

DISTURBANCES AND POWER QUALITY OF THE 18 KV CERN ELECTRICAL NETWORK AND THE 400/230 V UPS DISTRIBUTION SYSTEM FOR LHC

K. Kahle, CERN, Geneva, Switzerland

Abstract

This paper analyses the disturbances and power quality of CERN's 18 kV electrical network and gives statistics on the disturbances occurred during the last years. Focus is given to the different back-up levels of CERN's 18 kV network, such as the Autotransfer system and the diesel generators.

The paper also covers the structure of the uninterrupted power supply (UPS) network for LHC and gives an analysis of the expected power quality, reliability and autonomy of this UPS network.

INTRODUCTION

Network disturbances and power quality are issues of increasing importance, as the share of sensitive electronic circuits is increasing steadily in modern power systems. Network disturbances can be classified into transient events such as voltage sags, swells and spikes. Other events of longer duration are for example mains failures, harmonic voltage distortion and steady-state overvoltages and undervoltages.

As the causes of network disturbances are based on the fundamental laws of electricity and physics, they have to be considered to be normal phenomena in any electrical network. The most common causes of long-duration and transient voltage disturbances are:

- lightning strikes on the 130 kV and 400 kV overhead lines (~5 p.a.)
- short-circuits outside or inside CERN (~5 p.a.)
- inrush currents during the energization of large power transformers, switching ON/OFF of large electrical loads (~80 p.a.)
- switching ON of large capacitor banks or Static Var Compensators (~3 p.a.)
- mains faults (~1 p.a.)
- Emergency Stop operation (~1 p.a.)
- human error (~0.5 p.a.)

There are several strategies to reduce the occurrence and the impact of such disturbances, such as:

- careful design of power systems and installations in order to reduce the risk of short-circuits
- optimisation of the protection systems for fast and selective fault clearing
- installation of special back-up systems such as diesel generators or UPS systems
- reduction of human error
- redundancy of equipment and energy sources
- assurance of a certain immunity of user's equipment against disturbances.

This paper discusses the issue of network disturbances and power quality with a special focus to LHC.

RELIABILITY OF CERN'S 400 KV AND 130 KV SOURCES

With the 130 kV Meyrin and the 400 kV Preveessin network connections, CERN has two energy sources.

CERN's major supply and the only supply allowing LHC and SPS machine operation is the Preveessin 400 kV supply with its overhead line to the Genissiat HV station. In the near future a 400 kV connection towards the new Chamosson hydro power station (Valais CH) will be available. More detailed computer studies will have to be made in order to determine whether the LHC and SPS machines can be pulsed over this connection. Should this be possible, as previous studies already indicated, CERN would have a 400 kV back-up supply.

The Meyrin 130 kV supply from Verbois (GE) is a back-up destined to maintain critical loads in case of 400 kV power failures. It also offers a high degree of flexibility in winter and gives some advantages and potential cost savings when negotiating CERN's energy contracts.

RELIABILITY OF THE 18 KV NETWORK

The 18 kV network is the backbone for energy distribution at CERN.

In case of breakdown of one of the two sources 400 kV or 130 kV, CERN's de-centralised Automatic Source Transfer (Autotransfer) system automatically detects this situation individually for each major substation, and changes over to the remaining source. The Autotransfer sequence takes about 20 sec from the loss of power until the completion of the source transfer.

The Autotransfer system is limited to 60 MVA in total, and therefore limited to the SPS Stable Loop, LHC general services and part of the cryogenics.

As an additional back-up level, all LHC access points in France have a manual back-up connection to the local RTE (former EDF) 20 kV network. A manual switchover takes about 1 h. Normally only one of these points is foreseen to be used at any time. The maximum power per point is 3 MVA, therefore this supply is only used for safety equipment and part of the general services.

0.4 KV LEVELS OF AVAILABILITY

Normal supply

The normal supply is feeding the LHC machine and experiments.

The normal supply is the part of the network fed from the 400 kV or 130 kV high voltage grid. The equipment supplied from the normal supply will see all mains faults, transients and other perturbations likely to occur in large industrial installations.

The normal supply in a given zone is switched off following the actuation of an emergency stop in that zone. LV switchboards of the normal supply network are called EBDxx/xx.

Assured supply

The assured supply is used for the LHC general services, safety installations and critical compressors for cryogenics and chilled water.

The assured supply is in normal operation part of the normal supply. The only difference being, that in case of a mains fault, the load is transferred to a diesel generator set until the normal power supply returns.

The diesel generators are directly connected to the LV networks in all LHC points, except point 1. In point 1 the assured supply is part of a larger 18 kV generator back-up system, including the assured networks of Meyrin, LHC18, BA6 and BA7.

It takes about 45 sec following a mains failure before the diesel generators take over.

The assured supply in a given zone is switched off following the actuation of an emergency stop in that zone. LV switchboards of the *assured supply* network are called EADxx/xx.

Secured supply

The secured supply is functioning as the assured supply.

The secured supply in a given zone is NOT switched off when an emergency stop is actuated in that zone. LV switchboards of the *secured supply* network are called ESDxx/xx.

Uninterrupted supply

The highest level of reliability is offered by the uninterrupted supply network, feeding mainly safety systems, LHC cryogenics control and other critical systems.

An uninterrupted supply network is fed from an uninterrupted power supply (UPS) system. It is not susceptible to any transient perturbations occurring on the mains.

The uninterrupted supply has a battery giving it an autonomy of 5 min to 2 h, with most of the UPS systems for LHC having an autonomy time of 10 min. The uninterrupted supply can be defined with or without switch off following an emergency stop in its supply zone.

LV switchboards supplied by an UPS system are called EODxx/xx.

STATISTICS ON 18 KV NETWORK DISTURBANCES

For the permanent monitoring of network disturbances and power quality, CERN has installed a number of transient recorders (oscillostores) in strategic points of the 18 kV network. These oscillostores register all voltage and current variations above a certain trigger level. In average there are about 100 ... 150 events per year recorded in the 18 kV network.

The recordings show that the majority of network disturbances is in the range of 80 ... 120 % of nominal voltage, having an average duration of 50 ... 150 ms. The main causes of these events are sudden load changes, inrush currents of transformers and short-circuits located in remote areas of the power system.

There are also a few disturbances of much higher / much lower amplitude, these are mainly caused by short-circuits close to the point of measurement. Unsymmetrical short-circuits severely disturb the voltage balance of the three-phase power system and thus create large under- or overvoltages. The typical length of such rare events is about 80 ... 200 ms.

Another rare category of transient events is of longer duration (200 ... 1000 ms), but usually of smaller amplitude.

Finally, there could be very steep and very short voltage transients (spikes) on top of the 50 Hz voltage sinewave. Due to the short duration of about 100 μ s ... 1 ms, the energy contents of such events is very small and they could be filtered out by the user. The oscillostores installed in the 18 kV network did not record any of such events.

Figures 1 ... 3 show the statistical data of transient network disturbances for the years 2000, 2001 and 2002. Due to a data communication problem of the oscillostore, there are no disturbances recorded between 10 January and 28 April 2002, therefore about 25 % of the data for 2002 are not available. When comparing the data of the three different years it can be seen that the characteristics of the events are similar over any 12-months period.

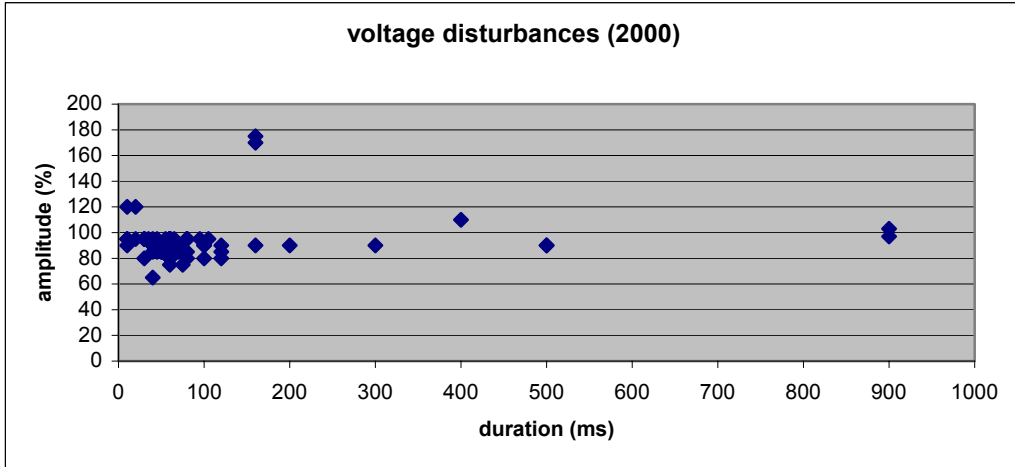


Figure 1: 18 kV voltage disturbances recorded in 2000

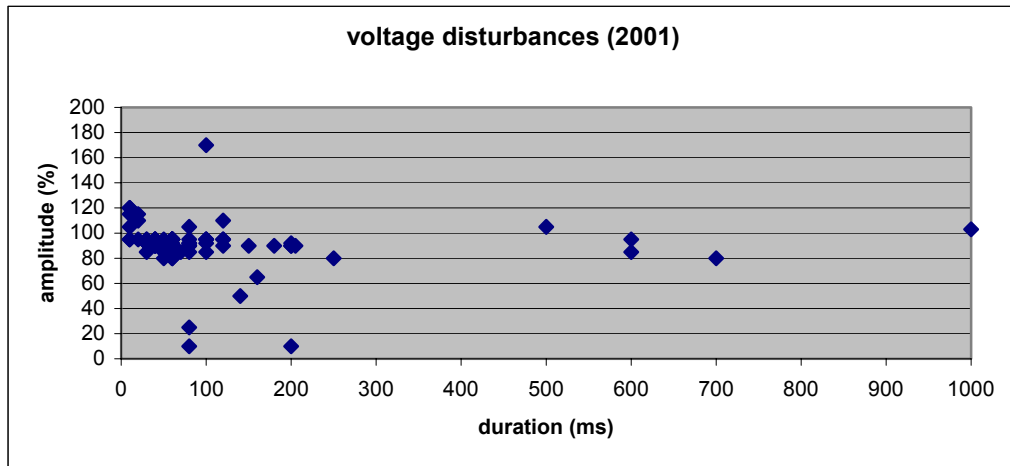


Figure 2: 18 kV voltage disturbances recorded in 2001

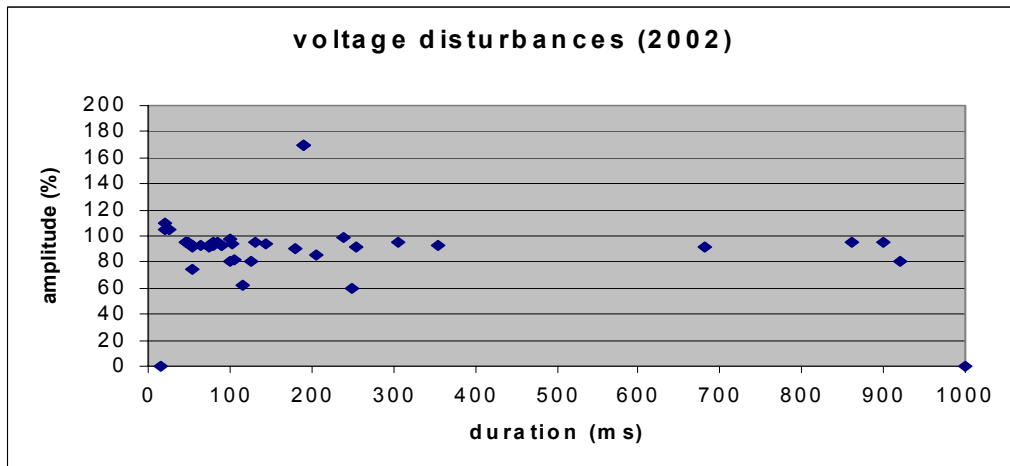


Figure 3: 18 kV voltage disturbances recorded in 2002

As an example, the typical characteristics, duration and amplitude are shown in figures 4 and 5 (example: 2001).

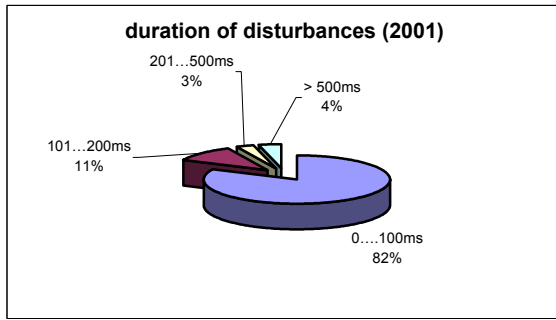


Figure 4: Typical duration of disturbances (e.g. 2001)

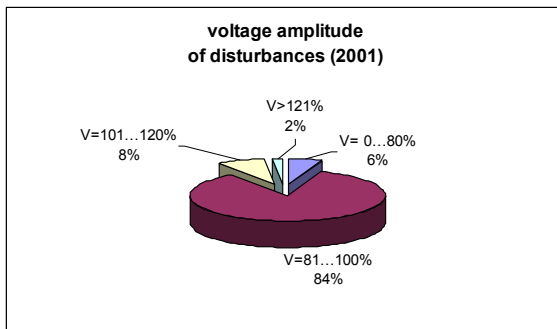


Figure 5: Typical voltage amplitude (e.g. 2001)

Based on statistics of past network disturbances, a certain minimum immunity of LHC electrical equipment was defined in the Engineering Specification “Main Parameters of the LHC 400/230 V Distribution System” [1]. This document covers the main parameters of CERN’s low voltage systems, their variations and power quality issues. User’s equipment should be designed to normally function within the following voltage variations and disturbances:

Nominal voltage	400/230 V
Maximum voltage variations	±10 %
Typical voltage variations	±5 %
Peak mains surges	1200 V for 0.2 s
Mains overvoltage, typ.value	+50 % of U_n , 10 ms
Voltage drops	-50 % of U_n , 100 ms

Equipment whose failure or malfunctioning would have more serious consequences, might be specified defining much higher immunity towards voltage disturbances.

Another key aspect of power quality is the harmonic distortion of the voltage. The two major sources of distortion in LV networks are harmonics generated by non-linear loads connected to the same LV network and harmonics coming from the feeding supply network.

In normal general services networks at CERN, there are usually no problems related to harmonics. The total harmonic distortion THD(U) in most cases remains below 5 % which is better than the tolerance levels specified in IEC 1000-2-2. The LHC Engineering Specification [1] specifies a THD(U) of 5 % for CERN’s LV networks.

THE UNINTERRUPTED POWER SUPPLY (UPS) NETWORK FOR LHC

Layout of the UPS network for LHC

The layout of the underground UPS network for the LHC, including the rating of the individual UPS units, is described in [2]. In total, 71 UPS units will be installed underground for the LHC. Equipment for cryogenics in the UX caverns will be fed from dedicated 10 kVA UPS systems. These systems will have an autonomy time of 10 min, bridging the time which is needed before the generator-backup has taken over.

Expected power quality

As said above, UPS systems protect the load from any disturbances coming from the supplying network. Furthermore, a UPS system also compensates for most of the disturbances created by the load itself. The following figures demonstrate the performance of UPS systems for the most relevant cases [3] (U_1 = input voltage, U_2 = output voltage, I_1 = input current, I_2 = output current). Figure 6 shows the performance of an UPS system during a mains failure.

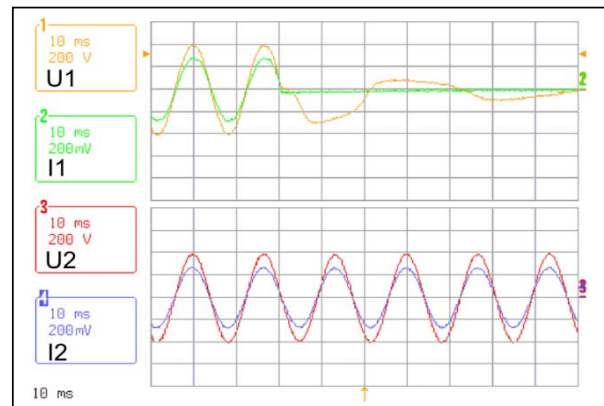


Figure 6: Mains failure with 100 % resistive load connected to the UPS system

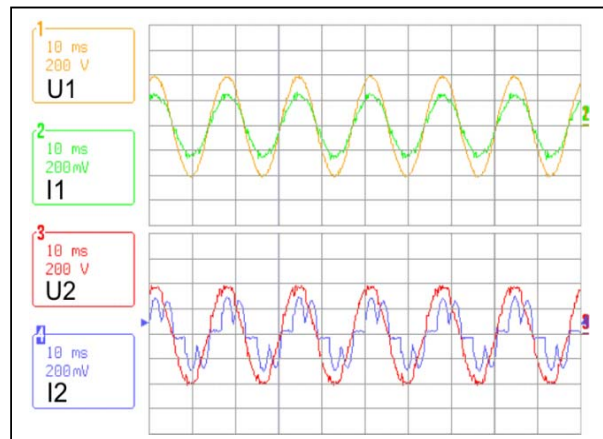


Figure 7: UPS with 100 % non-linear load in normal operation

Even at 100 % non-linear load, the output voltage remains sinusoidal with a low harmonic distortion, see figure 7. In case of an severe overload of the UPS system, the Static Bypass will automatically switch over to the normal feeding supply network and thus bypass the UPS system, see figure 8. From the moment of switch-over to the static bypass, the load is connected to the feeding normal 0.4 kV supply network with its much lower power quality.

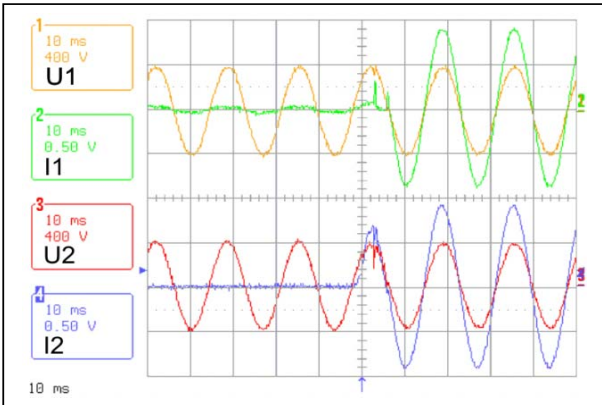


Figure 8: 0-312 % Load Step and Transfer to Static Bypass

The UPS output voltage is stabilised such that even large load steps from 0 to 100 % have almost no influence on the output voltage, see Figure 9.

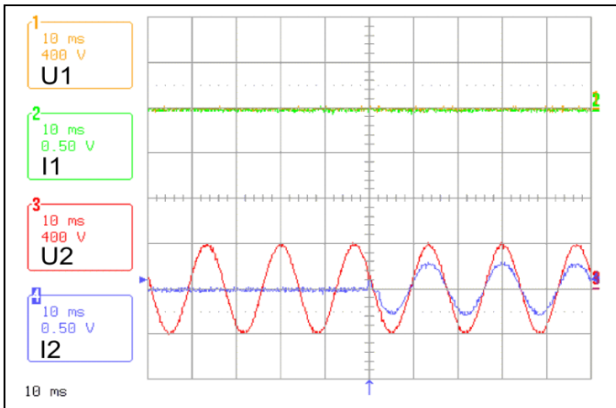


Figure 9: 0-100 % load step in battery operation

The above figures give an indication of the expected power quality of the UPS network for LHC. Nevertheless, even uninterrupted supply networks are not entirely free of disturbances. The most critical case is a short-circuit downstream of the UPS, for example at the busbar of the switchboard or within the user's equipment. In such a case, the UPS system is limiting the short-circuit current to about 3 times the nominal current, thus limiting the possible damage of UPS rectifier and user's equipment. On the other hand, the low short-circuit current creates

severe difficulties for fault detection and fault clearing. For the LHC UPS network, fast acting circuit breakers are used for overcurrent and short-circuit protection, clearing the fault within 5 ... 10 ms (see figure 10). Sensitive and safety related equipment connected to the UPS output should be able to continue to operate correctly during and after such event.

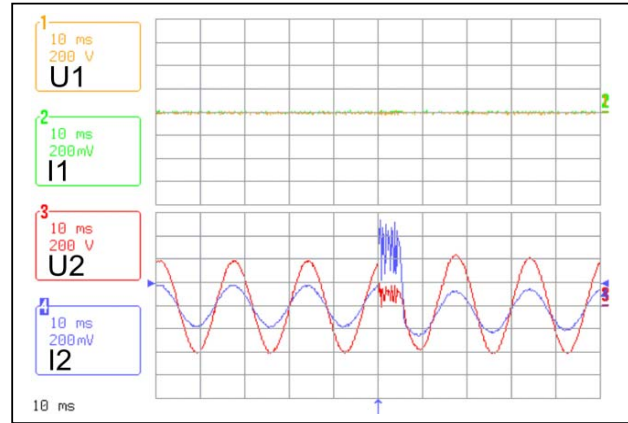


Figure 10: Short-circuit at UPS output during battery operation (scale: 10 ms/div)

Autonomy and Reliability

A Mean Time Between Failures (MTBF) of 125'000 hours was stated by the manufacturer for one UPS system in standalone mode.

To increase the reliability of the LHC uninterrupted supply network, the UPS systems will be installed in parallel redundant configuration. In such a configuration two UPS systems share the load at 50 %. Should one of them fail, the other system takes the full load, with the changeover not being noticeable for the user. Both UPS systems are completely independent with their own sets of batteries.

The UPS systems will signal a mains fault to the users upon which an energy ramp-down process of the magnet systems will be initiated.

To assure a continued high quality level of UPS operation, each unit will be covered by a renewable 5-years contract for corrective and preventive maintenance.

CONCLUSIONS

Statistics

Based on detailed statistics ranging over several years, the expected power quality for the LHC was evaluated. It was shown that the majority of network disturbances is in the range of 80 ... 120 % of nominal voltage with a duration of 50 ... 150 ms.

Mains failures

The reliability of the 400 kV and 130 kV sources, as well as of the 18 kV and 400 V distribution systems was analysed. It was outlined that, due to the high power

demand, there is no backup supply for the LHC machine and experiments.

It was also explained that for critical loads and safety equipment there are a number of back-up supply levels, such as the 400 kV/130 kV Autotransfer system (for general services), the diesel generator back-up (for safety equipment) and the manual back-up from EDF 20 kV (for safety equipment and part of general services). Finally the uninterrupted supply network, used for sensitive LHC equipment such as cryogenics controls, was outlined and the performance of the UPS systems evaluated.

Transient events

It was explained that transient disturbances cannot be completely eliminated, as many of the causes are out of our control (e.g. lightning strikes, inrush currents etc.). To assure the functioning of the equipment during and following network disturbances, tolerance levels for users equipment were defined in the LHC Engineering Specification “Main Parameters of the LHC 400/230 V Distribution System” [1]. It is recommended that LHC equipment should preferably be in conformity with this Engineering Specification.

REFERENCES

- [1] G. Fernqvist, J. Pedersen, “Main Parameters of the LHC 400/230 V Distribution System”, EDMS No. 113154, 29.9.2000
- [2] J. Gomez, J. Pedersen, “Underground Uninterrupted Power Supply for the LHC”, EDMS No. 356521, 24.9.2002
- [3] UPS test records and information kindly provided by Mr. Pedersen, GUTOR/APC Switzerland, Jan. 2003