Power Quality Application Guide

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Resilience

Resilient Power Supply in a Modern Office Building

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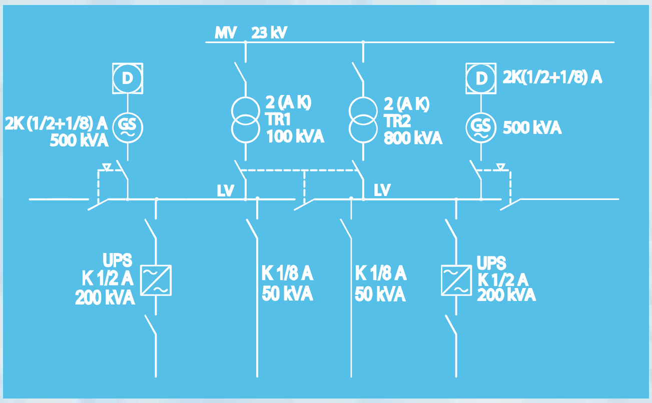

Resilience

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Resilience

Resilient Power Supply in a Modern Office Building

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Resilient Power Supply in a Modern Office Building

Introduction

This application note presents a design approach to assure a resilient and reliable power supply in an electronics-intensive modern office building. It describes a case study of a 10-floor office building in Milan, Italy (hereafter referred to as 'the building' for confidentiality reasons). The building is the head office of a major financial institution and is occupied by 500 employees using information technology equipment intensively.

Following an assessment of the current status of the electrical installation in the building, accompanied by the results of power quality measurements, two design proposals are presented that assure a resilient and reliable power supply. A cost analysis completes this report.

Description of initial situation

Distribution scheme

The building is connected to a 23 kV grid. The medium voltage main power supply consists of two 800 kVA transformers, 23/0.4 kV, 50 Hz. The low voltage side of the installation is designed as a TN-S system.

The load is subdivided into standard, preferential, and privileged loads, according to requirements for continuity of supply (this is discussed in greater detail later in the section). There is a second point of common coupling (PCC) to feed a small portion of the standard load. The two PCCs are fed from the same grid point and so are not independent.

To assure continuity of the power supply, two UPSs (80 + 200 kVA) and a motor generator (250 kVA) are installed according to the scheme in Figure 1. Note that in such a scheme it is imperative that the neutral conductor is connected to earth only once, at the main earthing terminal, and not at each transformer. Otherwise, the benefits of the TN-S wiring configuration – improved EMC and power quality - are lost.

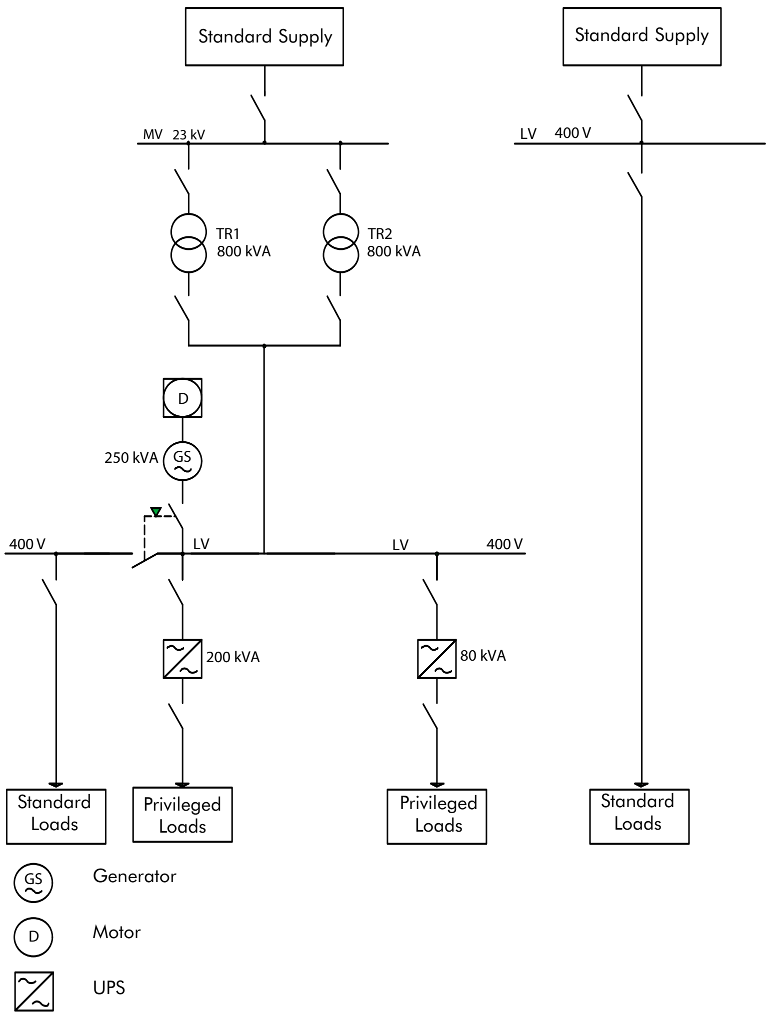

Figure 1 – Present distribution scheme

The primary distribution is a compromise between radial and shunt schemes[1]. The installation has grown in a haphazard way, without a consistent structure. This is a direct result of the many changes in power requirements experienced during

[1] *Shunt scheme: a rising busbar or power line is shared for all floors; at each floor, a connection is made to the LV panel at the floor. Radial scheme: each LV panel at each floor has a dedicated connection with its corresponding switchgear at the main LV distribution panel in the basement.*

the building's lifetime. Two distribution panels feed each floor. Each panel has two sections (standard and privileged) corresponding to the standard and privileged sections of the main LV power panel (Figure2). Final distribution uses a single radial scheme.

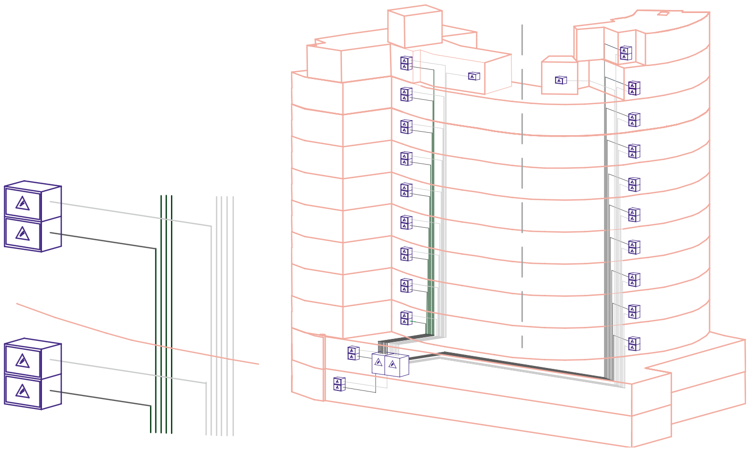

Figure 2 - Present distribution flow chart

Dark lines indicate standard distribution
Light lines indicate privileged distribution

Lines

The 3-phase distribution is made with multi-core copper cables. Where the phase conductor cross-sections were greater than 35 mm^2, half-sized neutral conductors had been used.

Load

The rated load for the office building is typical and consists of:

- Elevators (approx 80 kVA)
- Services (approx 100 kVA)
- Air-conditioning (approx 600 kVA)
- Horizontal distribution for lighting and power in the open office space (approx 35 kVA per floor).

Power quality

To evaluate the quality of the power supply, current harmonic content was measured at the main electrical lines feeding each floor and at the distribution panels for building services.

Figures 3 to 6 give examples of measured current and voltage waveforms and their harmonic content. The following points need to be highlighted:

Some phase conductors, particularly those for lighting circuits, have over 75% total harmonic current distortion (3rd, 5th, and 7th harmonic) – see Figure 6. There is significant 3rd harmonic current distortion in circuits serving IT and lighting equipment – see Figures 4, 5 (neutral conductor), and 6. In some neutral conductors, the harmonic currents are more than twice the phase current.

Both UPSs show current distortion in phase and neutral conductors – see Figures 4 and 5.

Even-order harmonics appear in more than one measurement (approx 30% in Figure 5). This means that the waveform of the current does not have the usual symmetry.

In some cases, the waveform produces more than two zero-crossings per cycle of the sine wave (Figure 5).

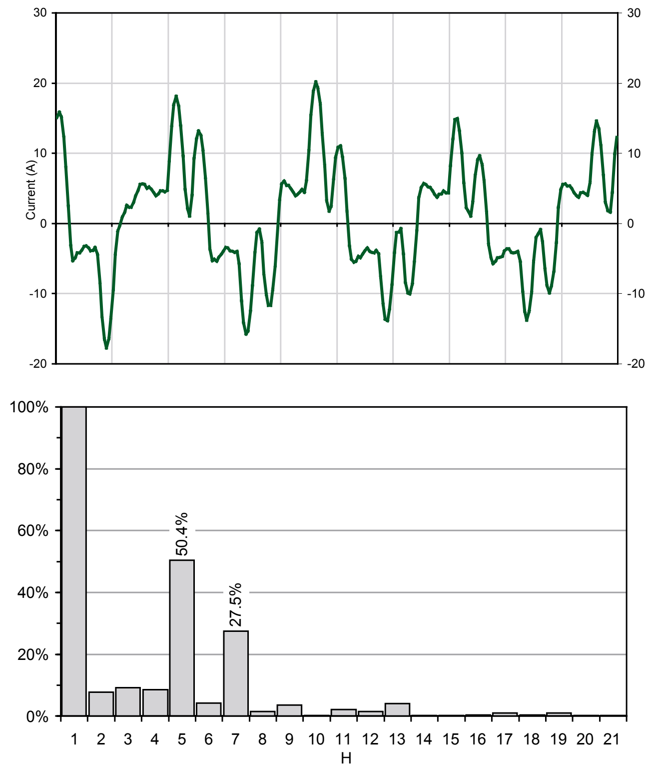

Figure 3 - Waveform and harmonic contents of phase current (phase L1) at main LV power panel in the line feeding elevators 1 and 2

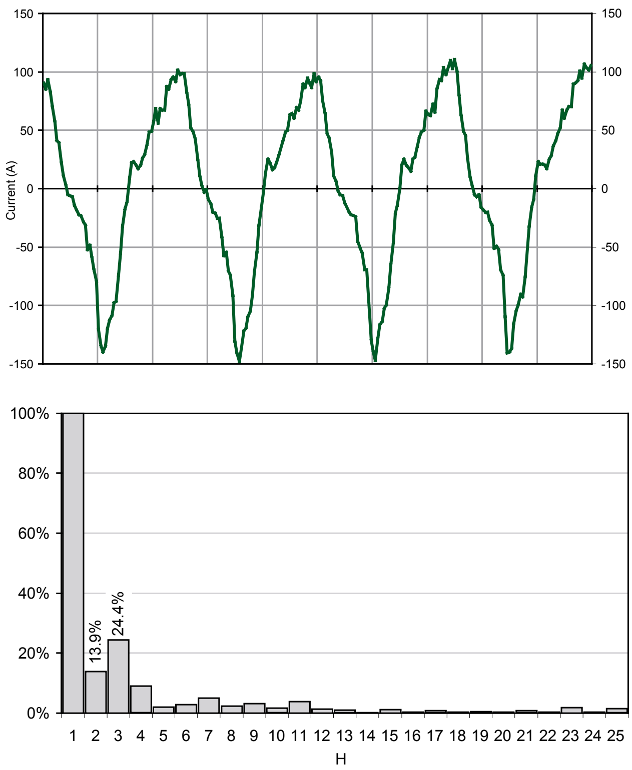

Figure 4 - Waveform and harmonic contents of phase current (phase L1) in the 80 kVA line to the un-interruptible power supply - UPS (open office space)

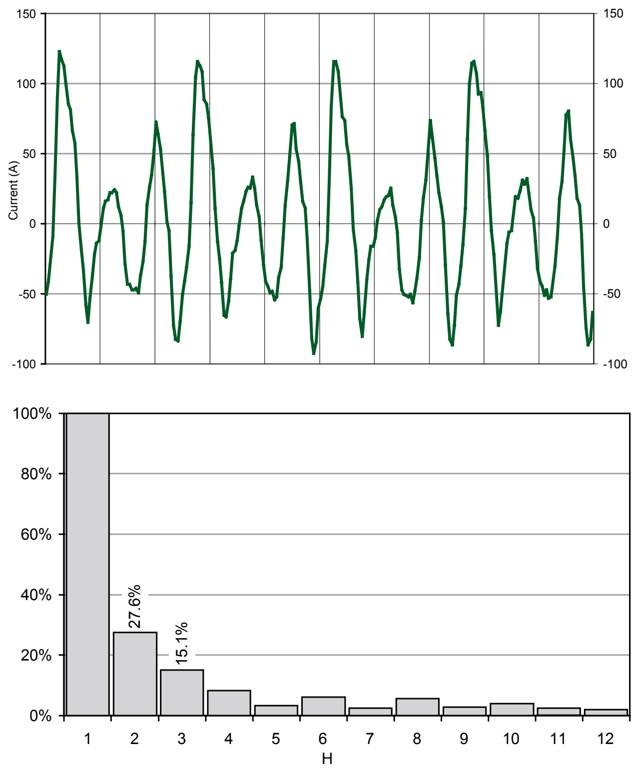

Figure 5 - Waveform and harmonic contents of neutral current in the 80 kVA UPS line (open office space)

Rather high permanent currents are detected in the ground conductor. This is a typical indication that the TN-S configuration has not been preserved, i.e. that there are multiple connections between the neutral conductor and earth. It must be ensured that there is only one main earthing point with a connection between neutral and ground. On-site personnel need to be briefed to avoid making any connection between the neutral and ground in the LV distribution.

The instrument used to make these measurements was a Fluke 43 single phase, 0 - 600 V, CT 600 A/1 mV/A power quality analyser.

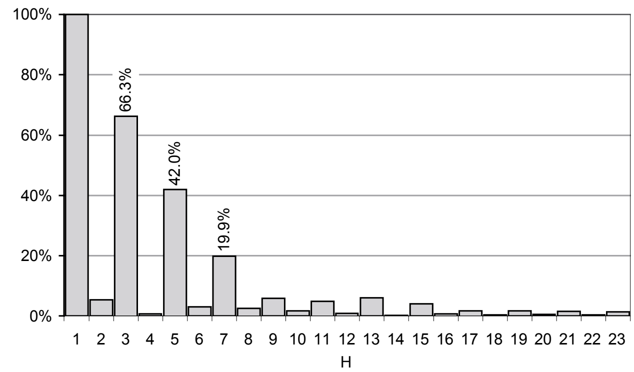

Figure 6 - Harmonic contents of phase L2 current at main LV distribution panel in the line feeding ground floor distribution panel (mainly lighting circuits)

Events

The building occupant experienced a high and increasing number of events and faults, principally related to the overheating of lines and nuisance tripping of protection devices.

Analysis – initial situation

The current installation lacks organisation and rationality in its approach. This is not compatible with the resilient design the company adopted at the start (supply low-voltage distribution through multiple transformers, UPS, and generator).

Some elements do not conform to current standards. Even full compliance to standards does not guarantee adequate performance from a power quality and EMC viewpoint for a building with mission-critical functions.

Distribution scheme

The distribution scheme is neither systematic nor rational, probably due to the numerous modifications since the original installation. There are important limitations relating to reserve capacity and independence. Some bottlenecks are present, e.g. at the level of the main LV busbar (Figure 1). The two transformers are not independent.

Line overheating

The high density of information technology equipment such as PCs, servers, etc and electronic lighting produces high levels of harmonic current in many lines.

These phenomena result in neutral overheating (elevated currents in a downsized neutral – see Sections 3.1 and 3.5.1) as well as nuisance tripping of protective devices.

Co-ordination among protection devices and lines

The current capacities of some lines are not co-ordinated with their over-currents protection devices. The large number of lines running in the same trunking make the problem more critical because the operating temperature is higher.

Analysis of a faulty line showed that prolonged overheating was the cause of failure, due to overheating in the trunking. The grouping factors given in informative annexes of national and international wiring regulations should be observed.

Neutral Status

In case of such a multiple feed with TN-S configuration, the neutral current needs to be brought back right to the main earthing terminal. Procedures must be in place to avoid making any additional connection between neutral and ground. Such connections create alternative paths for the neutral current, thus eliminating all the benefits of having a TN-S system.

Design approach

The building occupant, operating in the financial sector, needs to upgrade the installation since reliable power quality is considered mission-critical. The problems shown by the analysis of the current situation and the PQ measurements suggest consideration of an update of the electrical system at different levels:

- rationalisation of mains distribution, and
- renewal of the electrical installation on the floors.

Load classification

To optimise the main distribution rationalisation, the first step is the classification of the loads. All loads are classified into 3 groups:

- standard
- preferential
- privileged.

Standard loads are used for daily business, but their non-availability does not result in risk of personal injury, damage to equipment or disruption of business processes. A simple radial circuit suffices for the supply and relatively long intervention times can be tolerated (Table 1).

Preferential loads need a redundant power supply, for example as provided by a dual radial scheme, starting either from the risers or at the level of intermediate connections (Table 2).

Description of standard load	Type of power supply required	Timing needed for intervention
Allows regular functioning of the building, but their unavailability does not result in risk to personnel or equipment: General services, e.g. air conditioning (but not in server room) Normal lighting Heating Power sockets	Standard radial circuits Resumption of service can wait for some time without damage Loads can be switched off	None Unavailability of service for relatively long time periods can be tolerated

Table 1 - Description, criteria, design, and intervention requirements for standard loads

Description of preferential load	Type of power supply required	Timing needed for intervention
Regular functioning of the load is required for comfort and security of personnel and clients, as well as for ensuring smooth business operation. For example: Lighting of staircases, corridors, and certain rooms Minimum lighting conditions to avoid panic Heating or air conditioning of certain rooms Elevators UPS	Backup Dual radial primary supply, ensuring the functional and physical independence of the risers Two separate risers can be employed, supported either by a generator or supplied from two independent grid points Switching off the load is not acceptable	According to the norm, a 20 second intervention time for the generator group is acceptable for long interruptions. Typical values for a diesel group: First attempt within 5 seconds Second attempt within 10 seconds Third attempt within 15 seconds

Table 2 - Description, criteria, design, and intervention requirements for preferential loads

Description of privileged load	Type of power supply required	Timing needed for intervention
Essential services: Security lighting Servers Telecommunication systems Personnel retrieval Alarm & security systems Fire signalling and anti-fire systems Closed-loop TV circuits Certain auxiliary services	Secure Dual radial scheme, with independent risers At least one riser has to ensure high grid reliability Use of UPS For certain loads, a dedicated UPS can be considered	Loads with intervention within 15 seconds Short-interruption loads, within 0.15 seconds Some loads need continuous supply

Table 3 - Description, criteria, design, and intervention requirements for privileged loads

Privileged loads are mission-critical. Loss of service means grave danger to personnel or severe damage to the organisation's business processes. The level of independence needs to be determined for each load. At the very least, these loads must be supplied from two independent feeders with automatic switching (Table 3).

Type of load	Percentage
Standard	49%
Preferential	13%
Privileged	38%

Table 4 - Classification of type of loads

Main distribution schemes

To avoid the existing bottleneck at LV main busbar, the primary distribution must be modified as a dual radial distribution (Figure 7 left).

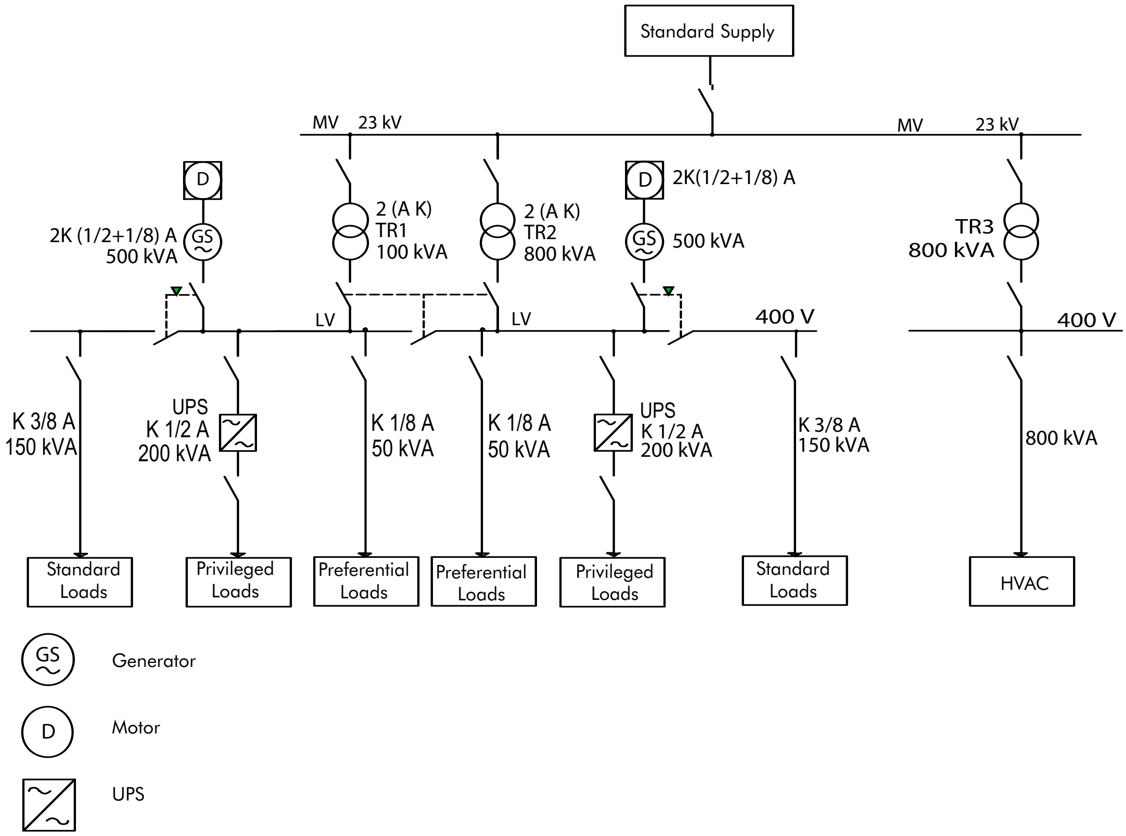

Figure 7 – New main distribution scheme

The rating of the transformers TR1 and TR2 must ensure that each can carry the full load. Considering that, because of the nature of the loads, the load current waveform will be highly distorted, the transformers must be sized to take account of the harmonic content. Rating transformers to cope with harmonic currents is discussed in Section 3.5.2.

To reduce short circuit currents, the system is normally managed with the main busbar-breaker open, but parallel operation between the two main transformers is possible for a short time.

To feed the thermal and HVAC services, the transformer section must be modified as shown in Figure 7 with a new 800 kVA transformer, TR3, in addition to the existing two.

Standard loads are supplied from a single grid point. The same grid power cable, riser, and radial distribution also supplies preferential and privileged loads.

Two generator groups supply preferential and privileged loads. Standard loads are switched off through the breakers at the extremity of the main busbar.

Two UPSs supply privileged loads in case of failure of normal and backup power supply.

Primary supply and backup supply are wired TN-S. UPS can be wired either TN-S or IT (meaning, here, isolated earth). Isolated earth systems are excellent for continuity of power supply, but cannot guarantee protection of personnel. Where an IT system is installed, proper security measures have to be taken to ensure that only authorised personnel can have access to the IT circuits.

The second LV PCC has been removed in Figure 7.

Each floor is still supplied by two distribution panels, each having three sections (standard, privileged and preferential) corresponding to the same sections of the main LV power panel.

Final distribution could be done using a shunt (Figure 8) or single radial (Figure 9) scheme.

The shunt scheme (shared line feeding all floors for each type of load) is cheaper and more flexible in the case of load growth. Unfortunately it is limited by poor resilience to faults in the main line and risers.

The single radial scheme (one line for each floor for each type of load) ensures:

- minimum interference and voltage drop caused by load
- in case of a fault, only loads supplied by the faulty line are out of service
- reduced maintenance problems.

The radial scheme is therefore the preferred scheme.

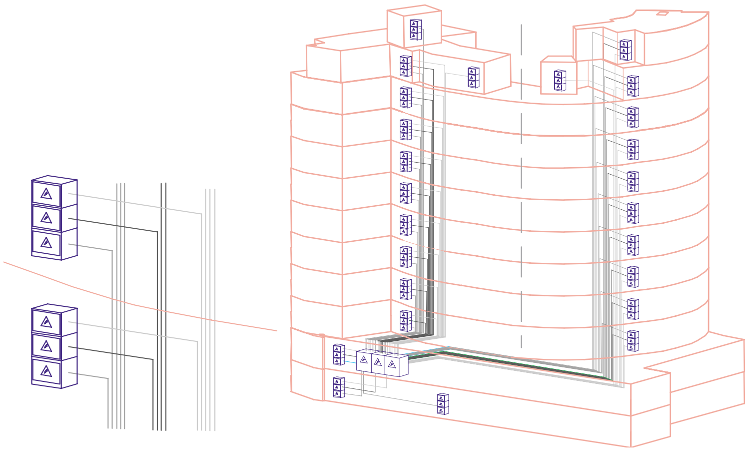

Figure 8 – Solution with radial scheme (10 floors with three types of load = 30 dedicated rising lines)

Dark line indicates standard distribution
Grey line indicates preferential distribution
Light line indicates privileged distribution

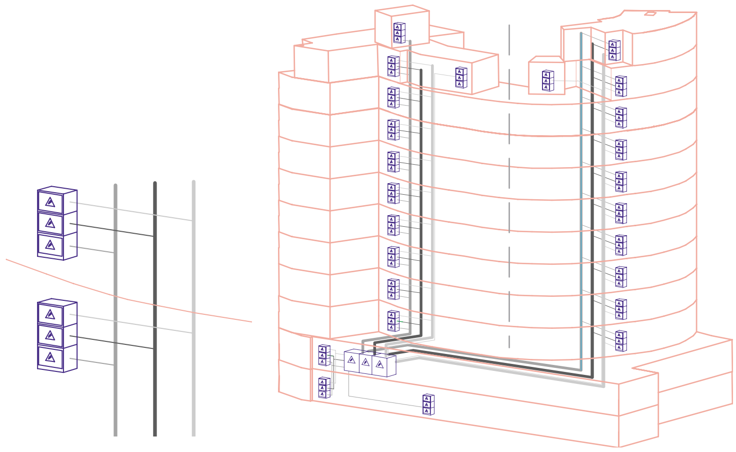

Figure 9 – Solution with unique riser lines (three types of load = three rising lines / busbar, shared by all floors)

Dark line indicates standard distribution
Grey line indicates preferential distribution
Light line indicates privileged distribution

Line sizing

Table 5 shows the power-considered sizing of all of the main sections of the system.

The total installed load (Columns 2 and 3) is multiplied by utilisation and contemporary factors (Columns 4 and 5) to calculate the power requirements of the load (Columns 6 and 7). As a margin for future load growth, lines are sized (Columns 8 and 9) considering an additional factor equal to 130% and 115% for power and lighting circuits respectively.

Load	Installed load (kVA)		Utilisation & Contemporary Factors		Power requirement (kVA)		Installed power (kVA)	
	Power (1)	Light (2)	Power (3)	Light (4)	Power (5)	Light (6)	Power (7)	Light (8)
Second underground	7	10	0.7	1	5	10	6.5	11.5
First underground	114	15	0.7	1	80	15	104	17.25
Ground and general services	43	15	0.7	1	30	15	39	17.25
First floor	50	17	0.7	1	35	17	45.5	19.55
Second floor	50	17	0.7	1	35	17	45.5	19.55
Third floor	50	17	0.7	1	35	17	45.5	19.55
Fourth floor	50	17	0.7	1	35	17	45.5	19.55
Fifth floor	50	17	0.7	1	35	17	45.5	19.55
Sixth floor	50	17	0.7	1	35	17	45.5	19.55
Seventh floor	50	17	0.7	1	35	17	45.5	19.55
Eighth floor	29	12	0.7	1	20	12	26	13.8
Ninth floor	3	2	0.7	1	2	2	2.6	2.3
Thermal Central	29	0	0.7	--	20	0	26	0
HVAC main station	843	0	0.7	--	590	0	767	0
Boxes	14	5	0.7	1	10	5	13	5.75
Elevators	114	0	0.7	1	80	0	104	0
TOTAL	1546	178	--	--	1082	178	1407	204.7

Table 5 - Peak-rated and actual sizing of primary distribution system

Considering the measured waveform of the current, all the new lines have been sized to take into account the harmonic profile and resilience requirements:

- neutral cross-section equal to that of phase (Section 3.5.1)
- derated cables (Section 3.1 and 3.5.1).

Special attention should be paid to neutral and phase conductor sizing to avoid overheating and faulty tripping of protection devices. The adoption of a UPS or motor generator is not useful if a line fault occurs after it.

Cost analysis

The cost of the existing installation is compared with two possible alternative solutions in Table 6. These alternatives differ only for risers, and hence for the cost of the main LV panel.

Solution 1 is the shunt scheme, and Solution 2 is the simple radial scheme, which is preferable for new buildings, but difficult to implement as an installation upgrade.

Cost when selected at initial design stage

Regarding this situation, the following needs to be highlighted:

- the percentages refer to the cost of the existing installation
- the extra cost of the better solutions is low, if considered at the initial design stage
- the cost of the best technical solution (i.e. Solution 2 – single radial scheme at final distribution) differs only by 3% from Solution 1 if considered at initial design stage, but the difference is much greater if considered at refurbishment stage only
- cost basis 2001
- the cost for the UPS considers only purchase and installation. The additional costs of maintenance must be taken into account.

Even if the evaluation of average costs related to a system designed according to good PQ practice is difficult, it must be recognised that:

- the cost estimates include the costs related to the practical difficulties of installing and renewing a building in the centre of a major city
- the modification of the main distribution scheme is the most important and useful action to undertake
- the solution with unique riser lines is very difficult to install with the building operational.

Item	Existing (€)	Solution 1 (€)	Solution 2 (€)
Cost at design stage			
Main LV panel	32 000	35 000	45 000
Risers	30 000	35 000	60 000
Horizontal distribution	107 000	135 000	135 000
Generator groups	87 000	107 000	107 000
UPS	55 000	105 000	105 000
Motive power	355 000	375 000	375 000
Lighting	500 000	525 000	525 000
Total	**1 166 000**	**1 317 000**	**1 352 000**
Differential cost		**151k (+13%)**	**186k (+16%)**
Cost for installation upgrade			
Additional cost		**422k (+36%)**	**543k (+46%)**

Table 6 - Cost Comparison

Conclusion

Initial low cost does not necessarily mean good value. A PQ compliant system, initially more expensive, can save a great deal of money during its life. The case study analysed in this paper shows that an electrical installation, designed without attention to PQ issues, results in a considerable amount of unnecessary expenditure. Decisions have to be made whether to resolve the issues or to simply live with the inconvenience and downtime they cause.

The cost/benefit analysis shows that resilience should be carefully considered at the design stage. A mere increase of 16% in the installation cost (1% of the building cost) provides:

- three lines of defence against power cuts for mission-critical loads (dual panels at each floor, generator, UPS)
- a highly resilient system, with each floor supplied by two distribution panels. Each panel is independent from the other, and from all panels on the other floors
- a highly flexible electrical system against future load growth.

Expensive though it may seem, the highly resilient solution would typically add only about 1% to the cost of the building. For commercial buildings, where the running costs amount to initial construction costs after 7-8 years, this initial investment will be paid back by a productivity increase of 10 minutes per week. All the rest is profit.

A design according to present standards does not guarantee optimum performance from power quality and EMC viewpoints and enhanced solutions have to be considered. At European level, better standards are at present under preparation.

References

1. *P Chizzolini, P L Noferi: Ottimizzazione degli interventi sulla rete di distribuzione mirati al miglioramento della continuita' del servizio elettrico. LXXXVII Riunione AEI, Firenze 1986.*
2. *T M Gruzs: 'A survey of neutral currents in three-phase computer power systems', IEEE Transaction on industry applications, vol. 26, n° 4 July/August 1990.*
3. *IEC 364-5-523 - Electrical installations of buildings - Part 5-52: Selection and erection of electrical equipment - Wiring systems.*
4. *A Baggini, A Bossi, 'Componenti e carichi suscettibili ai disturbi', Corso 'Interazioni elettromagnetiche tra componenti e sistemi in ambito industriale: compatibilità elettromagnetica in bassa frequenza' Dipartimento di Elettrotecnica del Politecnico di Milano, 21-25 febbraio 1994.*
5. *A Silvestri, F Tommazzolli, 'Schemi per gli impianti di energia: semplicità, affidabilità, risparmio, ridondanza dove e come', Corso 'Il progetto degli impianti elettrici di energia. Le norme e la regola dell'arte', Dipartimento di Ingegneria Elettrica dell'Università degli Studi di Pavia, AEI, CNR, Pavia, 10-13 giugno 1991.*

Notes

Notes

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