

# Improve patient safety through power availability and reliability

by Jean-Marie Hypolite

## Executive summary

The main mission of any hospital is providing high quality services and continuity of care for patients. Power problems can have serious consequences on human life, finances, technical operations, the environment, and the hospital's image and reputation, so creating and maintaining a healthy electrical distribution system is crucial. This paper describes how a balance between architecture, services and components can provide an ideal solution is key to true power reliability.

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# Abstract

The main mission of any hospital is providing high quality services and continuity of care for patients. Underpinning this mission are numerous complex systems, many of which require high power availability, power reliability, power quality and secure power.

Power problems can have serious consequences on human life, finances, technical operations, the environment, and the hospital's image and reputation, so creating and maintaining a healthy electrical distribution system is crucial.

Understanding how a balance between architecture, services and components can provide an ideal solution is key to true power reliability. Typical architectures for a hospital's electrical distribution system can help ensure the best possible solution, and include power monitoring as a critical component. The information from the power monitoring system can be used to manage the electrical distribution system independently or in conjunction with other hospital infrastructure like the building management system.

The effective design, operation and maintenance of these systems provide huge benefits to hospital facility managers, by providing a simpler and more comprehensive way to ensure that the hospital's electrical distribution system is always ready to provide the energy required for high-quality patient care.





## Energy availability and reliability, top concerns for patient safety

# Hospital constraints & pain-points

Healthcare facilities are often complex and integrate several different processes, including:

- Critical medical processes: Operating theatres, intensive care wards, labs, etc.
- Critical non-medical processes: Patient data systems (server rooms, data centers)
- Important medical processes: Hospitalization (patient rooms), normal care, radiology rooms
- Non-critical medical: Ambulatory care
- Non-critical and not medical: Parking, cafeteria, laundry, sterilization

As a result, healthcare facilities not only rely upon commercial loads (such as computers, servers, lighting systems) and industrial loads (such as food preparation equipment, laundry equipment, medical gas systems), but also rely on electronic medical loads (medical equipment) to operate the facility and provide patient care services.

In general, we can categorize the facilities into four main levels:

- Enterprise level: This level includes all the sites and buildings managed by the same health organization (for example, one enterprise may include one major hospital, four clinics and three retirement homes). For the electrical systems, it includes the supervision and monitoring terminals.
- Campus level: This level includes cross-over building infrastructure, common to all the buildings on the site (including non-medical buildings). For the electrical distribution, it covers the MV system when present.
- Building level: This level includes the building infrastructure specific to one building. For the electrical distribution, it covers the MV/LV transformers and its protective devices, the main LV panels, uninterruptible power supplies (UPS), and Low Voltage generator sets, and so on.
- Ward level: This level includes the different applications within a healthcare building, such as surgical care, in-patient hospitalization wards, and so on.

## Critical loads

The main mission of a hospital is quality and continuity of care.

There are numerous departments where uninterrupted energy is mandatory, such as operating theatres, intensive care units and data centers. In these areas, electrical power is essential, even vital to ensuring patient safety.

There are four key elements in measuring how effective a power source serves a critical power system: power availability, power reliability, power quality and secure power.

1. Power availability refers simply to a measure of whether or not power can be accessed at any given time. This is often referred to as “uptime” and is measured in number of nines”. For example, an uptime of 99.999% would be “5 nines”.
2. Power quality refers to the measurement of certain elements of power, such as harmonics, sags, swells, transients, and so on that can have major effects on the function of sensitive equipment.
3. Power reliability is a measure of combined power availability and power quality – determining how well the power source can provide suitable power for specific uses. (Poor power quality could result in some equipment being unusable, even if power is technically available.)
4. Secure power is power reliability enhanced with a back-up or redundant power supply – whether a secondary utility source, a UPS, a generator set, or combination thereof.

Problems stemming from power availability and reliability are often underestimated, and can have serious consequences on human life, finances, technical operations and the environment, not to mention its potential negative impact on the hospital's image and reputation.

There is no such thing as zero risk, but failures can be prevented by adopting a secure power approach. This strategy consists of correlating site managers' needs with qualified, proven technical solutions, developed specifically for critical activities, throughout the different steps in the construction of buildings and infrastructures. The primary objective is, of course, to guarantee the reliability and availability of power so that processes and systems keep functioning in all circumstances.

## Key pain points

Based on extensive interviews with key hospital stakeholders, there are several main goals that hospitals have, which each have associated pain points – many of which are shared by multiple groups within the hospital environment. While not all the pain points listed below are affected by the reliability of the hospital's electrical infrastructure, a surprising number are influenced by it, reinforcing why it is critical for a hospital to have a dependable and secure power system.

Hospital goals	Pain points related to goal	Facility manager	CFO	IT officer	Security officer	Physician/med staff
Enhanced financial balance	Improve existing efficiency actions of staff	●	●	●	●	●
	Optimize investments	●	●	●	●	●
	Find new efficiency opportunities					●
	Identify & remove non-efficient actions			●		●
Improved patient satisfaction	Welcome (for patients & visitors)				●	
	Hotel quality facilities & services	●				●
	Medical care & facilities	●			●	●
	Hospitalization costs			●		●
Attract & retain skilled staff	Healthcare oriented staff	●	●	●	●	●
	Attract high-quality applicants	●	●	●	●	●
	Retain existing staff	●	●	●	●	●
	Professional development & training	●	●	●	●	●
Risk management	Surgery	●				●
	Hospital-borne infections	●				●
	Security	●				●
	Infrastructure	●			●	
	Legal	●		●		●
Hospital updates, renovations & expansion of services	Compliance to rules, standards & accreditation	●			●	●
	New activities, expansion of services	●		●	●	●
	Skills adaptation to new activities	●		●	●	●
	New healthcare management	●		●	●	●
	Looking for funding			●		●
Improve hospital reputation	With patients	●		●	●	●
	With physicians					●

Fig. 1\_ Pain points of key stakeholders in the hospital setting

## Rules and standards

### Shock sensitivity

There are four key definitions used in explaining the different levels of shock sensitivity within a hospital setting:

1. **Definition: Applied parts**  
Part of the medical electrical equipment which, in normal use, necessarily comes into physical contact with the patient for the equipment to perform its function, or can be brought into contact with the patient, or needs to be touched by the patient.
2. **Definition: Group 0**  
Medical location where no applied parts are intended to be used.
3. **Definition: Group 1**  
Medical location where applied parts are intended to be used as follows: externally, invasively to any part of the body, except where following chapter applies.
4. **Definition: Group 2**  
Medical location where applied parts are intended to be used in applications such as intra-cardiac procedures, operating theatres and vital treatment where discontinuity (failure) of the supply can cause danger to life.

### Criticality levels

Three levels of criticality are used to define the different tolerances for power interruptions in a hospital setting:

Criticality level	Continuity of service requirements	Max.duraton for power cut & switch to back-up	Min. endurance of back-up power source
1	Permanent power supply	< 0.5 seconds	3 hours
2	Brief interruption	< 15 seconds	24 hours
3	Long interruption	< 3 minutes	24 hours

Fig. 2 \_ IEC criticality level



## Applying criticality levels to building care departments and utilities

The three levels of criticality defined above apply to specific areas within a hospital:

Application of criticality level		1	2	3
Technical installations	Operating theatre	█		
	Obstetrics	█		
	Intensive care units	█		
	Emergency ward	█		
Hospitalization	Attentive care	█	█	
	Intensive care	█		
	Standard care			
Medical imaging	Computer and monitoring equipment is level 1, all others are level 2		█	█
Administration	IT equipment is level 1, all others are level 2		█	█
Laboratories	Automated analysis equipment is level 1, all others are level 3		█	
Pharmacy				█
Equipment room	Elevators			█
	Medical air conditioning			█
	Heating, ventilation, air conditioning			█
	Cold room			█
	Automation systems	█		
First Safety	Detection	█		
	Smoke extraction	█		

Fig. 3 \_ IEC criticality level

# Power availability

## Definition

Availability is essential for secured power, in conjunction with power quality. It is defined as the “ability of an item to be in a state to perform a required function in given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided” (IEC 61508). In practice, it is the proportion of time during which an electrical installation is operational and capable of supplying power with the appropriate quality level for the equipment being powered. It is conveyed by an availability or “uptime” rate:

Availability (%) =  $(1 - \text{MTTR}/\text{MTBF}) \times 100$ , where

- MTTR (Mean Time To Recovery) is the mean servicing time needed to make the installation operational again after a failure.
- MTBF (Mean Time between Failures) is the mean installation uptime between failures. The availability rate translates an operating probability that is, in fact, very difficult to calculate and is generally assessed using MTBF and MTTR statistics.

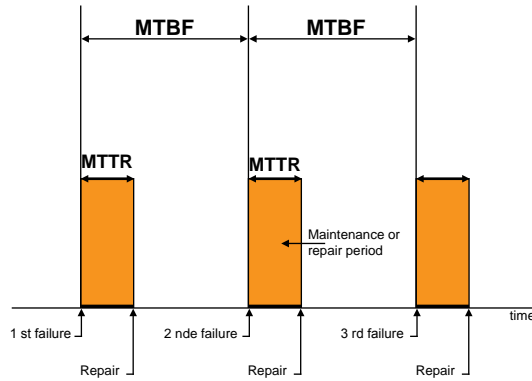


Fig. 4\_ Relationship between Mean Time Between Failures (MTBF) and Mean Time To Recovery (MTTR)

## Increasing power availability

A 100% availability rate is equivalent to a zero MTTR (instantaneous repair) or an infinite MTBF (failure-free operation). The objective is to get as close as possible to these conditions, by either:

- Reducing the MTTR through equipment maintenance performance and an efficient, proactive and reactive organization; or
- Increasing the MTBF through the reliability of sub-assemblies and components, acquired from proven suppliers.

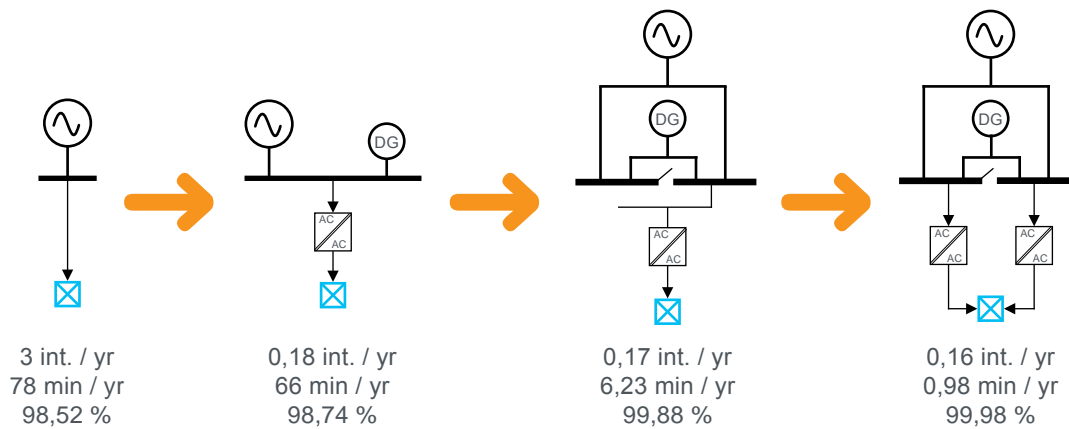


Fig. 5\_ Increasing availability of an electrical distribution system

## Defining the most appropriate secure power solution

Malfunctions related to electrical power are many and of various origins. The consequences on human life, business and the environment depend on the nature and criticality of the installation. Even if experience tends to prove that no universal solution can guarantee 100% secure power, there are specific, effective approaches available that take into account regulatory requirements and what is at stake for the site.

### Main principles to follow

Electrical installation performance should be viewed in the long term, according to evolving needs of the hospital, throughout its life cycle. Installations must be capable of adapting to new technologies and, of course, allow for maintenance work with no interruption in service.

These objectives stem from three main principles:

1. The use of redundancy and the design of resilient electrical installations - in other words, installations capable of adapting to unpredicted (and unpredictable) events;
2. The proactive scheduling of maintenance
3. The adaptability of the electrical distribution installation to allow for evolution of the site in terms of either growth or new technologies.

These solutions are based on a proven methodology and produce a set of best practices which may be extended to other sites:

- Do a thorough analysis of installation needs.

This enables the criticality levels of the various applications to be identified and the different sources of risk to be addressed. The analysis must be updated over time, and the different sources of risk to be addressed. The analysis must be updated over time.

- Design the architecture of the electrical system and size the installation with future needs in mind.
- Enable maintenance, testing and operation without disturbing hospital activities. This must include generator set testing as well as HV switchboards, LV switchboards, and UPSs. Staff must also be trained to handle crisis situations.
- Have informed and well-trained personnel available, and ensure regular professional development and skills upgrades to allow them to make the right decisions and act quickly.
- Ensure full event traceability to improve procedures and create comprehensive reports when needed.
- Proactively prepare for electrical crisis management through exercises and drills.
- Implement a resilient system, in two key ways:
  - In the design phase, by developing a dependable, contingency-enabled system with effective protection.
  - Throughout the system's lifetime, by analyzing incidents and how they were managed, and applying that experience to any new incidents to improve responsiveness.
- Adopt a dependability approach which encompasses reliability, maintainability and availability requirements.



#### Resilience:

- An organization's ability to cope with situations with minimal losses.

#### Dependability:

- A system's capability to fulfil all operational performance requirements, involving the concepts of reliability, maintainability and availability.

Fig. 6 \_ Resilience & dependability definitions

# The ideal solution

## Balancing architecture, services and components

To achieve and maintain ideal performance in an electrical distribution system throughout its life cycle requires balance between the three key pillars of the system:

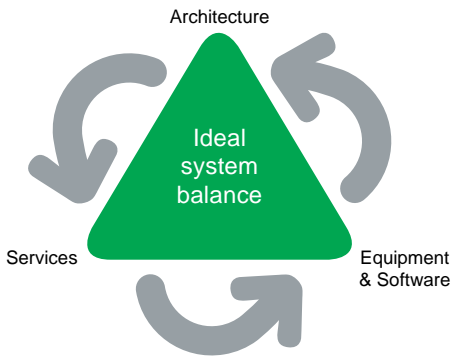


Figure 7 – The 3 pillars of system resilience

### 1. Electrical Distribution & Power Monitoring Architecture:

The architecture must be designed to ensure electrical distribution system availability according to the facility's different levels of criticality:

- Design and sizing of installations with redundancy
- Analysis of electrical risks
- Studies of dependability, coordination, lightning, harmonics, etc.
- Monitoring and control, and so on

### 2. Equipment & Software:

To enable communication with a monitoring system or building management system, key components are chosen and installed according to standards, in compliance with the architecture and with the goal of resilient operation:

- Medium voltage network, medium voltage loop reconfiguration
- Generator set
- Automated load shedding system
- LV switchboards
- Operating theatre switchboard
- Power monitoring system
- UPSs for uninterrupted power and STS (static transfer switch) depending on architecture

### 3. Operating and Maintenance Services:

Services must fit the required level of performance, throughout the installation life cycle, backed by communicating products:

- Monitoring and control
- Scheduled maintenance
- Maintenance operations
- Repair
- Routine testing such as generator set (or emergency power supply system) testing
- Emergency assistance (particularly for crisis management)
- Training, and so on

## Electrical distribution architecture

The following diagram provides an example of a teaching hospital architecture that includes several buildings on a large campus:

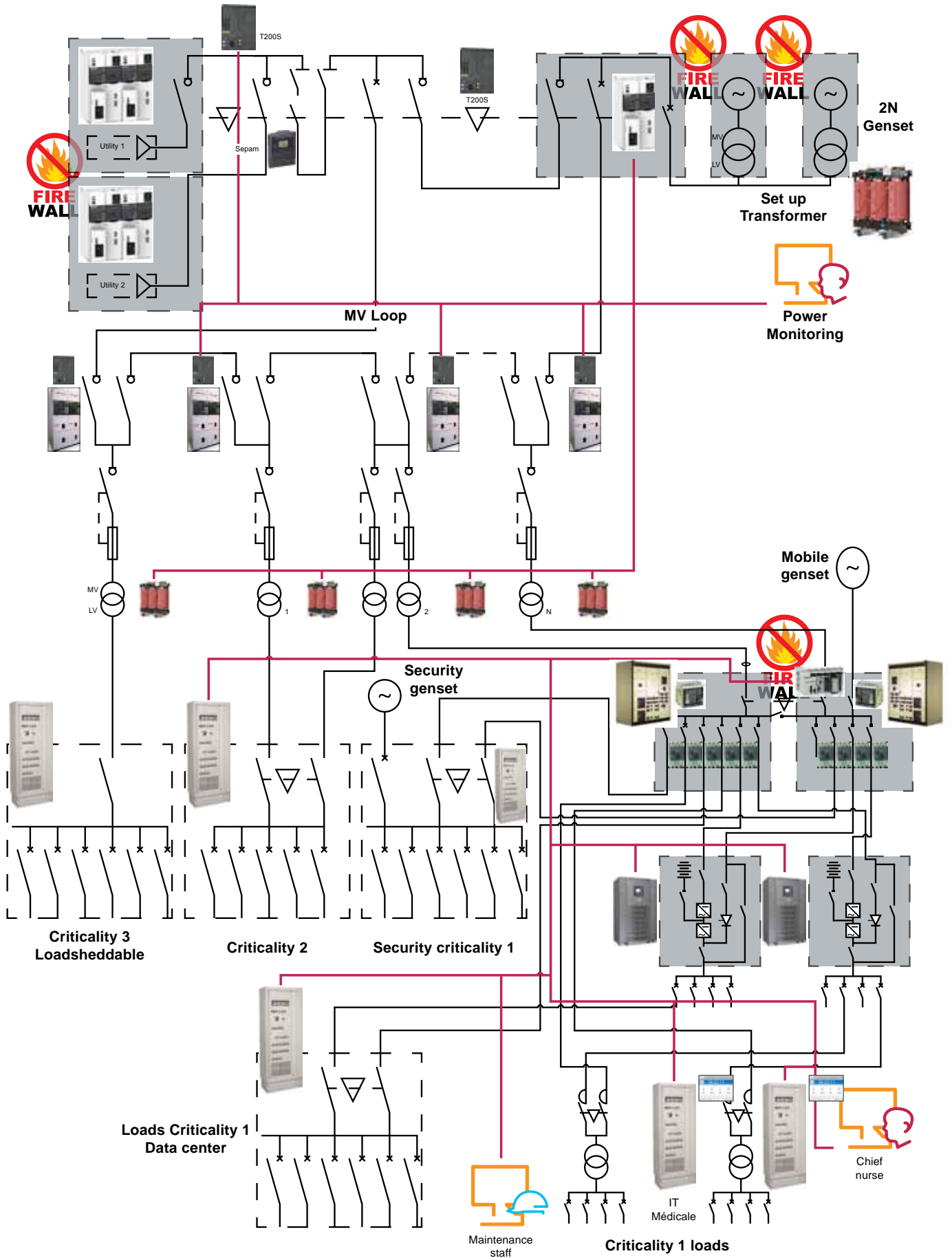


Fig. 8 \_ Example teaching hospital architecture

The typical scenario for this type of architecture is a large hospital, comprised of a single or multiple buildings, with more than 500 beds and more than 10 operating theatres. It has power requirements of more than 2,000 kVA.

The system has a number of key elements, numbered to correlate with the diagram above, including:

### 1. Utility incomer and utility backup source

The utility service entrance includes two medium voltage (MV) incomers coming from two different public grid substations. Both feed an MV loop distribution network either within a single building or more generally within a campus of multiple buildings. The advantage of this MV loop distribution path is that in case of a fault on the cable, it is possible to re-energize by another path. This redirection can be made manually or automatically (which is recommended).

In case of a power outage from the utility source or fault from the transformer or MV switchboard bus bar, the generator set will start and re-energize the hospital's MV loop.

The 2 sub-station incomers must be located in different rooms equipped with fire protection.

### 2. Medium voltage (MV) substation and MV loop distribution

The MV substation architecture is characterized as a single loop electrical distribution network, with an automatic loop reconfiguration, fed by 3 incomers – two from utility substations, as described above, and one from the back-up generator set.

This configuration is well adapted for large campuses, and assures a good level of secure power availability. In case of a fault on a specific sub-station, the loop can be reenergized within 3 seconds.

As an option, a high priority substation can be equipped with a redundant transformer to feed a high priority low voltage (LV) switchboard as shown on the single line diagram.

### 3. Backup power

The backup power system is made of one or more redundant generator sets, to power the critical loads of the hospital in case of a utility power outage. Generator sets are sized to feed the entire installation except for sheddable loads.

Generally we find the overall back-up generation capacity of a hospital is designed to include N+1 gensets, where N gensets are sufficient to feed the total loads, and one additional genset is available in case one of the main gensets fail.

A generator set is connected at the main LV switchboard. It will start within a few seconds after an outage.

An Uninterruptible Power Supply (UPS) will feed all class 1 & 2 loads.

Centralized UPS is the optimized configuration versus cost and features. It optimizes the batteries life and could be made of a N+1 or 2N configuration to increase the availability level.

In case of a utility power outage, to provide power to critical circuits until the back-up power system has come on line.

### 4. High-quality low voltage (LV) switchboard

The main LV switchboard is actually made of two coupled switchboards that supply the same loads, with a transfer switch connecting them. This system design improves availability and allows for maintenance or crisis management without shutdown of the whole switchboard.

A mobile generator set can be connected in case of a shut-down of the MV switchboard.

The other LV switchboards are divided by priority requirements, and could also be backed up by a mobile genset.

### 5. Security switchboard

The security switchboard is fed by two incomers coming from each of the two parts of the high-quality LV switchboard.

It feeds critical loads (Criticality Level 1) like smoke extractors, fire detection and suppression, security lifts, and so on. A mobile genset can be connected for redundancy.

### 6. UPS

A centralized UPS will feed very critical loads like operating theatres, the data center and life support equipment. The configuration of this UPS is on line. It is equipped with a static switch in case of fault and a bypass for maintenance.

### 7. Operating theatres

An operating theatre is fed with two incomers – the main feeder that comes from the utility source through the UPS, and a secondary feeder that comes directly from the utility source, that can be used in case of UPS maintenance or failure. The transfer between sources will occur within 0.5 seconds.

### 8. Operation & maintenance

Maintenance on the LV switchboard can be conducted live, if the system design allows it (that is, if it includes two coupled switchboards, as described in point 4, above), or unpowered.

### 9. Power monitoring & control system

A consistent and coherent power monitoring system is mandatory to bring the facilities staff the tools they need to manage and control the electrical network - especially to transfer source at the MV level and at the LV switchboard level. The power monitoring and control system can also provide:

- MV loop monitoring and reconfiguration
- Status of devices and equipment
- Status of the reconfiguration electrical distribution process
- Alarms monitoring, including alarms sent to maintenance staff through SMS
- Genset test information, including run times and follow-up
- Crisis management tools and assistance to recover
- Energy consumption data
- Maintenance information
- Traceability of events and alarms

## Requirements for highly secured power system

This electrical distribution system is easily classified as a highly secured system if:

1. It has redundant path and energy sources to feed critical loads:
  - Double MV incomer + backup
  - MV loop distribution + automatic reconfiguration
  - Redundant high quality LV switchboard
  - Double feeding of critical loads: operating theatres, security panels
2. It is made of type tested sub-assemblies

This electrical distribution system is made of critical sub-assemblies like genset, MV and LV ATS, high quality LV switchboard, UPS, operating theatres, that need to be type tested to enhance their commissioning, but also to improve their behavior during the life cycle.

3. It has to be operated and maintained efficiently

Resilient architecture and type tested sub-assemblies have to be tested and maintained regularly to keep the electrical distribution system up and running throughout its life cycle. Power monitoring is key, and will be discussed in detail later in this paper.

The performance of the system is extremely important, as any component or distribution path failure will impact medical devices.

The site is susceptible to disruption from both planned and unplanned activities. Due to redundancy of some key components, maintenance is possible without a complete shutdown of the hospital.

## Power monitoring system

As described above, power monitoring is a key component of the electrical distribution system.

It is the primary human-machine interface that assists maintenance staff to handle any situation that arises by gathering relevant data and displaying it in a way that helps staff efficiently manage energy within the hospital.

The information below provides a look at a typical power monitoring architecture and a description of a typical power monitoring solution.



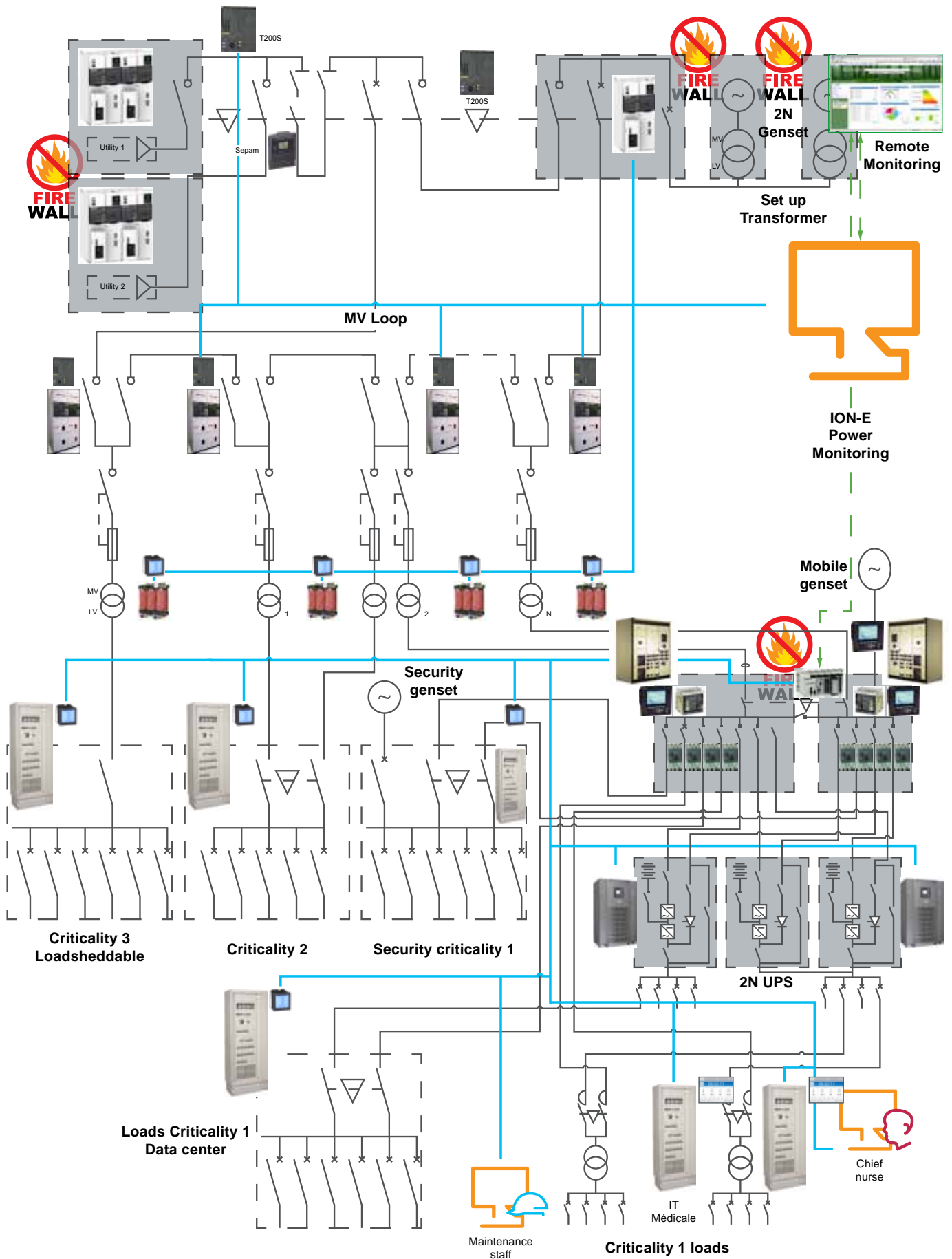


Fig. 9 \_ Typical power monitoring system architecture

## Description of the solution

A Power Monitoring and Control System (PMCS) is a monitoring and control system dedicated to electrical network management.

It monitors and controls each device from medium to low voltage, brings all relevant information to electrical staff, as well as provides general building management for energy consumption and optimization.

A PMCS will help track real-time power conditions, analyze power quality and reliability, and respond quickly to alarms to avoid critical situations. It facilitates the study of historical trends to reveal energy waste or unused capacity as well as verify efficiency improvements and allocate costs to buildings, departments or processes.

The software includes sophisticated load aggregation and arithmetic calculation. Coordinated control capabilities can be used to manage demand or power factor and to manage loads or generators.

This system provides the hospital electrical staff with information to help with:

- Energy management
- Load control
- Utility contract optimization
- Electrical network status, maintenance, troubles analysis
- Peak shaving
- Utility optimization
- Cost allocation
- Sub billing
- Energy modeling

## Secured monitoring & control of an electrical distribution network

- HMI SCADA real-time monitoring & control over the network with high-end time performance
- Screen animation
- Operating modes management
- Secured operation features on monitoring: monitoring validation of the measures, system supervision, select before operate, interlocking functions, control acknowledgements, maintenance tagging

## Critical power functions

- MV loop management
- Emergency power supply system monitoring (of genset & transfer sources)
- Events logging & alarms management on-board with 1ms time-stamping (time synchronization throughout site) and a PC-based alert module for advanced alarm management
- System redundancy (e.g. I/O servers, communication network)
- Waveform captures of events
- Electrical distribution automation functions: load shedding, load sharing, ATS management, automatic restarts, PLC function blocks

## Energy efficiency functions

- Waveform captures of trends, power quality analysis
- Real-time trending
- Simulation tools

## Maintenance functions

- Maintenance mode trending (historical) and archiving, reporting, web interface

## Building managements systems and power monitoring

The power monitoring system (as described above) is tied to the building management system to collectively supervise and monitor all of the hospital's facilities: HVAC, security, lighting, energy, and so on.

Integration of these systems offers great benefits to staff, by providing integrated access to information about the hospital's entire infrastructure.

The information below provides a look at an integrated building management and power monitoring architecture and a description of this integrated solution.

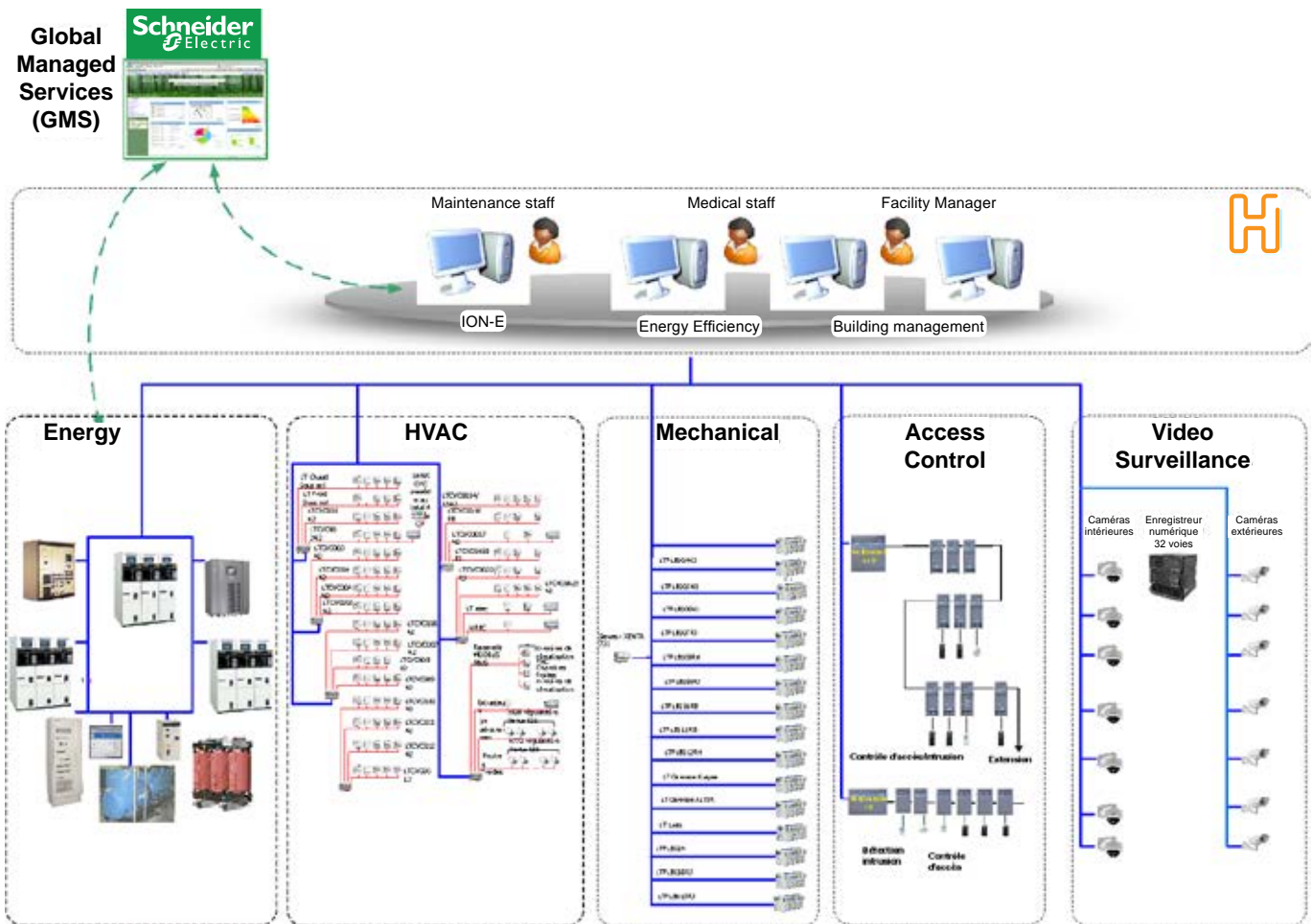


Fig. 10 \_ Combined building management and power monitoring solution

## Description of the solution

The building management system and power monitoring system will run together while exchanging data at the software level. There are three basic methods that allow the systems to be tightly integrated:

- BMS can poll real-time meter data directly from the field devices to facilitate alarming and integration with other non-power data
- Web pages from the field devices can be framed within the BMS
- Web pages from the PMCS software can be embedded in the BMS

Another possibility is database to database transfer of logged data between the two systems.

Typical values exchanged within an integrated solution can include:

- Operation: real-time voltages, currents, power (kW, kVAR, kVA), power factor and frequency, alarming
- Status of the main electrical devices
- Main alarms
- Consumption: accumulated energy and peak demand
- Power quality: voltage, current harmonics and voltage disturbances
- Trending & forecasting: graphical trends, forecasts for selected parameters

## Operation and maintenance

As the main hospitals have to run 24/7/365, operation and maintenance are mandatory to keep performance at the highest level and to ensure that system users are prepared to manage any crisis that arises.

As previously mentioned, design, construction and commissioning have to be carried out in a way that specifically meets a reliability approach.

Moreover, maintenance procedures have to be set up to:

- Be compliant with standards and rules in the healthcare industry
- Ensure each device and key component in the reliability process maintains its performance throughout the life cycle of the system

Power monitoring systems must be simple and easy to use, and give the user all relevant information needed to help with:

- Maintenance
- Regular testing and reporting (i.e. generator set testing)
- Relevant actions in case of crisis
- Post-mortem analysis

In addition, the evolution of the electrical distribution network has to be considered -- first at the early stages of the design; then at the construction phase when choosing relevant equipment and implementation processes; and finally, throughout the life cycle of the system.

During its life, a hospital is constantly evolving, adding new processes and new biomedical devices, increasing digitization of information and facing new standards and healthcare regulations. The evolution of the electrical distribution network must evolve as well, to support these challenges with a truly reliable system, based on the 3 pillars that were presented earlier.

Design of the electrical distribution network and its power monitoring and control system will improve cost of operation & maintenance, and improve:

### 1. Medical staff performance

- Improve nurse monitoring of infrastructure events as needed
- Compliance with medical procedure processes (e.g. preparation of operating rooms)

- Event traceability

### 2. Maintenance staff performance

- Ease of infrastructure management
- Ease of monitoring and controlling the electrical distribution network

- Training capabilities

- Maintenance capabilities

- Crisis management, diagnostics and recovery

### 3. Infrastructure performance throughout the hospital's life cycle

- Design of the electrical distribution network will determine operation & maintenance costs

- Keep up and running no matter what happens, and continue running during evolutions

- Accreditation preparation

### 4. Aging equipment prevention

- Battery fault detection, circuit breakers aging, selectivity, thermal imaging

# Conclusion

Reliability of electrical energy is vital in hospital buildings.

The resilience of the electrical distribution network depends on 3 main pillars:

- The architecture of the power network and the power monitoring system
- The products, equipment and software which are the key components of the electrical distribution network
- The operation and maintenance required to keep the electrical distribution network up and running throughout the hospital's life cycle and are mandatory to meet healthcare regulations.

Sizing the electrical distribution network appropriately depends on three main criteria:

1. Loads
2. Hospital operation (24/7/365) and activities (surgery, cardiology, neonatal, etc.)
3. Importance of critical loads

Monitoring and controlling the electrical distribution is essential, as it:

- Gives staff notification of any alarms that occurs on the electrical distribution network, and provides tools to analyze faults, conduct system diagnostics, and recover from a crisis
- Trains users how to manage the system
- Ensures adequate exercise of the backup generation source and source transfer equipment
- Provides critical information for decision-making during crisis management
- Provides event traceability, recording of alarms and events for post-mortem analysis

Schneider Electric Industries SAS

35, rue Joseph Monier  
CS 30323  
F- 92506 Rueil Malmaison Cedex

RCS Nanterre 954 503 439  
Capital social 896 313 776 €  
[www.schneider-electric.com](http://www.schneider-electric.com)