



Electricity in HPC Centres

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Abstract

The design of the electrical distribution network for an HPC centre is an important strategic task when planning a new centre or planning the upgrade of an existing one. All decisions taken at the design stage may have long-term effects on the operation, maintenance and later upgrade of the power supply infrastructure.

Based on a survey of the PRACE community, this paper describes common issues related to HPC centres power distribution, discusses available solutions to the common problems associated with electrical energy distribution and eventually gives recommendations that may be useful for general or technical managers facing a new facility design or upgrade project.

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Introduction

Consumers with specific needs such as HPC centres that run large Petascale (or Exascale in the future) computing machines have high requirements regarding the power distribution network capacities and arrangement.

It is caused by very high power consumption of connected devices knowing that some protection against power supply interruption may be desirable even if it is not as important as for commercial data centres.

In the past, with power demand ranging from tens to hundreds of kilowatts, the distribution network was commonly supported by diesel generators and static UPS. This arrangement created a good and reliable solution. The overhead costs of approx. 20 % were acceptable.

In today's Petascale era and in the near future Exascale, where the power consumption of a single machine is likely to reach 25 MW, power losses inherent to the traditional power supply organization are no longer unacceptable.

The advent of these machines is one of the main drivers in changing power distribution design. Replacing the traditional power supply model by innovative use of already known solutions such as Direct Current power network, trigeneration or cogeneration can reduce energy losses in the computing centre; it can be also obtained by careful optimisation of power distribution. This document contains information about issues and common practices related to delivering electricity to the computing centre, whilst taking into account the aforementioned needs.

The collected survey results are presented for the benefit of PRACE partners who run or plan to build a computing centre. Analysis of the questionnaire helped us to determine best practices that could be applied by persons responsible for running and/or planning the power distribution network for an HPC centre. Additionally we present a detailed description of basic terms, technologies and solutions commonly used in electrical power distribution.

Given the fact that this document is addressed to management staff, some issues related to power distribution were omitted in this document. For example, details about grounding/earthing, power factor, safety (shock protection, selection of protective devices and working safety rules) are not addressed in this document..

1. General information about the electrical power distribution

Nowadays, no technology project can do without energy. One of the most widely used forms of energy is electricity. The reason for this is the simplicity with which electricity can be processed into other forms of energy such as heat, mechanical energy and electricity with other parameters. The production and supply of electricity are typically achieved using devices connected to the power system (Figure 1).

One part of the above system is the distribution network. It is the final element of the power system responsible for supplying electricity to customers or final receivers. Every distribution network typically consists of the following elements:

- transmission lines (cable and overhead) and supporting structures used for power transmission between devices
- switchgear and protective equipment used for power distribution between network elements and receiver equipment
- distribution transformers used for changing voltage
- measuring devices for controlling the network and enabling billing between suppliers and buyers of electricity

Besides the primary task, i.e. the supply of electricity, the distribution network must meet the following criteria:

- high security of the network (it should not constitute any risk to users and other persons)
- high reliability of supply (very short and infrequent or no power outages)
- quick and easy reconfiguration of the network in order to improve the reliability of supply and simplify maintenance procedures
- possibility of planning and carrying out maintenance work
- possibility of expansion, the implementation of the network itself in all these tasks
- aesthetics of the particular network elements.

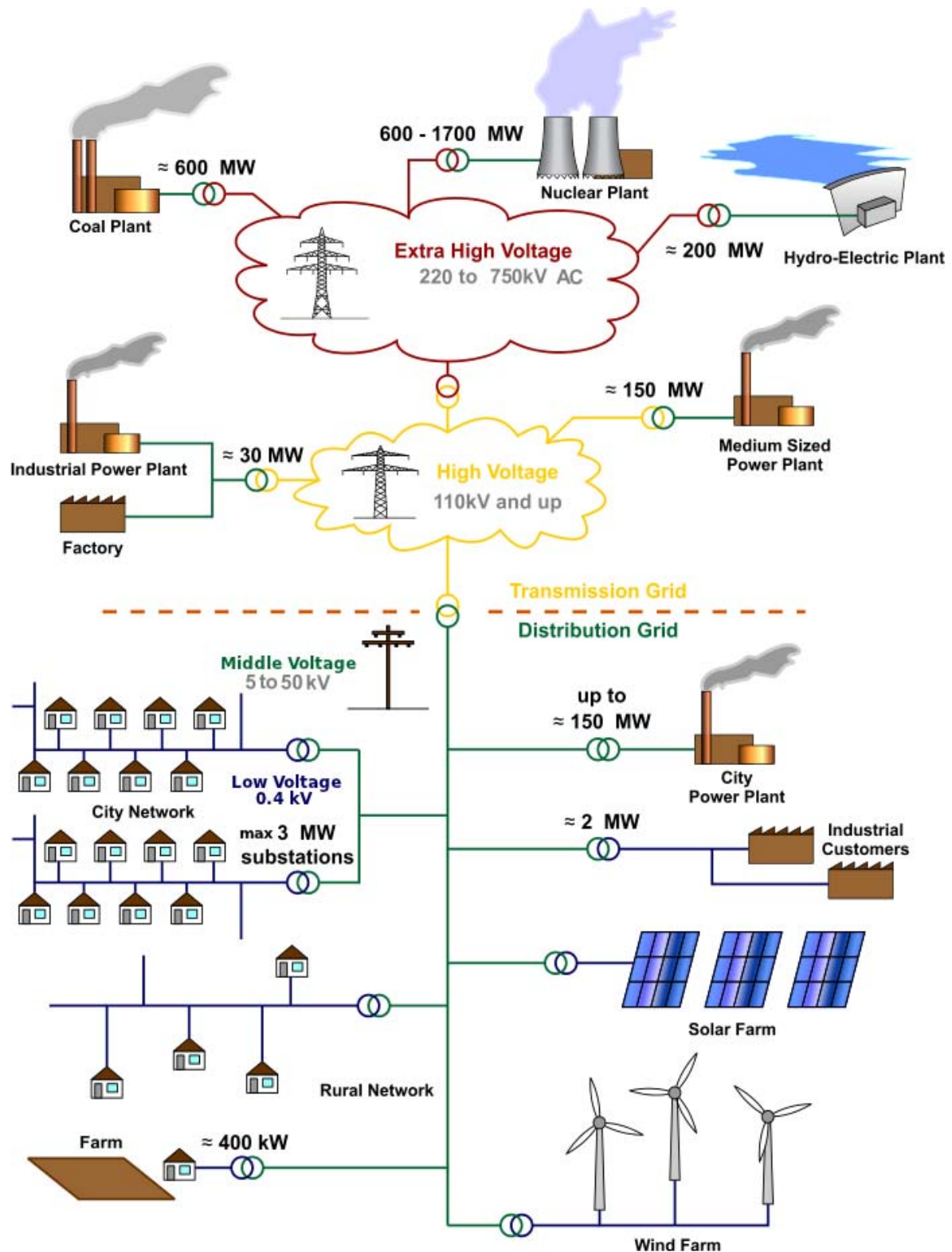


Figure 1: Electric power production, transmission and distribution ⁹

⁹Source : Wikipedia : http://en.wikipedia.org/wiki/File:Electricity_Grid_Schematic_English.svg

1.1. HPC centre power distribution network and its challenges

Energy distribution within the HPC centre is a very challenging task. This is due to the specific requirements of a modern IT environment: the desired high reliability of the power supply for critical services, high amount of power consumed by a single systems and the need to deal with the ongoing maintenance and development of the energy distribution network itself.

Uninterruptible power must be supplied for some receivers in the centre to ensure their continuous operation or to reduce risks of damages to fragile components. Uninterrupted operation of critical services, such as network and storage devices, critical data processing systems (ie. e-mail, Web sites) or a set of computing machines, is one of the prerequisites to ensure the quality of services provided by these objects. Achieving a reliable and uninterrupted power supply for critical facilities is most often accomplished by making the power supply redundant and installing resilient devices to maintain power in at least one of the supplies.

The required computational power, the available storage space and bandwidth of access networks are rapidly growing from year to year. The power requirements of computing systems increase accordingly. Each generation of hardware provides more computing power per kW of electricity taken from the power source. However, the requirements for computing power in the form of services provided by HPC centre grow even faster, thereby increasing the overall power demand. An additional aspect that impacts on the growth in power consumption is the dramatic increase in the performance of cooling devices, such as direct water-cooling systems. This in turn has allowed compute systems to be much more densely packed. Such abrupt increases in power density make it necessary to extend or completely reconstruct the electrical distribution network. At present, a single computing system can take up to 13 MW from the power source and the Exascale target systems will draw about 25 MW or more.

To ensure efficient and, when needed, uninterrupted power supply for receivers fitted in the centre, several steps should be performed to control, evaluate and improve the technical condition of the distribution network. These activities are carried out periodically and are called maintenance. To enable the installation of new data processing systems, usually with increased power consumption, the expansion of the distribution network should be ensured. Both of these operations, i.e. maintenance and expansion of the network, must be conducted without impacting on the work of critical systems and services. If the electrical distribution network is appropriately designed, expansion and maintenance can be carried out most of the time without interrupting or affecting operations.

1.2. Common approach to powering HPC and data centres

Results of the survey show two trends in the approach to the distribution of energy in the centre:

- traditional using proven methods to provide uninterruptible power for receivers
- modern, focused on minimizing power losses and reducing costs associated with the maintenance of the distribution network.

The modern approach is described in the section 2.

The traditional approach is described, for reference, in the next section.

1.3. Traditional approach

The figure below shows the traditional approach which is only applicable for “small” HPC centres or for commercial data centres for which the large additional costs (both investment and running) of providing uninterruptible power for all receivers is meaningful.

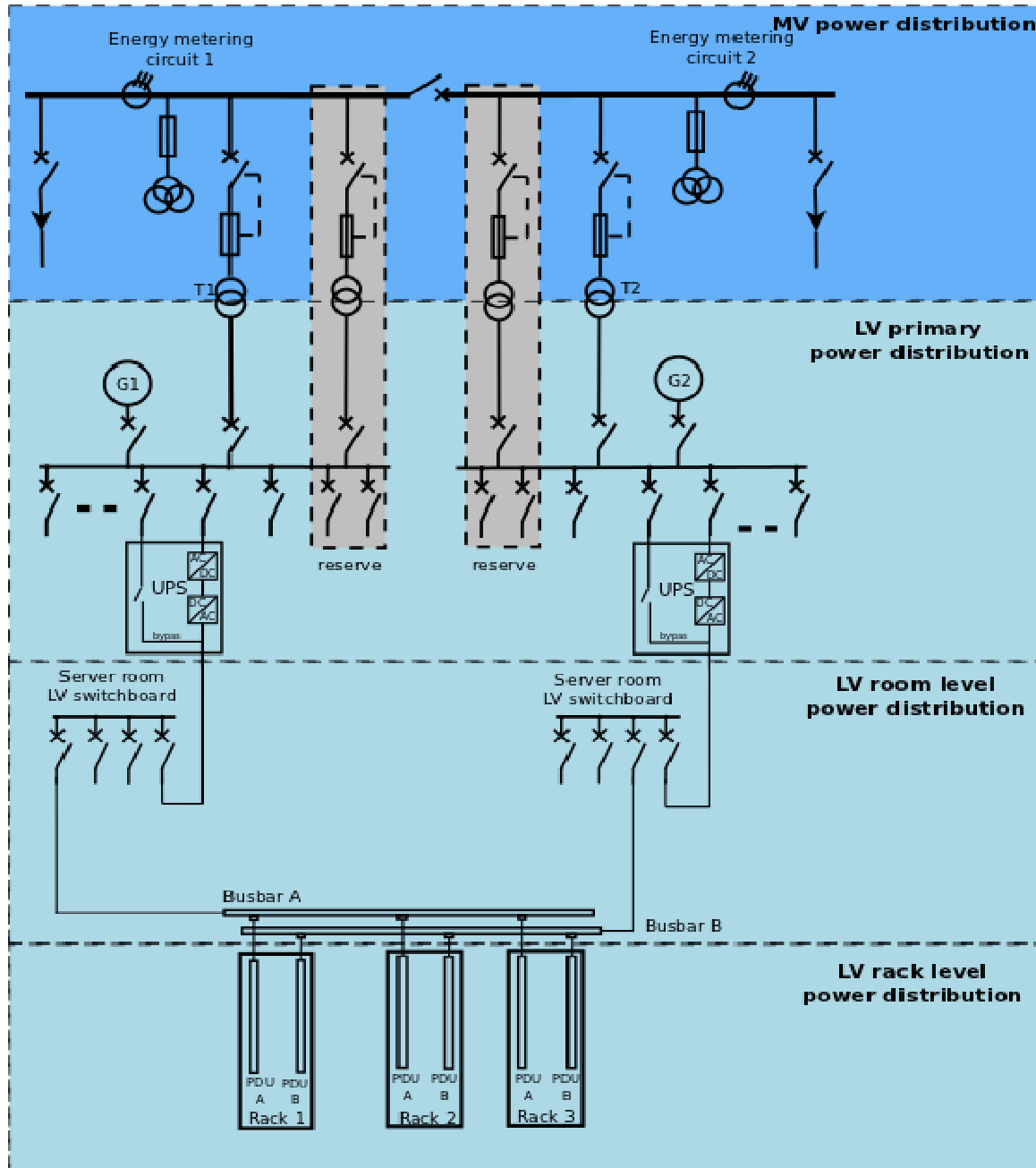


Figure 2: Traditional Data Centre power distribution network

Power of such an object is most commonly delivered from the Distribution Network Operator using two independent Medium Voltage (MV) power lines at voltages ranging from 6 to 20 kV. Both supplies are connected to the MV switchboards. MV switchboards are usually divided into two sections and coupled together via a bus bar. The installation of an Automatic Transfer Switch (ATS) change-over device upstream to the MV panel provides enhanced system resilience and the ability to transfer electrical loads between supplies should one supply line fail.

The receiving equipment such as computer devices operates at a voltage of 400/230 V. Distribution transformers are typically used to step down the voltage from MV (6 to 20 kV) to Low Voltage (LV : 400/230V) voltages. Usually multiple Medium Voltage to Low Voltage (MV/LV) transformers are connected to different sections of the MV distribution switchboard. The Medium Voltage (MV) distribution switchboard sections are connected using bus connectors which are Normally Open (NO) during normal operating conditions. The transformers secondary windings are connected to the Low Voltage (LV) distribution switchboards. In a typical LV distribution network for a data centre there are usually multiple LV distribution switchboards often connected by another ATS device. Further downstream is a

group of Uninterruptible Power Supply (UPS) devices, which usually consists of a static UPS, equipped with batteries and potentially backed up with a diesel generator coupled to the LV switchboard. The aim of this design is to ensure continuous supply in case of a prolonged power outage from the Distribution Network Operator (DNO), even if the two supply lines fail simultaneously. In this case the static UPS system provides short-term (up to 10 minutes) backup which gives enough time to start the backup generator. The backup generator powered by a diesel engine will continue to supply power as long as it has fuel. The UPS output circuits are connected to a distribution board in the server room. The energy from the server room distribution boards is then supplied to the server racks, equipped with their own distribution equipment called Power Distribution Unit (PDU). The receiving device, such as data processing equipment, data storage systems and network devices are powered directly from the PDU. Due to the resilient dual supply to "power rails" the continuous supply to the power receiving device is secured and the device will remain operational in the event of a power failure.

The measuring devices installed in switchboards and cabinets help to monitor the conditions of the distribution network. In many cases, these are the simplest stationary measuring instruments such as ammeter, voltmeter and voltage control systems. However, more and more often digital analysers of network parameters are used, which are equipped with communication interfaces, capable of recording and monitoring parameters such as current, voltage, power consumed by the consumers and the level of harmonics in the supply network.

In order to conduct the settlement with the energy supplier and internal settlements in the distribution network, accounting measurement systems consisting of electronic energy meters, matching circuits and, more and more commonly, communication interfaces are installed in order to allow billing both by the supplier and within the centre.

1.4. HPC centre power metrics

There are several characteristic electrical parameters that are specific and common for a standard distribution network. Establishing these parameters allows the optimal selection of preferable electrical solutions for the computing centres electrical distribution network design.

The connected power P_{demand} is a parameter indicating the maximum power consumption with an average over a period of time (usually 15 minutes). This parameter specifies the maximum demand to the centre distribution network and it can be found from the billing energy meter. The P_{demand} parameter is expressed in units of active power, usually in kW or MW.

Design power P_{design} defines the level of (instantaneous) power for which the main power supplies are designed. This is a design parameter that specifies the maximum usable power consumption in the centre. The P_{design} parameter is expressed in units of active power (kW or MW), except that it is necessary to specify the target power factor.

Contracted power $P_{\text{contracted}}$ is the maximum level of active (instantaneous) power consumed by the centre under contract with the Distribution Network Operator (DNO). This parameter is a contractually agreed limit between the DNO and the end user and may be altered by changing the contract between them.

In cases of correct operation of the distribution network, both the centre and DNO distribution network shall agree the following relationship between power parameters:

$$P_{\text{design}} \geq P_{\text{contracted}} \geq P_{\text{demand}}$$

The first characteristic power parameter is the **power loss factor** which expresses what portion of the active power drawn is lost in the process of energy distribution in the network inside the computing centre. This parameter can be calculated using the efficiency data or equipment losses. It should be noted that both the distribution and actual usage of electrical energy cause power losses. For large distribution networks, such as DNO and alike, power loss factors range between 10 and 15 percent. In a computing centre, the loss factor could reach 20 percent for the traditional distribution approach. This means that a fifth of the energy paid for by the centre operator is converted into heat and no longer available for the computing equipment.

Another characteristic parameter specific to computing or data centre design is **Power Usage Effectiveness (PUE)**. PUE determines the ratio of energy consumed by the whole centre to the energy consumed by IT equipment. PUE is expressed in dimensionless units and is by definition always greater than 1. PUE has become a very important figure for defining the energy efficiency of a computing or data centre; it should be noted, however, that measuring PUE is not simple since the boundary between infrastructure and IT equipment can be quite complex in modern centres.

2. New technologies in power distribution

The "New Technologies" in the electrical energy distribution are mostly existing technologies that have been modified and/or applied differently. Generally the aim of such systems or modifications is to reduce maintenance costs and energy losses in computing centres. Introducing new solutions to the electrical network may potentially decrease network losses, maintenance costs and improve the efficiency of energy utilization (PUE).

2.1. Low loss distribution transformers

The first element that generates considerable power losses in the distribution network is the Medium Voltage to Low Voltage (MV/LV) transformer. Transformers provide voltage level matching between the DNO MV network (ranging between 6 and 20 kV) to the voltage level of equipment in the centre (usually Low Voltage 400/230V). This equipment generates no-load losses caused by constant magnetisation and demagnetisation of the core and additional losses when the transformer operates (load losses), caused by current flow through the windings. Reducing the losses generated by the distribution transformers can be achieved in two ways:

- appropriate selection of structural materials of the core
- appropriate selection of structural materials for winding and winding parameters.

The use of modern construction materials in the creation of a transformer core of amorphous steel can reduce load losses by about 80 percent compared to traditional construction.

The use of better materials for the windings (copper) and a slight oversizing of the winding cross section limit load losses by 20 percent. Unfortunately, each of these activities is associated with increased purchase costs as the above modifications would result in ordering "special" equipment as opposed to standard off-the shelf products.

2.2. DC power distribution

Another devices that generates high losses in the computing centre distribution network are Static USP devices. Double conversion on-line Static UPS contains the following parts:

- rectifier
- battery (typically acid-lead)
- inverter
- bypass switch.

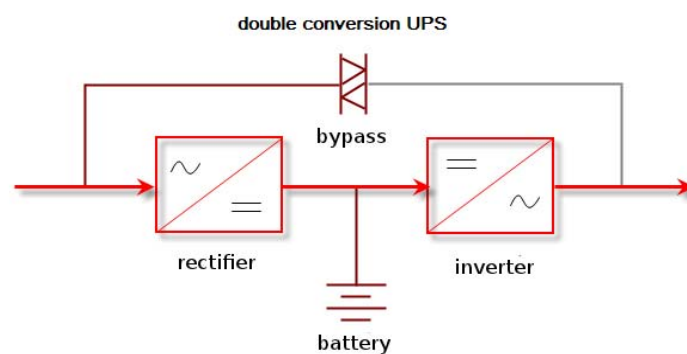


Figure 3: Static UPS device ^h

^hSource : Wikipedia : http://commons.wikimedia.org/wiki/File:Double_conversion_UPS.png

During regular operation the device performs the double energy conversion: alternating current (AC) is straightened by the rectifier and passed to the Direct Current (DC) internal power rail. The battery is connected to the DC power rail and forms an energy storage. The energy from the DC internal rail is then converted back to AC using an inverter, which provides voltage matching the one required by the devices in the computing centre.

Each of these conversions (AC to DC and DC to AC) causes power losses, which in large Static UPS devices reaches about 10 percent.

Such loss can be reduced by using UPS only for critical components.

Further gain can be obtained by eliminating the second stage of processing (inverter) these losses can be reduced to about 1.5-2 percent. However, this requires a total or partial rebuild of the Low Voltage (LV) distribution network in the centre.

2.3. Distributed short-term UPS devices

Another solution that can decrease the energy losses and running costs of the distribution network is the use of Distributed Uninterruptible Power Supply devices.

This solution assumes the installation of an electrical energy storage device such as a battery or a large capacitor inside the power supply of the computer device. Power-up time for such an internal UPS varies between 300 ms for the capacitor to 10 minutes for standard 12V gel batteries. This allows the removal of large Static UPS units from the computing centre infrastructure, while reducing energy losses in the network. This solution guarantees a rapid (less than 300 ms) switching time via ATS switch. The use of distributed backup power devices can reduce energy losses caused by large Static UPS units.

Unfortunately, the maintenance of distributed backup power systems is expensive, especially for units with standard lead-acid batteries. Also, not all computer systems allow space for the installation of such equipment.

2.4. Cogeneration and Trigeneration

Trigeneration is a solution which reduces supply costs of electricity for the computing centre and, in certain cases, increases the available installed capacity. Trigeneration is a process that allows simultaneous production of electricity, heat and coolant. This technology has been developed from a different technology called Cogeneration. Cogeneration is the generation of electricity and thermal energy from fuel combustion, most commonly natural gas or coal. Trigeneration was invented by using absorption chillers powered by the stream of heat (instead of combustible) to generate a stream of coolant. The refrigerant can then be used to cool the ambient air inside the computer equipment rooms.

A number of relevant resources on these topics of cogeneration and trigeneration can be found on the CODE (Cogeneration Observatory and Dissemination Europe) project web site: <http://www.code-project.eu>.

2.5. Monitoring of power distribution network

To ensure correct exploitation of the distribution network its condition should be constantly monitored, in particular, the information on the current load on each power circuit. This information can be obtained using dedicated devices that can be installed either within or in addition to a standard switchgear. The switchgear and its inlets can be equipped with the measurement and communication modules. The most frequently used measurement devices are network data recorders. These devices are mounted in electrical switchboards, mainly on the incoming feeds. They are used to carry out measurements and record the electrical parameters such as line current, voltage and power in the network. More advanced versions also offer additional features such as energy and distortion level measurement and logging. Most recorders are equipped with a communication interface that allows data exchange with the monitoring system.

Switchgear manufacturers have responded to the need for continuous recording of certain parameters of the distribution network and the equipment they offer also takes care of distribution protection such as circuit breakers, isolation switches equipped with measuring devices and communication interfaces. This allows a monitoring system to be implemented without incurring unnecessary costs associated with the installation of dedicated devices.

Devices such as Static UPS units with communication modules can pass the full set of working metrics to the monitoring system.

It should be noted that the simple installation of measuring devices such as analogue voltage and current pointer instrument does not allow for continuous observation of the phenomena occurring in the computing centre distribution network. In particular cases, the measurements taken by such devices may be misleading.

Another part of the monitoring system is the management system. In most cases this is a computer-based Supervisory Control and Data Acquisition (SCADA) system. This system is capable of collecting data from the measurement and distribution devices, presenting the network status and logging the current and historical data.

These technologies allow the removal of some of the costly devices from the distribution network (eg. the removal of the Static UPS) or significant reduction of losses generated in the distribution network.

Unfortunately, each of them causes an increase in costs associated with purchase and installation. Any decision related to the adaptation of "novelties" in the centre distribution network should be based on a detailed analysis of long term costs.

3. Survey results: current status in PRACE Tier-0 and Tier-1

The questionnaire which was sent to the HPC centres included three series of questions. Each of the series was related to the following topics:

- structure of the distribution network in the computing centre, its technical parameters and redundancy
- maintenance procedures, development and experiences of past performance
- procedures associated with the choice of how to purchase the energy and selection of the tariff.

15 European HPC centres of different sizes responded to the survey. In the studied centres contracted power varied from 0.6 MW to 16 MW. There is a clear division between small and medium-sized HPC centres (power contracted in the range of 0.6 to 5 MW) and large HPC centres with contracted power of 10 MW or more.

Small centres mostly use a traditional approach to energy distribution, i.e. the power supply of most IT equipment is protected by a system consisting of Static UPS and in some cases a diesel generator. If the centres have two redundant supplies, the backup diesel generator is often omitted.

Large centres where the power consumed by a single computing system is greater than 1 MW present a different approach to power distribution. These centres tend to limit energy losses in distribution facilities and reduce the costs associated with the purchase, installation and operation of distribution facilities. The assumption is that not all receiving devices in the computing centre must be backed-up in the event of a power cut. A group of receivers, such as backbone IT network equipment, storage equipment, some air conditioning systems, and systems that cover commercial services were deemed critical. These systems are powered in a traditional way, usually using two supplies, and they are typically supported by Static UPS and sometimes diesel generators to ensure backup power.

Other systems, including large computational systems, are powered by a separate, independent MV supply with an ATS device and one of the newer short-term backup power systems such as flywheel-based UPS or distributed UPS based on ultra capacitors. For large computing systems there is usually no long-term power backup through diesel generators because of the large cost of such systems.

To carry out maintenance work, part of the distribution facility must be duplicated. For example, in order to implement the periodic inspection of an MV to LV transformer, the device must be switched off. To maintain supply to the receivers during transformers maintenance one has to either use diesel generators or backup MV/LV transformers. In addition, the installation of the redundant power distribution devices in the power distribution network allows fast reconfiguration of the network if one of them is damaged.

Most centres tend to secure the redundancy at the supply side of the system. Most of the surveyed HPC centres have or seek to have two supplies. Centres that use Static UPS strive to install either two sets of such equipment or modular UPS, ensuring that a failure or maintenance to one of them will not endanger the continuity of operation. Most of the centres design their infrastructures to ensure redundancy arrangements of $N + 1$ (where $N = 1$ or $N = 2$) for key distribution network equipment such as MV/LV transformers and UPS.

The majority of surveyed HPC centres also installed energy monitoring devices within the distribution network. However, this monitoring does not always support all levels of power distribution. Usually it monitors the power inlets of the MV and LV switchboards. More than 2/3 of respondents outsource the maintenance of their distribution network to other companies. More than half of the respondents stressed the need to coordinate maintenance work to the distribution network maintenance work on receiving devices.

About 75 percent of respondents are planning to rebuild or expand their distribution network to meet the growing demands of computing systems. At the same time they point out that the expansion and/or development of computing centre distribution network must be planned well in advance and the need for a significant increase in the power connection and the possibility of a distribution network should be taken into account.

A fifth of respondents pointed out the limitations in the form of the maximum available electrical capacities that DNO upstream supply rings can offer. This results in multiple limitations to the development of the centre potential supply upgrade:

- impossibility to install larger HPC systems
- even if the respondent can install or upgrade their "power sources", for example with a trigeneration device, the power capacity limitation of the power supplies will result in much complicated structure of your distribution network, including using a separated network powered from this power sources

Most of the respondents point out the need to train their staff in the procedures of how to use and maintain key electrical equipment.

4. Running costs

One of the main running costs incurred in HPC and data centres is the purchase and supply of electricity. After splitting the costs of buying the energy into the cost of the energy and the cost of the supply, it appears that in the traditional approach to network design in typical centres, energy losses in the network can reach about 10 to 30 percent. The new approach of replacing the high-loss equipment with of low-loss equivalents or omitting the UPS units partially or completely in the computing centre can reduce power losses in the distribution network to the level of around 5 percent or less.

Due to the liberalization of the energy market as a result of the implementation of Directive 2003/96/EC of the European Council and following Council Directive 2005/89/EC of the European Parliament by members of the European Union, every electricity consumer can freely choose their electricity provider, thus breaking the former mandatory link to the closes provider.

The range of distribution service providers is limited by the Distribution Network Operators, whose networks connect the local installations.

The choice of electricity supplier can help reduce costs associated with the purchase of energy. This means that selection of the energy supplier can provide significant decrease of energy cost for a computing or data centre operator.

This is not the only way to reduce the cost of buying energy. Another way to reduce energy purchase costs is to reduce losses in the distribution network. This can be done by using low-loss devices within distribution facilities, such as low-loss distribution transformers. Another way of reducing losses is to remove the devices that generate losses, replacing them with newer ones. This relates to equipment such as standard Static UPS being replaced by distributed UPS systems based on ultra-capacitors and fast ATS devices.

Costs associated with delivery of distribution services are partly dependent on the amount of energy consumed and partly dependent on violation of agreements with DNO such as crossing the power metrics and the introduction of harmonics into the DNO distribution network.

The cost of electrical demand can be decreased by:

- reduction of energy consumption (this will lower some of the electrical billing charges of the system-wide energy usage)
- maintaining the consumed power below the contracted values or adapting/ renegotiating the original contract as necessary
- permanent monitoring of the network parameters for early warnings when nearing the contractually agreed capacities and parameters (reactive power consumption, harmonics entering the network) and appropriate preventive action.

The above can be achieved by using a computerized system for monitoring parameters of the Distribution Network and / or SCADA systems.

5. Recommendations

This chapter presents a set of recommendations and good practices, based on the experience of PRACE partners, analysis of the current state of art and practices of designing big facilities. The goal was to support Tier-0 and Tier-1 sites at the process of upgrading or designing new electrical facilities.

Recommendation 1: Provide only the necessary level of redundancy

- Understand the expectation of the users in terms of required availability of systems. Carefully consider what level of redundancy is required for which systems and what the percentage of the total power load is.
- Redundancy should only be implemented where required since it has impact both on investment costs and on running costs.
- Make sure to get statistics about the quality of electricity at your site for the past years in order to take a well-thought-out decision. Good quality of the electricity source where the centre will be powered may allow to decrease the redundancy level and further maintenance costs.

Recommendation 2: Implement redundancy in a 'clever' way

- Provide at least two independent main supplies, sized to match calculated maximum demand of power. Additionally, the supplies can be further sized so that one of them covers with its capacity the most of the connected load, whereas the second one is sized mainly to take care of the critical loads/systems. It practically means that the second system is much smaller than the main UPS.
- Optimise the mix of generators, UPS, distributed short-term UPS devices.

Recommendation 3: Internal experts

- Have in-house a team of infrastructure experts or at least qualified staff for infrastructure issues
- Involve this team as much as possible in the decision making process about future systems.
- Visit HPC centres of a size similar to yours and attend conferences on infrastructure issues.

Recommendation 4: Think TCO

- Power distribution equipment has typically a very long life time. This should be taken into account when comparing TCO costs.

Recommendation 5: Reduce electricity conversion losses

- It is desirable that high voltage, from a technical point of view, should be as close to the load as possible. For small and medium-sized computing or data centres it is clear that medium voltage supply is the most efficient. For Petaflops and Exaflop facilities it may be more economical to request higher supply voltage, usually in the range between 100 and 137 kV.
- Reduce costs of power losses in a power distribution network through the use of low-loss distribution equipment or exchanging high-losses devices into new technology systems.
- Take into account the real efficiency of power distribution equipment under the expected load.

Recommendation 6: Introduce a design phase in order to make future evolution easier

- Design a network using modular approaches: i.e. one transformer per LV switchboard section, two interleaved downstream UPS units per LV section. This will certainly help to keep the infrastructure design coherent and will decrease design errors or inconsistencies.
- Always ensure that the distribution system is designed in order to account for future expansion. 30 to 35 percent of spare capacity on both the electrical supply size as well as on physical size of distribution equipment is a typical overestimation.
- The electrical network must be "future proof" and the process of selecting equipment should ensure that infrastructure provider will guarantee spare and replacement parts available in the future.
- If installation of water based cooling systems is considered, try to separate the placement of electric bus bars and water pipes, for example, place the bus bars above the racks and water pipes under cabinets (under the raised floor).

Recommendation 7: Monitor the power distribution system

- Deploy a monitoring system throughout the distribution network in order to ensure more efficient use of the available energy and facilitate the maintenance of the network.
- Assessment of the condition of the power distribution network should be carried out annually and after any modification to the existing electrical infrastructure. The results of technical condition assessment together with the data from the monitoring system should aid in planning any upgrade and maintenance works.
- For the technical condition assessment the use of modern diagnostic methods such as thermal imaging and vibration monitoring devices is advised. They allow greater accuracy in early detection of equipment faults.

Recommendation 8: Minimize the impact of maintenance

- System maintenance must be carried out in accordance with a previously scheduled and detailed operation plan.
- Make sure that the periodic technical inspection of power distribution devices are scheduled in accordance with the requirements of the equipment manufacturer or local regulations.
- Maintenance work should be scheduled so as to minimise downtime of HPC infrastructure and critical services.

Recommendation 9: Select the right electricity provider

- In view of the energy market liberalization introduced in the EU, it is possible to negotiate the price of energy with several energy suppliers or consider joining the energy market. Even a small HPC centre with power consumption reaching 1MW is generally classified as a major customer by energy suppliers.
- Reduce the cost of supply charges by ensuring there is no violation of any of the agreed electrical parameters described in an agreement with DNO and energy supplier.
- Limit the usage of harmonics generating by equipment, which back feed the distortions to the DNO network.
- Ensure the distribution network contains elements that help correct reactive power and power factor.

Recommendation 10: Consider regulation and safety

- Regardless of whether the electrical supplies and network elements are operated by the centre staff or are commissioned to an external company, provide comprehensive training for the staff prior to undertaking any work.
- Construction, maintenance and operation should always be executed in accordance with all applicable local regulations.
- Make sure that access to key distribution network is restricted to authorized and properly trained personnel. This may require additional access control devices to restrict access to the distribution network cabinets, rooms etc.

6. Conclusion

With the increasing electrical power demand of HPC systems installed in computing centres, it is vital to improve electrical system efficiency and operation profiles.

Nowadays electricity is the largest cost component of running computing systems and is comparable to the cost of purchasing computing system. Therefore it is important, and almost critical, to achieve maximum efficiency in whole process of electric power supply, distribution and utilization.

During the financial planning of an HPC centre development and operation it should be taken into account that the TCO have to account also costs related to power supply and distribution, including cost of power losses and distribution network maintenance.

The new or upgraded electrical infrastructure will only be immune to technical problems and will provide some degree of future flexibility, resilience and reliability if it is developed accordingly to long-term strategy.

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Abbreviations list

HPC	High Performance Computing
MV	Medium voltage, usually between 1 and 50 kV
LV	Low voltage, in Europe: 230/400 V
kW	Active power unit = 1 000 W
MW	Active power unit = 1 000 000 W
ATS	Automatic Transfer Switch
USP	Uninterruptible Power Supply
DNO	Distribution Network operator