost a doubling of the

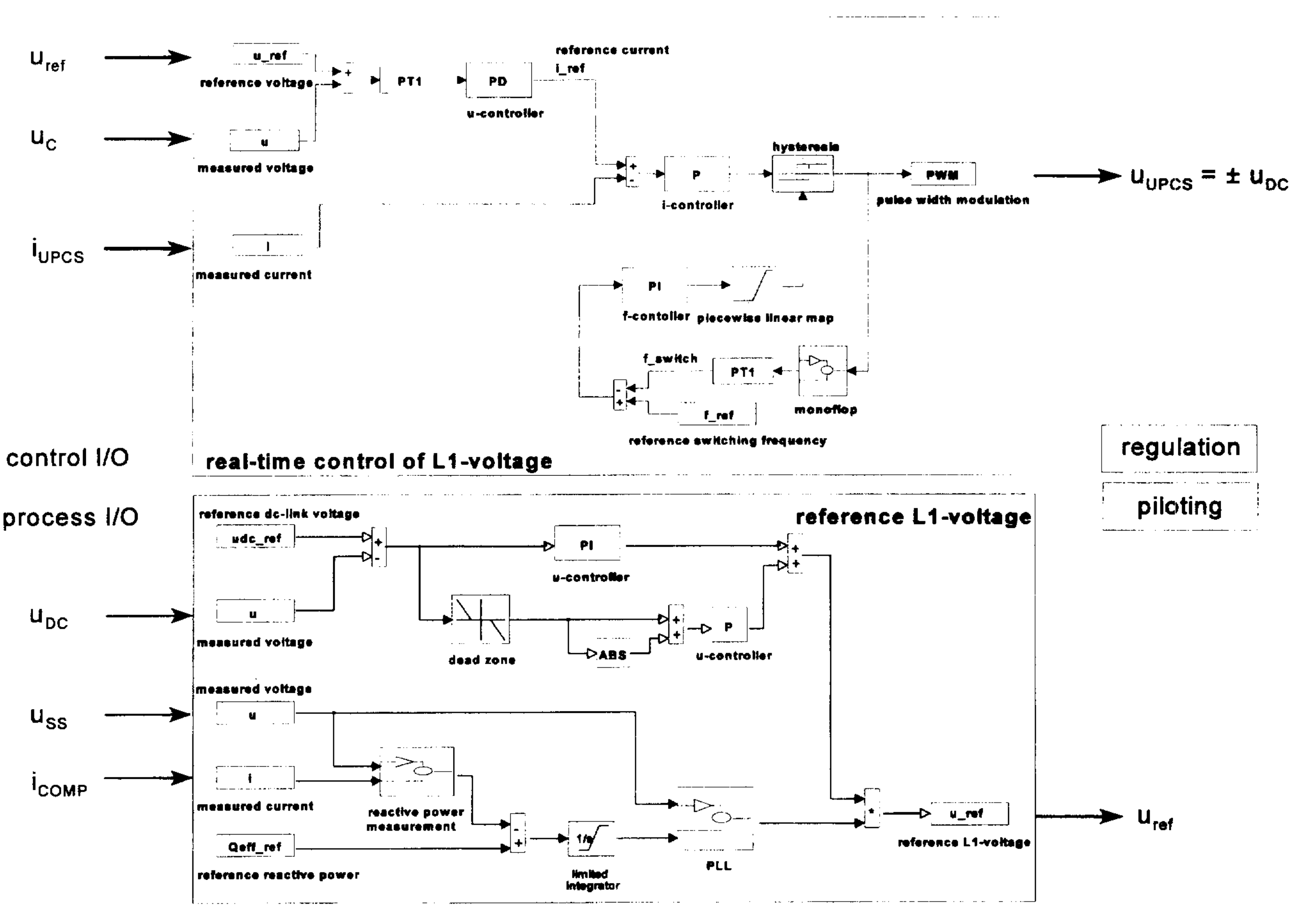

Fig. 3. Real-time control of busbar phase voltages.

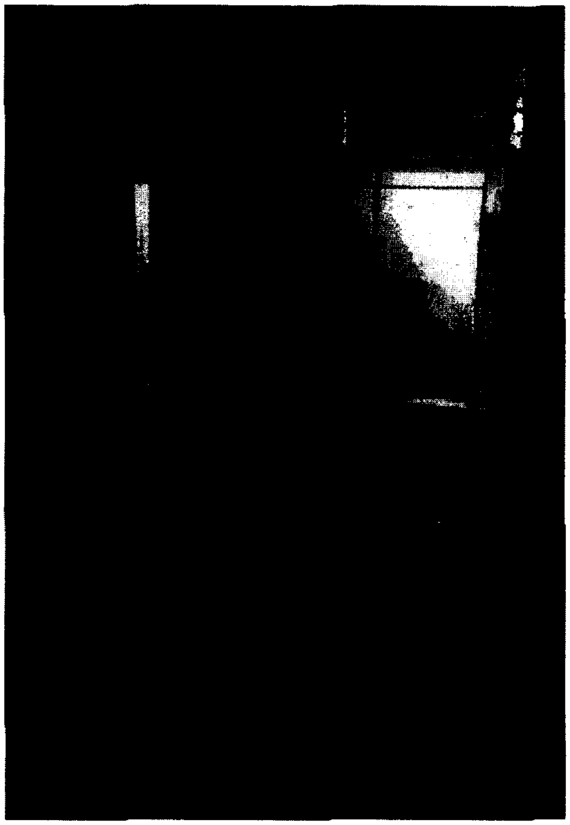

Fig. 4. Prototype of UPC system realized at the PILLER laboratories.

equipment and, correspondingly, of the costs. In the future, the plant will be able to reduce its disturbances to an acceptable level via a UPC system (local grid-tuning). This permits working with a single electrical power system that is less expensive.

6.2. *Area 2: a production process of the plant causes failures in the neighbouring low voltage grid*

Every plant wants to limit the disturbances of the individual production processes to a level that is accept-

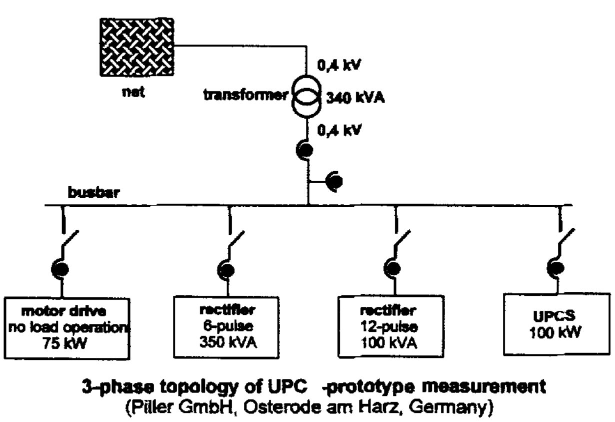

Fig. 5. Substitute diagram of the operation grid with the UPC system.

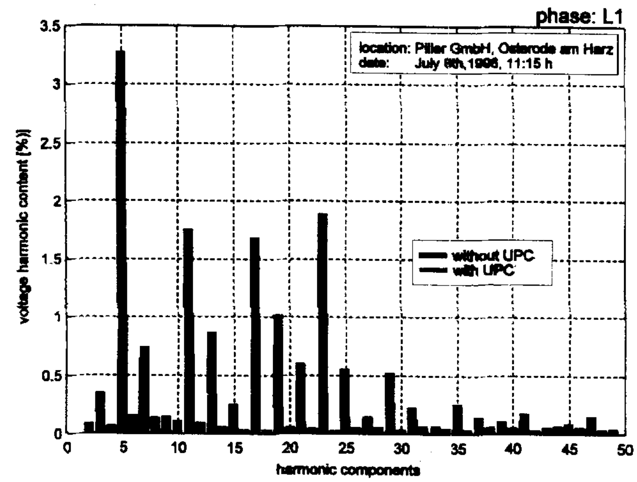

Fig. 6. Dynamic performance of the UPC system in terms of harmonics (frequency analysis).

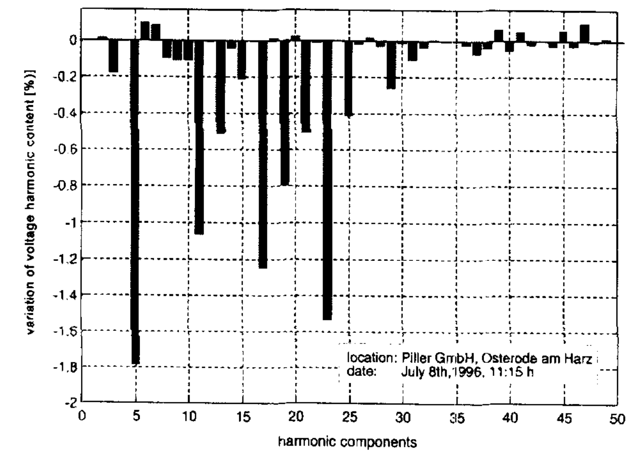

Fig. 7. Harmonics compensation performance of UPC systems.

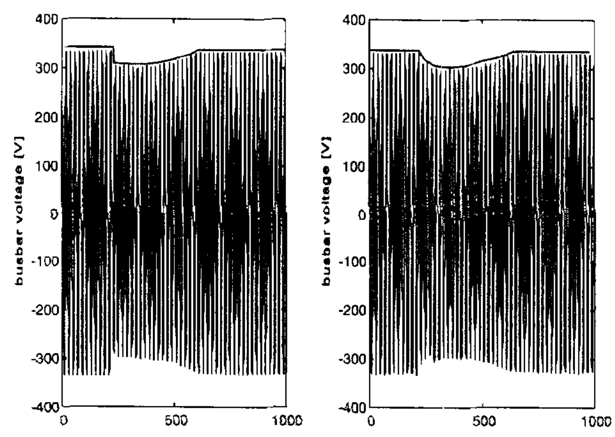

Fig. 8. Dynamic performance of UPC system in case of voltage sags caused by delta starting of an asynchronous motor (75 kW).

able by all devices. In a major industry, for example, this would mean that larger speed-variable motor drives (e.g., rolling-mill streets) have a very powerful supply connection or that a large part of the emitted interferences must be compensated directly at the place of origin. Both cases cause high costs. As many of the disturbances are corrected already in the first part of the distribution system, and only a few secondary distribution systems show a critical disturbance level, it is sufficient to 'clean' the most disturbed systems by a UPC system (local grid-tuning). The required compensating power is much lower than the power that should be installed directly at the place of origin of the emitted interference.

This solution has clear advantages for the plant, namely: (i) less disturbances/production failures; (ii) no separate power supply for 'clean' and 'dirty' operation systems; (iii) no filters, compensation systems; (iv) lower thermal load of the equipment and, therefore, longer lifetime, and (v) reliable supply of the emergency loads (controls, computers, etc.).