Smart tricks to improve power supply reliability
White paper series

Power Distribution

Power distribution systems

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Executive summary

For data centers, hospitals and other mission-critical applications, the reliability and resilience of power distribution systems are top priorities and essential to securing the critical ICT load.

Equally essential are maintaining safety and eliminating risk to personnel and equipment during both normal and fault conditions.

This white paper looks at how to improve power supply reliability and safety, including the dangers of arc flash and how to mitigate against it through careful power system design and the benefits of power distribution monitoring.

Powering Business Worldwide

Introduction to power distribution

For hospitals, data centers and other mission-critical applications, power distribution system integrity is essential in securing the critical ICT load. Accordingly, emergency diesel generators and UPSs are used to ensure the level of integrity required; these can be used in many different ways to achieve reliable power distribution. For UPSs in particular, there are many factors to be included as part of these considerations.

Elements of a power distribution system

For the reasons above, mission critical applications use a dual-sourced feed for their power input. One source is the utility grid, while the other is an emergency supply, often a standby generator. Both supplies are rated for the total load, which comprises the ICT load and services such as cooling essential to keep the load running. The input configuration must support automatic transfer of the load to an alternative supply; this function should be implemented as a complete solution integrated into the input switchgear and should include a starting signal for the generator set.

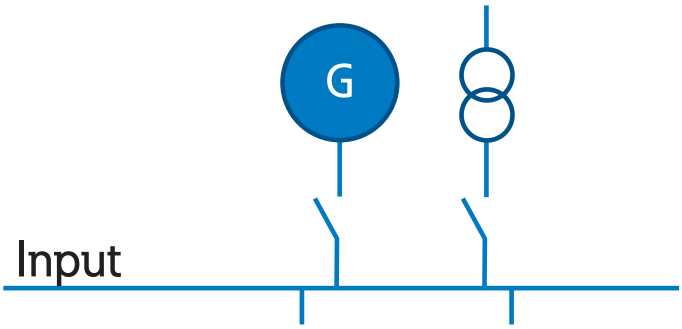

Fig.1: Power input configuration

Ensuring uninterrupted power

A UPS is used to ensure power quality and to prevent a power break during any utility supply disturbance or transition between sources. UPS configurations typically comprise one or more power modules with one integrated static bypass. Figure 2 shows this arrangement.

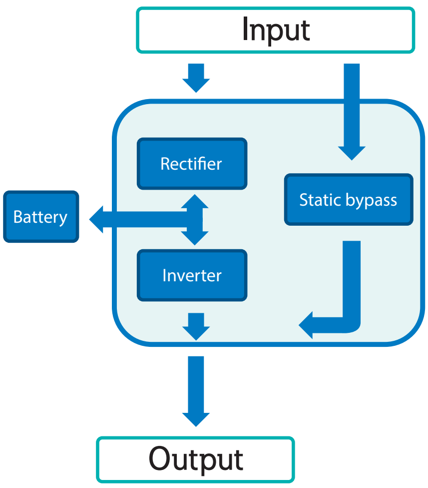

Fig.2: UPS configuration overview

UPS abbreviations

Abbreviations as below are often used for UPSs, breakers and modules:

- UPS Uninterruptible Power Supply
- ISB Integrated Static Bypass
- SBM Static Bypass Module (often a distributed unit)

Distribution of power to the load

A distribution configuration is used to deliver power to the load. This configuration usually comprises a main load breaker (LB) and multiple branches, each protected by their own breaker as shown in Fig.3. Sometimes the power distribution is integrated into a single Power Distribution Unit, or PDU. If an electrical problem such as a short circuit or overload occurs, it should be limited to the affected branches without reaching others. This containment can be achieved by designing in selectivity between the branch circuit breakers and the upstream protection. Accordingly, it is important to use circuit breakers that allow discrimination.

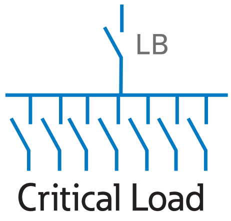

Fig.3: Power distribution configuration with upstream and downstream breakers

Power distribution systems that contain UPSs typically include an input and output configuration with a load distribution part. Below we look at examples of these, from the most basic to more complex and sophisticated.

Simple input and output configuration

A set of circuit breakers is necessary to protect both the input to and output from the UPS. These can be packaged with input switchgear and output switchgear, while combined UPS Input/Output switchboards are becoming increasingly common. These provide a constant feed to the UPS system and include the bypass arrangement and UPS output. The most basic Input/Output functionality comprises a module input breaker (MIB), module output breaker (MOB) and a maintenance bypass switch (MBS), as shown in Fig.4.

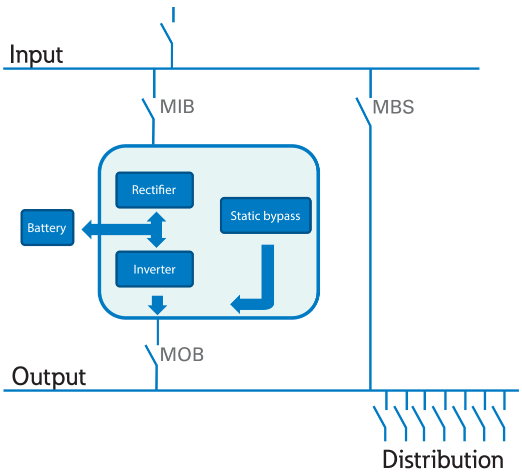

Fig.4: Basic power distribution configuration

Comprehensive UPS configuration

Components can be added to the basic configuration to develop a more comprehensive solution as appropriate to a particular installation. Additional possibilities include:

- Rectifier Input Breaker (RIB)
- Static Bypass Input Breaker (BIB)
- Maintenance bypass switch (MBS)
- Maintenance isolation switch (MIS)
- Load Bank Breaker (LBB)
- Load Breaker (LB)

Fig.5 below shows how this switchgear can be deployed around the UPS, including generators and transformers.

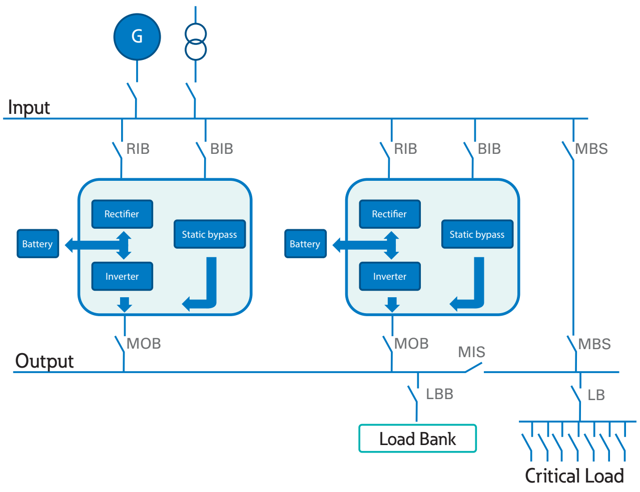

Fig.5: Power distribution configuration

Rectifier Input Breaker and Bypass Input Breaker

To protect each device independently, a separate Rectifier Input Breaker (RIB) and static Bypass Input Breaker (BIB) can be used instead of a rectifier and static bypass with one common input. The rectifier input typically also carries the battery charging current. A further benefit of separated breakers is that the load can be supplied via the static bypass.

Maintenance Bypass Switch

Adding a Maintenance Bypass Switch (MBS) allows an entire UPS module to be bypassed and taken off line. The MBS is primarily used to allow voltage free maintenance work on the UPS modules without disconnecting the load. The MBS can comprise two breakers and a cable connection between the input and output switchboard. Alternatively, these switchboards can be combined into a single unit if only one MBS is required.

Load Bank Breaker

For load testing, UPSs have a test mode that feeds battery stored energy back into the supply grid. However, some applications require testing via a load bank. If so, a Load Bank Breaker (LBB) can be added to handle the load bank connection.

Maintenance Isolation Switch

A maintenance isolation switch (MIS) can be added to allow UPS testing and servicing without affecting the load.

Latest norms for power distribution

IEC regulations set standards for safe products. Often, they also provide guidelines on specifications that should be agreed between power system manufacturers and their users.

Possible consequences of inadequate specification

Mission critical systems place high demands on the power distribution equipment they use. IEC standards provide a good starting point for protecting users, however they are open to interpretation. Therefore, expectations should be discussed and agreed between the manufacturer and user, to avoid delivery of a system that is low cost and IEC-compliant, yet not fit for purpose.

IEC61439- switchgear build

The new IEC 61439 series of international standards establishes clear regulations for low-voltage switchgear and control gear assemblies. It specifies electrical equipment safety requirements for planners, system engineers, electricians and end users, to define protection objectives for people and industrial plant with regards to electrical installations. Annex C of IEC61439-1 ""Items subject to agreement between the assembly manufacturer and the user" provides a useful overview of an agreement between the assembly manufacturer and user for power switchgear and control gear assemblies. It Lists all user defined functions and characteristics individually and indicates the standard arrangements.

Detailed description of the 61439 can be found in "Power Switchgear and Controlgear, Assemblies and Distribution Boards according to EN 61439" by Eur.-Phys. And Dipl.-Ing. Alfred Mörx.

IEC TR 61641 Arc Flash

IEC 61439 does not describe internal Arc, but IEC TR 61641 does. The 61641 edition 2.0 is a Technical Report and not a product standard; it is not part of IEC 61439 and it is not a mandatory test. It is an additional set of testing circumstances to increase protection of people and assemblies. This guideline indicates three classes:

- Personal protection
- assembly protection
- limited continued operation

Personal protection, is achieved when criteria 1 to 6 are fulfilled:

1. Correctly secured doors, covers, etc., do not open
2. Parts (of the ASSEMBLY), which may cause a hazard, do not fly off. (This includes large parts or those with sharp edges, for example inspection windows, pressure relief flaps, cover plates, etc.)
3. Arcing does not cause holes to develop in the freely accessible external parts of the enclosure as a result of burning or other effects
4. Vertically arranged indicators do not ignite (indicators ignited as a result of paint or stickers burning are excluded from this assessment)
5. The protective circuit for accessible parts of the enclosure is still effective
6. The ASSEMBLY is capable of confining the arc to the defined area where it ignited, and there is no propagation of the arc to other areas within the ASSEMBLY

In addition, if specified by the manufacturer, criterion 7 applies where the ASSEMBLY is to be suitable for limited continued operation:

7. After clearing of the fault or after isolation or disassembly of the affected functional units in the defined area, emergency operation of the remaining ASSEMBLY is possible. This is verified by a dielectric test with a value of 1.5 times the rated operational voltage for 1 minute.

4.1 Classification with regard to the protection characteristic

According to their characteristics under arcing conditions ASSEMBLIES can be classified by the manufacturer into:

Arcing class A – ASSEMBLY providing personnel protection under arcing condition by arc tested zones conforming to arcing conditions in 8.7, criteria 1 to 5, and by arc ignition protected zones, if any;

Arcing class B – ASSEMBLY providing personnel and ASSEMBLY protection under arcing conditions by arc tested zones conforming to arcing conditions to 8.7, criteria 1 to 6, and by arc ignition protected zones, if any;

Arcing class C – ASSEMBLY providing personnel and ASSEMBLY protection under arcing conditions by arc tested zones conforming to arcing conditions with limited operation in 8.7, criteria 1 to 7, and by arc ignition protected zones, if any;

Arcing class I – ASSEMBLY providing a reduced risk of arcing faults solely by means of arc ignition protected zones.

The power switchgear's manufacturer and user must agree on the arcing class.

Arc flash risk and mitigation

The risk of arc flash is always present in LV switchgear. The results of an arc flash event can be devastating, in terms of personnel injury or even death, damage to equipment and extended system downtime. However, the risk can be mitigated by following the steps below.

Background

Most LV switchgear have air insulated busbars. Supports maintain a safe distance between the bars, with a sufficient insulating air gap. If this insulation value falls below a critical ignition point an arc flash is initiated, and can continue until the energy source is cut off.

Arc flashes mostly occur during maintenance. While the probability of such an event is low, the consequences can be devastating, with extremely severe effects.

Possible consequences of an arc flash

An arc flash occurring in a 400 VAC switchboard can result in the load being shut down, with a long period needed for cleaning or replacing the switchgear. The arc flash risk has a direct impact on uptime when switchgear is used in mission-critical applications.

During an arc flash intense heat and light is emitted, sufficient to cause burns, and destroy skin and clothes. The heat energy can melt metal parts and blast molten droplets. These can burn skin and clothes, and may cause lung damage. High current arcs also produce pressure waves; sufficient to throw human victims and cause injuries through falling or colliding with nearby objects. The blast may also lead to hearing loss and chronic pain.

Besides the unwanted risk of human damage or injuries, there are the equipment issues; loss of production, repair costs and consequential damage. However, end-customers are seldom aware of these consequences, and so fail to take adequate arc reduction or prevention measures. Education in this area is important, as arc awareness and prevention increases personnel safety and improves reliability and uptime. Possible measures include minimizing the chance of arc flashes, and providing system redundancies. System redundancy also provides a reduction of downtime if an arc does occur.

Minimizing personnel danger from arc flash

Some market segments do not accept the risk of arc flash injury to personnel, but will accept the possibility of damage to equipment and (partial) power supply outage. Their approach is to build strong cabinets with top-mounted flaps to create 'arc-proof' systems. If an arc flash occurs, humans in front of the cabinet will be safe and only the equipment is damaged. The same results can be achieved without needing such elaborate cabinet construction, by using Eaton's 'Arcon' product, which limits the consequences of an arc and keeps people safe.

Preventing arc flash

Higher market segments do not accept damage to personnel or equipment. Such users specify insulated main and vertical busbar systems designed to eliminate the risk of an arc flash completely. However not all areas can be made arc-free; some must be made arc-proof. An arc occurring in an arc-proof area must be confined to one functional unit. Switching the system back on and continuing operation after an arc event should be possible.

IEC norms and arc flash

Naturally, switchgear must be built according to IEC 61439. Eaton is proud that all its products are verified by testing, which is the most rigid of IEC's verification methods.

Yet a potential danger still exists because IEC 61439 does not place any demand on open arc switchgear behavior. Though IEC TR 61641 does act as a guideline, unfortunately most end-customers lack detailed awareness of this standard. See under 'Latest norms for power distribution' for more information about IEC TR 61641.

Arc flash free designs

As indicated above, achieving a 100% arc-free low voltage system is not possible. Some areas such as the incoming cable connections and the outgoing functional unit behind the short circuit protection device cannot be made arc-free. The rest of the system, including the main and vertical busbars can be made arc-free by using epoxy coated insulated bars or shrink sleeve covered bars.

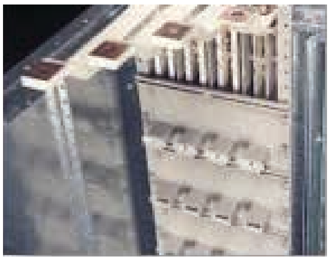

Fig.6: Examples of insulated bus bars

Eaton switchgear is based on 'arc-free design', implementing a strategy of prevention being better than cure. All risk areas are considered and designed so that no arc flashes can occur. A fault free zone is created by ensuring that the phases cannot 'see' each other. The complete set of measures employed to create a fault-free zone between incomer and outgoing protection include:

- Full insulation by epoxy coating of main busbars.
- Epoxy insulated connection bars between main and distribution busbars.
- Epoxy powder insulated connection bars between incomer/buscoupler and main bars.
- Phase-to-phase, phase-to-neutral and phase-to-earth screened terminations at both busbar and cable side of incoming feeders.

Arc proof design – functional outgoing unit

When an arc occurs behind the short circuit protection device, consequences are reduced because the energy levels are limited by the NH-fuses or MCCBs. This decreases the amount of arc energy in outgoing cables. In the design of motor starters the type of fuse or MCCB applied depends on whether type 1 or type 2 coordination is required. The coordination type determines the combination of short circuit protection device with the contactor. Type 2 means that the short circuit protection device also protects the contactor if a short circuit occurs. (This is not a demand in type1 coordination). Limiting-type MCCBs allow for higher short time withstand current values. They have minimally improved arc limitation functionality compared to non-limiting MCCB types. Within Eaton low voltage switchgear, tests have been performed for both fused and MCCB designs to assure that when an arc occurs, personnel are safe in front of the system as specified in criteria 1-5 IEC TR 61641.

Arc Flash Reduction Maintenance System

Eaton Magnum and NRX range ACBs offer an Arc Flash Reduction Maintenance System (ARMS™) option. ARMS provides a reduced energy protection setting that reduces the arc energy while staff are working close to the devices. ARMS is a separate integral analogue protection circuit that provides an accelerated instantaneous trip to reduce arc flash, allowing the ACB to trip in as little as 18 ms.

The operator can pre-select from five levels of protection to optimally balance arc flash reduction against nuisance tripping during planned startup and maintenance operations, without disturbing the normal operational trip unit settings. Local and remote enabling and indication capabilities are provided as well as provision for Lock-out/Tag-out procedures. ARMS is available on Magnum Digitrip 520MC & 1150, as well as Series NRX Digitrip 520M and 1150.

Customers embrace the ARMS functionality of the Magnum/NRX ACBs. Door switches connected to the Digitrip with ARMS functionality allow for better personnel safety in abnormal conditions such as maintenance operations.

Arc detection

An arc detection system should only operate when it 'sees' an internal arc, preferably in combination with a current surge. The duration of the arc flash is limited to approximately 100 ms; the time needed to detect and switch off the incoming breaker current. Energy within the arc flash is equal to I^2t. The 100ms reduction decreases the arc flash energy level.

Arc mitigation

An arc mitigation device should only operate when it 'sees' an internal arc. Its use will cause limited system damage, but it will mean that at least the quenching device must be removed before the system can resume operation after an arc flash. This may be acceptable in some applications such as hospitals, large commercial buildings and general industries, but in most cases such a safety option is viewed as an add-on to an intrinsically safe (arc proof) design and not as the only way to protect a switchboard.

Arc killer Arcon

Reducing the arc energy reduces the damage to a power distribution system caused by an internal open arc event. With protection settings only, arcing time is typically 50 ms. Eaton's Arcon arc killer product can reduce the arc time to less than 3 ms, significantly reducing the arc energy. Less arc energy means reduced damage and a faster recovery time.

Arc flash reduction – 208 V versus 400 V circuits

In a 120V/208 V circuit, arcs tend to self-extinguish. This self-extinguishing is caused by the high impedance in the 208/120 V supply transformer. By contrast, an accidental short circuit in a 230/400 V system can initiate an arc that does not self-extinguish. Typically an arc flash propagates from the source at a speed of 100 meters per second, finding its extinguishing point at the far end of the switchgear.

Internal separation in low voltage switchgear

A low voltage switchgear panel is built up from multiple functional units. The form of internal separation indicates how these units are separated from each other. Increasing levels of internal separation make the switchgear increasingly complicated to build, but increasingly easy to maintain. In any case, it is beneficial for maintenance purposes to indicate clearly the form of internal separation used between the switchgear's functional units. Fig.6: Fig.7: Forms of internal separation – examples

Implications of internal separation forms

The form of internal separation determines the ease of access to live parts within the switchgear. If a Form 1 switchgear type (see IEC 61439-2 below) needs a modification such as connecting a cable, the complete switchgear assembly must be disconnected. Higher forms of separation mean that only part of the switchgear assembly needs disconnecting. For each extension or alteration the total connected load needs to be de-energized.

Forms of internal separation – IEC 61439-2 definition

IEC 61439-2 clearly indicates the forms of internal separations between busbar, functional units and terminals for external conductors as shown in Table 1 below.

Description	Form
No internal separation	1
Separation between busbar and functional units	2a
Separation between busbar and functional units, terminals for external conductors separate from busbar	2b
Separation between busbar and functional units, separation of functional units from each other, terminals for external conductors separate from functional units (not from each other)	3a
Separation between busbar and functional units, separation of functional units from each other, terminals for external conductors separate from busbar and functional units (not from each other)	3b
Separation between busbar and functional units, separation of functional units from each other, terminals for external conductors separate from functional units and each other.	4a
Separation between busbar and functional units, separation of all functional units from each other. Terminals for external conductors from the functional units are separate from busbar, the functional units, and each other.	4b

Table 1 – forms of internal separation

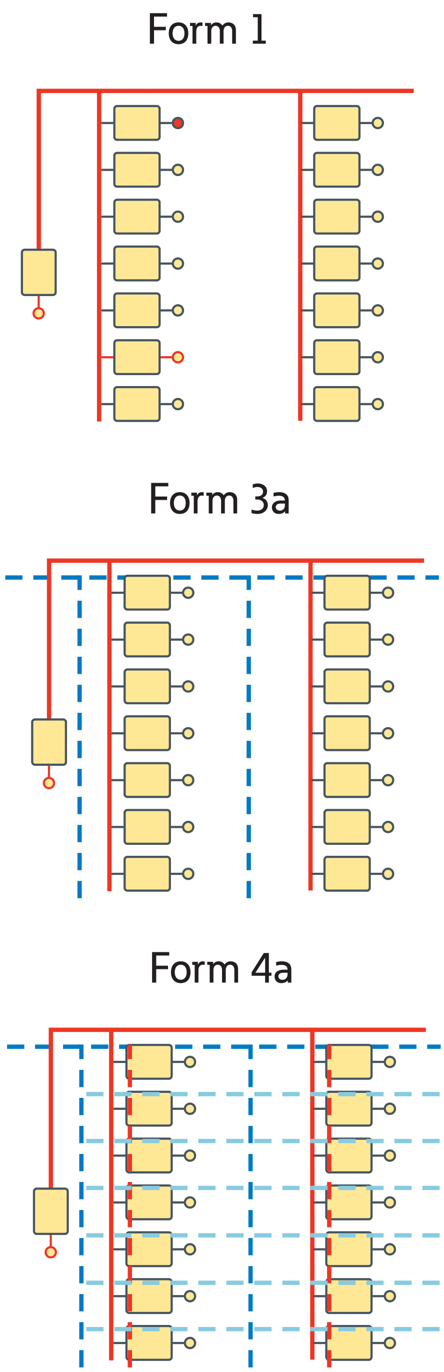

Fig.7: Forms of internal separation – examples

Internal separation forms and their implications for de-energization

Different forms of internal separation allow different degrees of de-energization when performing maintenance work such as connecting a new cable, as shown in Table 2 below.

Form	De-energize with cable work
1	Whole board, all loads.
2a	Whole board, all loads.
2b	Whole board, all loads.
3a	Whole panel, all loads in that panel
3b	Whole panel, all loads in that panel
4a	Whole panel, all loads in that panel, or functional unit depending on construction
4b	Only functional unit

Table 2: Forms of internal separation and de-energizing implications

Form of internal separation according to British Standard

Although IEC 61439-2 clearly indicates the separation between busbars, functional units and terminals for external conductors, it does not specify cable glanding. Therefore, the British Standard version of IEC 61439 has added types of Form 4b to cover this.

Form	Type	De-energize with cable work
1	1	Separation by insulation, Cables may be glanded elsewhere
2a	2	Separation by metal, Cables may be glanded elsewhere
2b	3	Each functional unit has its own integral glanding facility
3a	4	Separation by metal, Each functional unit has its own integral glanding facility
3b	5	Terminals separated by insulated coverings, and glanded in common cabling chambers
4a	6	All separation is by metallic or non-metallic rigid barriers or partitions. Cables are glanded in common cabling chamber.
4b	7	All separation is by rigid barriers or partitions. The termination for each functional unit has its own integral glanding facility.

Table 3: British Standard for forms of separation and cable glanding

Remark

These forms of separation are not relevant to arc fault containment which is not the subject of this definition. Arc fault containment is subject to a separate agreement between the manufacturer, and the client.

Diagnostics

A low voltage switchgear panel is typically intended to operate for 20 or more years. Throughout this extended lifetime, months may pass between even the most cursory of visual inspections. But does this provide sufficient diagnostic input to for adequate intervention?

Implications of long intervals of inspection

During these long periods, a small problem like a bad connection could develop into a major failure. Overheating of a joint increases the temperature and this increases the resistance, converting the small problem into a potential switchgear failure. Many maintenance crews have asked for the switchgear to be equipped with IR viewing windows. These IR viewing windows on crucial positions allow for periodically checking the connections for temperature behavior. However there can still be long intervals between checks, and a strong dependence on load and ambient temperatures. Accordingly, an efficient diagnostics system that can detect and provide early warning of such problems is highly desirable if not essential.

Power distribution monitoring – Eaton Diagnose system

EATON Diagnose System is specifically designed to provide continuous predictive monitoring of switchgear used in mission critical applications. Diagnose identifies and recognizes hotspot issues and problems before they progress into a major failure. It identifies faulty joints or connections by the excess heat they generate.

EATON Diagnose System detects problems early through continuous monitoring. It provides warnings and information for diagnostics purposes, helping to record the state of the switchgear and give an insight into its availability. It provides log file records and integrates into existing SCADA systems.

The monitoring system is wireless, meaning that no wiring of the sensors is required, and is quick and easy to install. Permanent status transmission is established immediately on installation, and continuous thermal condition monitoring of critical joints within the energized electrical equipment is realized.

This enables permanent, non-invasive, round the clock detection of hotspots at an early stage of their development, so avoiding potential downtime resulting from arc flash or power outage incidents.

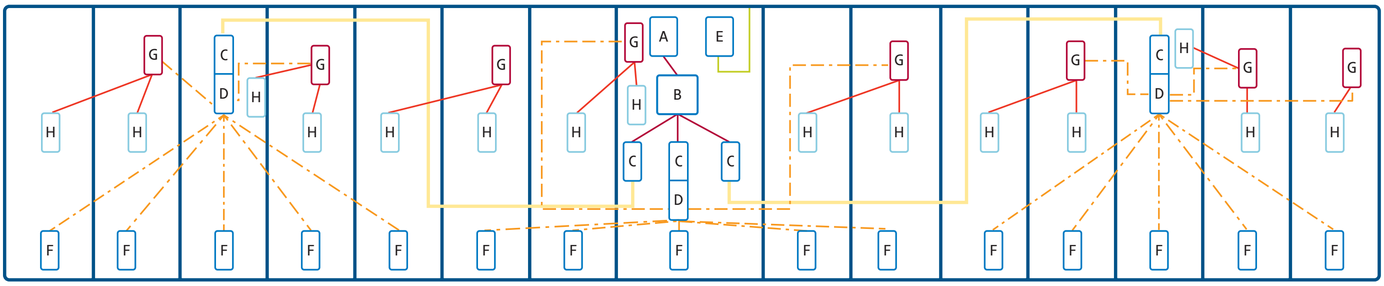

Fig.8: EATON Diagnose system overview

Conclusions

A Power Distribution system in a mission critical application typically includes a backup source such as a standby generator, with a UPS to ensure power quality and continuity during utility power problems or changeover between power sources. The UPS and other devices must be connected into the power distribution system through a suitable set of switches and circuit breakers to limit any power outage to the area where the fault occurs, and to take the UPS safely off line for maintenance.

Alongside reliability and resilience, maintaining safety and eliminating risk to personnel and equipment are vital parts of an overall protection strategy for the power distribution system. There are IEC regulations that set standards for safe products, which must be met.

For instance, many users are unaware of the ever-present risk of arc flash in Power Distribution systems – or how dangerous it can be. This is why mitigation of arc flash is so crucial to system safety and why adhering to safety standards is critical.

Forms of internal separation is another practical and important topic, as they indicate how functional units are separated from one another within low voltage switchgear units. This in turn dictates the extent to which a system must be de-energized before making extensions or alterations to the switchgear.

Finally, diagnostics and monitoring is an important step in ensuring that the system is running as intended and in providing early warning of any potential risks or failures.

Together, these measures help users to operate and maintain the power distribution system with maximum safety and minimal downtime.

About the authors

Janne Paananen is Technology Manager in the Critical Power Solutions organization for Eaton EMEA. He is specializing in large UPS system solutions for datacenters and special applications. Janne has more than 15 years of experience with large three phase UPS products and has been working in after- and pre-sales organizations providing tailored UPS solutions, support and in-depth product trainings for Eaton's personnel and customers world-wide. Janne Paananen is also a guest lecturer for educational institutes and participating in the international standardization work around data centers.

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