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SERIES L: CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF OUTSIDE PLANT

Architecture of power feeding systems of up to 400 VDC

Recommendation ITU-T L.1201

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Architecture of power feeding systems of up to 400 VDC

Summary

Recommendation ITU-T L.1201 describes the architecture of power feeding systems of up to 400 VDC for information and communication technology (ICT) equipment in telecommunication centres, data centres and customer premises. It describes aspects such as configuration, redundancy, power distribution and monitoring, in order to construct safe, reliable and manageable power feeding systems. It can be used also as an architecture reference model for further Recommendations e.g., on the performance of DC power feeding systems.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T L.1201	2014-03-01	5	11.1002/1000/12135

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FOREWORD

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In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

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Introduction

Power feeding systems of up to 400 VDC have been developed to cope with an increase in power consumption and equipment power density. Consideration is given to improvements in energy efficiency, as well as the reduction in greenhouse gas (GHG) emissions and raw materials.

Recommendation ITU-T L.1200 specifies the 'up to 400 VDC' interface between the power feeding system and any ICT equipment connected to it. This Recommendation specifies the architecture of up to 400 VDC power feeding systems and aims to provide a safe architecture reference for an 'up to 400 VDC' power feeding system with reliability and manageability adapted to suit specific requirements.

One of the advantages of 'up to 400 VDC' power feeding is that it reduces intermediate power conversion stages (e.g., the inverter and power factor compensator can be eliminated) and gives lower current usage than –48 VDC feeding, for the same power requirement.

Many papers have assessed the potential gains of using DC power feeding systems for ICT equipment in telecommunication centres, data centres and customer premises, e.g., [b-CCSAYD/T 2378], [b-Hirose], [b-Qi], [b-Marquet]; these papers refer to many other references.

The common range of energy saving is generally up to 15% depending on the legacy solution based on the AC UPS that is replaced, and especially if the best class of DC power feeding system is used. This saving could be applied to the 200 TWh of datacentre energy consumption assessed at the global level e.g., by the Koomey assessment [b-Koomey].

Improvements in reliability and availability vary between factors of 2 for a simple architecture to 20 for a full end-to-end redundant architecture; this is based on many of the papers listed in the bibliography: [b-Kervarrec], [b-Qiguo], [b-Tsumara], [b-Bauer] and [b-Liu].

Compared to a centralized –48 VDC architecture, a reduction of 10% to 50% in copper usage has been precisely assessed, while for a decentralized –48VDC architecture, a reduction of 60% in battery sizes could be reached [b-DC wiring design Intelec 2012].

Many studies show that there is a reduction in the initial set-up costs that can be as high as 20%, and also for the running costs where savings could come from making less site interventions and trips. Also, there is in general less maintenance with modular rectifiers because the system is easier to operate. In addition, the ICT equipment is directly backed up by the battery power directly coupled to the DC outputs.

Additional gains are presumed in the simplification of connecting renewable DC sources or other distributed generators (fuel cells, DC engine generators, DC wind generators etc.).

Recommendation ITU-T L.1201

Architecture of power feeding systems of up to 400 VDC

1 Scope

This Recommendation specifies a power feeding architecture for power feeding systems of up to 400 VDC at telecommunications centres, datacentres and customer premises [ITU-T L.1200]. This Recommendation aims at providing an architecture reference for an up to 400 VDC power feeding system with high reliability, safety and manageability. This Recommendation covers the following items for power feeding systems of up to 400 VDC:

1) configuration of power feeding systems of up to 400 VDC;
2) requirements of the main basic elements for power feeding systems of up to 400 VDC (rectifiers, power distribution units (PDUs), batteries and distribution power lines);
3) monitoring and management functions.

This Recommendation ensures a safe, operable, electromagnetic compatibility (EMC)-compliant and reliable cohabitation of power feeding systems of up to 400 VDC with AC and –48 VDC [EN 300 132-2] systems in sites combining these power feeding interfaces.

The full description of a battery, grid AC supply, backup generator and power supply units (PSU) in ICT equipment and renewable or distributed energy sources are out of the boundaries of this Recommendation, but indications are given on their influence on the architecture of power feeding systems of up to 400 VDC.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T K.21] Recommendation ITU-T K.21 (2011), *Resistibility of telecommunication equipment installed in customer premises to overvoltages and overcurrents*.

[ITU-T K.44] Recommendation ITU-T K.44 (2012), *Resistibility tests for telecommunication equipment exposed to overvoltages and overcurrents – Basic Recommendation*.

[ITU-T K.85] Recommendation ITU-T K.85 (2011), *Requirements for the mitigation of lightning effects on home networks installed in customer premises*.

[ITU-T L.1200] Recommendation ITU-T L.1200 (2012), *Direct current power feeding interface up to 400 V at the input to telecommunication and ICT equipment.*

[ETSI EN 300 132-2] ETSI EN 300 132-2 V2.4.6 (2011-12), *Environmental Engineering (EE); Power supply interface at the input to telecommunications and datacom (ICT) equipment; Part 2: Operated by –48 V direct current (dc).*

[ETSI EN 301 605] ETSI EN 301 605 V1.1.1 (2013-10), *Environmental Engineering (EE); Earthing and bonding of 400 VDC data and telecom (ICT) equipment.*

[ETSI ES 202 336-1]	ETSI ES 202 336-1 V1.2.1 (2011-07), *Environmental Engineering (EE); Monitoring and Control Interface for Infrastructure Equipment (Power, Cooling and Building Environment Systems used in Telecommunication Networks) Part 1: Generic Interface.*
[ETSI ES 202 336-x]	ETSI ES 202 336-x (in force), *Environmental Engineering (EE); Monitoring and Control Interface for Infrastructure Equipment; Parts 2 to 10 information model series.*
[IEC 60364-1]	IEC60364-1 (2005), *Low-voltage electrical installations – Part 1: Fundamental principles, assessment of general characteristics, definitions.*
[IEC60364-4-41]	IEC60364-4-41 (2005), *Low-voltage electrical installations – Part 4-41: Protection for safety – Protection against electric shock.*

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 interface P [ITU-T L.1200]: Interface, physical point, at which a power feeding system is connected to operate ICT equipment.

3.1.2 ICT equipment [ITU-T L.1200]: Information and communication equipment (e.g., switch, transmitter, router, server, and peripheral devices) used in telecommunication centres, data centres and customer premises.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 distributed power source: A local electrical power source where energy is produced close to the user and distributed by a microgrid by opposition to a centralized power plant with a long distance electricity transport grid. This local power source can be an individual user power system or a small collective energy power plant for a group of customers. It can include energy sources or storage or cogeneration of heat and electricity using any primary energy renewable or not.

3.2.2 renewable energy: This is mainly non-fossil fuel converted into electricity (e.g., solar energy, wind, water flow, biomass).

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

AC	Alternating Current
DC	Direct Current
EMC	Electromagnetic Compatibility
FC	Fuel Cell
ICT	Information and Communication Technology
IMD	Insulation Monitoring Device
MTTR	Mean Time To Repair
PDU	Power Distribution Unit
PSU	Power Supply Unit

PV	Photovoltaic
UPS	Uninterruptible Power Supply
VDC	Volts DC
VRLA	Valve-Regulated Lead Acid
WG	Wind Generator

5 Conventions

5.1 Earthing configurations

[IEC 60364-1] distinguishes three families of earthing arrangements, using the two-letter codes **TN**, **TT** and **IT**.

The first letter indicates the connection between earth and the power-supply equipment (generator or transformer):

"T" – Direct connection of a point with earth (Latin: terra).

"I" – No point is connected with earth (isolation), except perhaps via a high impedance.

The second letter indicates the connection between earth and the electrical device being supplied:

"T" – Direct connection of a point with earth.

"N" – Direct connection to neutral at the origin of installation, which is connected to the earth.

6 Configuration of power feeding systems of up to 400 VDC

A power feeding system of up to 400 VDC is part of a power feeding system. Figure 1 shows a typical configuration of a power feeding system in the end-to-end power chain. This figure provides a functional description of a power system without any redundancy.

The power feeding system of up to 400 VDC is powered by an AC supply (e.g., AC grid with AC backup generator) and feeds power to interface P. The power feeding system of up to 400 VDC consists of a rectifier, a battery, a PDU and power distribution lines.

The rectifier converts AC power to DC power and regulates DC voltage. It feeds power to interface P through a PDU. PSUs installed in the input of ICT equipment convert the power to operate loads, such as CPUs and peripherals in ICT equipment. The battery can be recharged in DC power by the same rectifier, which has the charging control functions. Distribution power lines connect the battery to the rectifier, the rectifier to the PDU and the PDU to interface P.

NOTE 1 – [b-ITU-T L.1001] adapters with the [ITU-T L.1200] DC power interface, quoted in clause 6.1 of [b-ITU-T L.1001], also enable the powering by the DC power feeding system of ICT terminal devices which require backup and may be used in telecommunication/data communication rooms and in a tertiary office, while avoiding having to install a small dedicated AC UPS for terminal devices.

NOTE 2 – The output of AC power supply should be compliant with the specification of the input of the rectifiers in terms of voltage, current, frequency, etc.

This clause presents several configurations of power feeding systems of up to 400 VDC with regard to reliability, safety and manageability.

System configuration should be chosen in consideration of user requirements and the features of the system configuration. The main items to consider for the 'up to 400 VDC' power system configuration choice are as follows:

– reliability and unavailability requirements;

– delay for intervention;

– simplicity of maintenance and the skill of maintenance staff: without or with voltage (hot plug);
– redundancy level inside ICT equipment.

NOTE 3 – Reliability, unavailability and efficiency performance assessment will be defined in a future Recommendation.

NOTE 4 – The AC grid, the AC backup generator (e.g., diesel generator, gas turbine generator) and the PSU in ICT equipment are out of the scope of this Recommendation. Power feeding systems of up to 400 VDC with renewable energy or distributed power sources are also out of the scope of this Recommendation. However, systems with renewable energy or distributed power sources are described in Appendix V.

NOTE 5 – There are several possible architectures for the AC power supply. In a large centre, there can be AC backup generators, while in a small centre, the AC backup generator is not necessary when there is sufficient battery-operating time (discharge time).

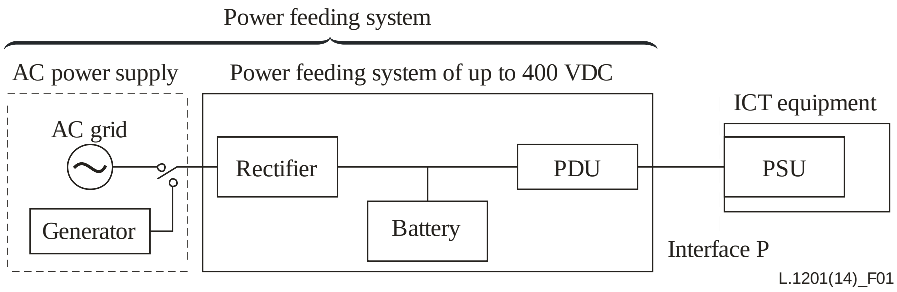

Figure 1 – Typical power feeding system configuration integrating a power feeding system of up to 400 VDC

6.1 Basic single DC power feeding system configuration

The simplest configuration of an 'up to 400 VDC' power feeding system shown in Figure 2 includes only the following main elements: rectifier, PDU and distribution power lines. This system is more cost-effective than other configurations. However, there are neither backup AC or DC power sources nor any redundancy. Therefore, this power feeding system of up to 400 VDC is not able to feed power to devices such as CPUs and peripherals in case of electrical outage of the AC grid, failure of one element of the power feeding system (rectifier, PSU, distribution power lines), or failure of the PSU.

Figure 2 – Simplest system configuration of up to 400 VDC power feeding

6.2 Power feeding system of up to 400 VDC with backup solution

In order to provide power to interface P without interruption due to electrical outages of the AC grid or the failure of a rectifier, the power feeding system of up to 400 VDC can integrate a battery, and it can be fed by an AC power supply with a backup power source such as a generator.

Figure 3 shows the power feeding system of up to 400 VDC with a battery and an AC backup generator.

NOTE 1 – The AC power supply can be ensured by AC power source (the AC grid and an AC backup generator). The AC power source can be in a single or redundant configuration depending on the required level of power availability. The rectifier can be powered from multiple AC grid distribution paths in case of failure of one of the AC grid distribution paths. The same is possible from the AC backup generator.

The batteries provide power to interface P instead of the rectifier in case of failure of the rectifier or AC power supply interruption. The battery can be configured with redundancy. The battery redundancy is obtained by two or more strings. The battery redundancy allows a partial tolerance to battery fault i.e., a battery string can fail in an open circuit without losing its backup ability but battery-operating time (discharge time) is reduced. This also allows for battery maintenance without completely losing its backup function during a battery cell or battery string replacement.

In cases where an AC backup generator is installed, the length of battery-operating time is less critical. However, a battery's main mission is to provide power during the starting time of the AC backup generator. Therefore, when an AC backup generator is installed, batteries should be also installed.

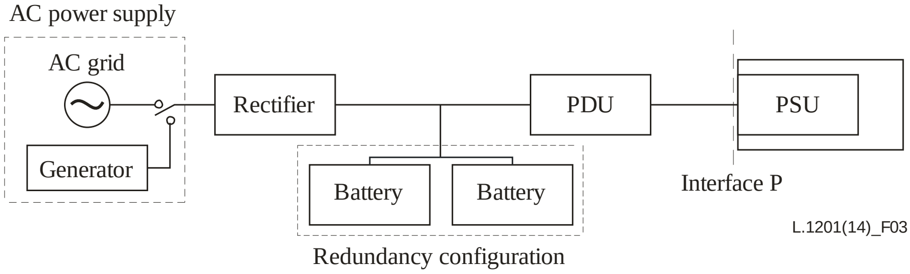

Figure 3 – Power feeding system of up to 400 VDC with backup solution

NOTE 2 – It is also possible to have a DC backup generator coupled at the DC power chain at the output of a rectifier.

NOTE 3 – Other configurations can improve the availability such as:

– A connection arrangement for an external emergency mobile AC generator to power the site in case of AC power supply problems (e.g., due to long duration AC grid maintenance by the electricity supplier or due to common mode failures of the AC grid and local AC backup generator).

– A connection arrangement of a DC backup generator directly to the DC power chain on the DC bus which is useful in case of failure of the AC power path to the rectifier's input (e.g., due to fire in the AC distribution).

6.3 Redundant DC power feeding configurations

In order to provide power to interface P without interruption due to the failure of a rectifier, PDU, or PSU, rectifiers, PDUs, and PSUs can be configured with redundancy. Depending on the importance of the ICT equipment or the operator's strategy, there are several possible redundant configurations for power feeding systems of up to 400 VDC.

All these configurations can be without a battery, or with single or multiple battery strings. The double string battery is described in clause 6.2.

In all the following configurations, the AC input power comes from single or redundant AC sources (e.g., AC grid alone or AC grid with AC backup generator). In Figures 4 to 9, the AC power source of the power feeding system of up to 400 VDC is named as the AC power supply shown in Figure 1.

6.3.1 Different levels of redundancy for single ICT equipment input

Figure 4 shows a power feeding system of up to 400 VDC with redundant rectifiers. The configuration keeps feeding power to interface P in case of a failure of one rectifier. This configuration can tolerate one rectifier failure, without altering the power feeding mission and without battery discharge.

NOTE – For big systems, there can be a set of rectifiers in several cabinets working in parallel on the same output DC bus.

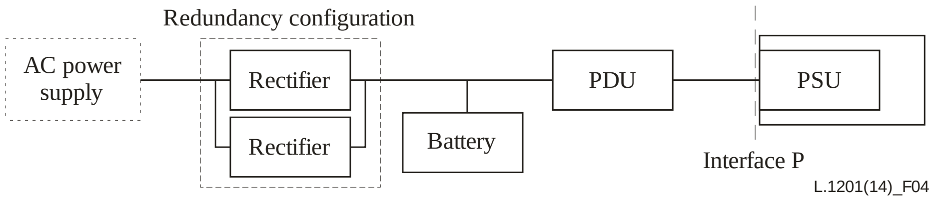

Figure 4 – Example of a system configuration with redundant rectifiers

6.3.2 Different level of redundancy for redundant ICT equipment input

In order to provide power to devices such as CPUs and peripherals without interruption due to failures of the PSU in ICT equipment, PSUs can be configured with redundancy for greater reliability. A power feeding system of up to 400 VDC has separated DC power distribution paths to provide power to each PSU.

NOTE – If the operation and maintenance skill level is low, a double power chain enabling the off and out of voltage maintenance would be preferred.

6.3.2.1 Target system configurations

Figures 5 to 8 show various kinds of configurations of power feeding systems of up to 400 VDC for the redundant input of ICT equipment.

NOTE – In all the following configurations, the rectifier can be redundant.

In Figure 5, only the final distribution is redundant.

For tolerance of one distribution fault in one single PDU, a double distribution and PSU redundancy is required.

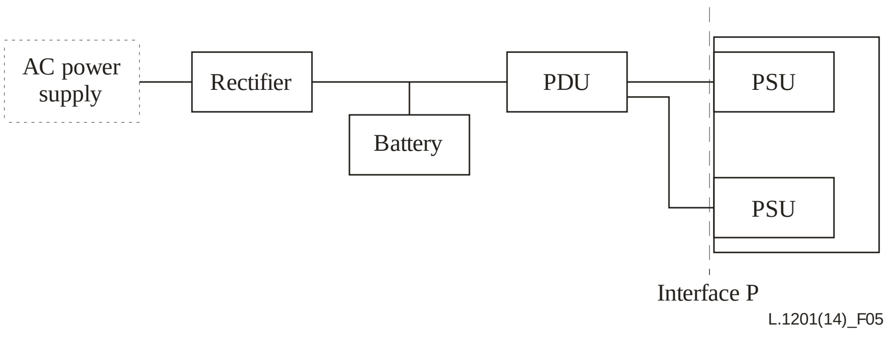

Figure 5 – System configuration with the redundant input of ICT equipment

In Figure 6, the PDU is redundant. For tolerance of one PDU fault, redundancy is required for the PDU. Redundancy of the PDU is also useful to reduce voltage change of interface P caused by a short circuit (see clause 6.3.2). There is still redundancy of the distribution and PSU.

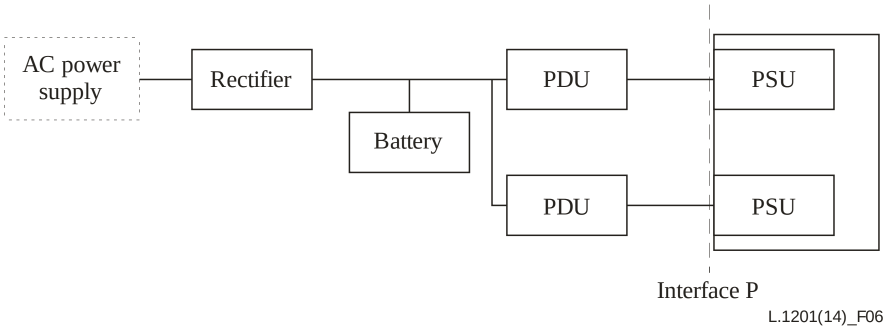

Figure 6 – System configuration with redundant PDUs for the redundant input of ICT equipment

In Figure 7, the rectifier and DC distribution are redundant. For the tolerance of a one fault DC power chain (i.e., both a rectifier and a battery fail simultaneously), a double DC power chain would be preferred.

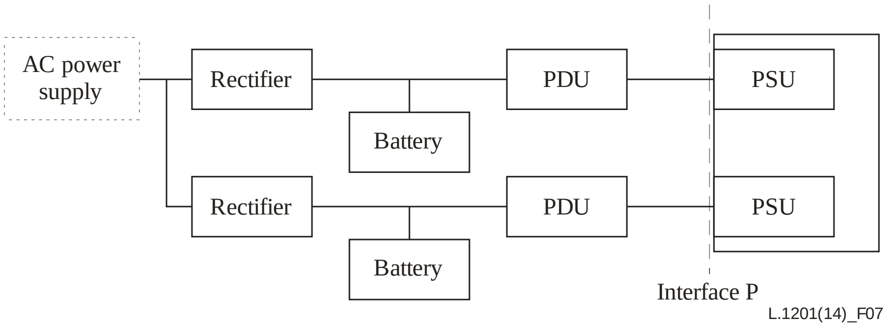

Figure 7 – System configuration with redundant rectifiers and DC distributions for the redundant input of ICT equipment

In Figure 8, there are end-to-end redundancies of power feeding systems. For the tolerance of long-term failure of one AC power supply, end-to-end redundancies of power feeding systems are preferred.

Mainly in this highly reliable configuration, the AC power supply can have both AC grid redundancy and AC backup generator redundancy.

This system configuration is the most reliable of these system configurations.

It can even provide power to interface P, though both a rectifier and a PDU can fail simultaneously on one path. In addition, this system is more tolerant to power line failure compared to redundant elements in a single power chain system as shown in Figures 7 and 8.

NOTE – By using an emergency switch to exchange AC paths on the input of each DC power chain, a redundant AC distribution path can improve availability.

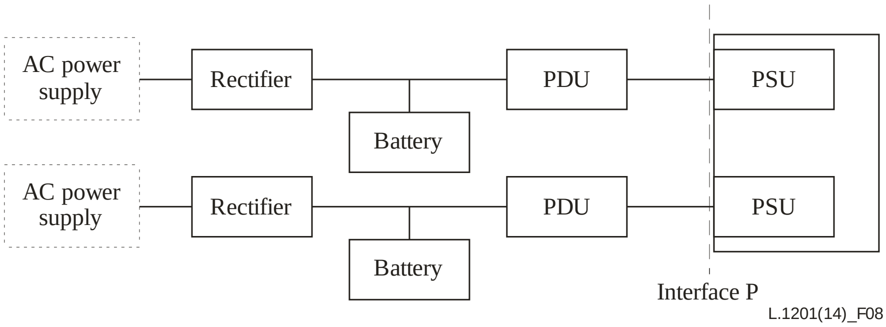

Figure 8 – System configuration with end-to-end redundancies of power feeding systems for the redundant inputs of ICT equipment

6.3.2.2 Transitional system configuration

When there are redundant PSUs on ICT equipment, asymmetric power chain configurations are possible e.g., the AC grid could power most of the time a redundant power chain, while the AC backup could power the ICT by a single power. AC and DC power feeding system configuration for redundant inputs of ICT equipment is shown in Figure 9. This configuration is for transitional solutions, in some regions only.

NOTE – There can be AC uninterruptible power supply (AC-UPS) for greater reliability.

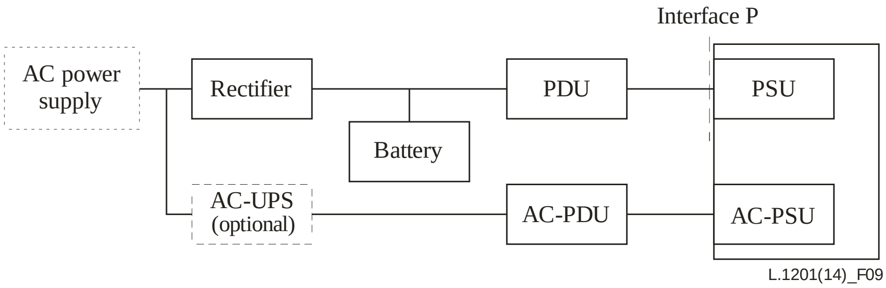

Figure 9 – AC and 'up to 400 VDC' power feeding system configuration for redundant inputs of ICT equipment

7 Elements of power feeding systems of up to 400 VDC

This clause presents requirements for the main elements of power feeding systems of up to 400 VDC.

7.1 General requirements

7.1.1 Safety

Every element of a power feeding system of up to 400 VDC shall comply with [IEC 60364-1].

To maintain safety and high reliability, earthing and bonding configuration is important. The earthing and bonding configuration affects safety requirements of every element. Earthing and bonding method shall be chosen in consideration of safety, system operation, and skill level of accessible people.

Useful information of the earthing and bonding configurations for ICT equipment of 'up to 400 VDC' power feeding system is provided in [EN 301 605].

An IT system with earthed high-ohmic mid-point terminal should be chosen for maximizing safety. In [EN 301 605], it is described as the preferable configuration.

NOTE – The general safety issues are also described in [EN 301 605].

7.1.2 EMC

Every element of a power feeding system of up to 400 VDC should comply with applicable EMC standards.

NOTE – There are many EMC standards applicable. Normally, emission requirements are described in [b-CISPR 22], and immunity requirements are described in [b-CISPR 24] and [b-ITU-T K.74]. The transition from [b-CISPR 22] to [b-CISPR 32] should be respected. National regulations override the content of this Recommendation.

7.1.3 Resistibility

Resistibility tests and levels are given in [ITU-T K.44] and [ITU-T K.21]. The system resistibility requirements shall be in line with the basic test level.

Where the basic resistibility requirements are not sufficient due to environmental conditions, national regulations, economic and technical considerations, installation standards or grade of service requirements, network operators may request the enhanced or special resistibility requirements.

Guidance on the applicability of enhanced test levels and special levels is given in [ITU-T K.85].

7.2 Rectifier requirements

7.2.1 Rectifier configuration

The rectifier function may consist of rectifier units. These units are commonly modular and hot-plug capable for simplifying maintenance and reducing repair time.

There are various rectifier configurations. Figure 10 shows a basic configuration with direct connection of a battery to the DC system. This configuration is simple and the mostly used. Other configurations are possible to reduce the voltage range and improve PSU efficiency but care is necessary for reliability. They are described in Appendix IV in detail.

A rectifier configuration should be chosen in consideration of configuration features.

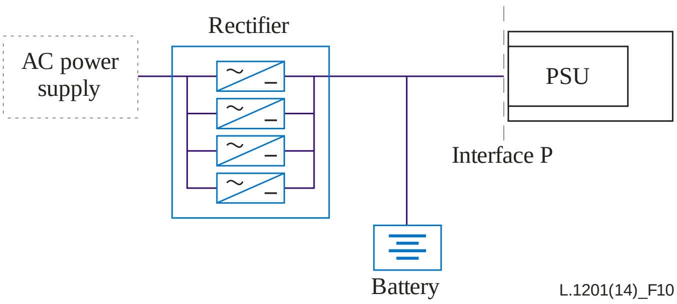

Figure 10 – Basic configuration of rectifier

7.2.2 Rectifier electrical characteristic

The output voltage range of rectifiers should be adapted to interface P of [ITU-T L.1200].

In case of a failure in a rectifier unit in a rectifier cabinet, each rectifier unit should be able to operate and maintain safe operation and reliability.

A rectifier shall be isolated between the AC input and the DC output unless there is an isolation transformer, which isolates other earthing-configuration systems, upstream of the rectifiers.

NOTE – If a rectifier is not isolated between the AC input and DC output, electrical potential of DC positive and negative lines are influenced by lines of the AC system. For example, when an earthing system of an AC system is a TT or TN system, a distribution power line of up to 400 VDC power feeding system may be also directly connected to the earth of the AC system. To ensure the IT system of a DC power feeding system, it is recommended to check expected failure current patterns. (e.g., DC ground fault current flows through the ground line, grounded transformer and non-isolated rectifier).

7.3 Power distribution unit (PDU) requirements

The PDU contains protection devices such as fuses or breakers against a current fault. Protection devices protect power distribution lines and ICT equipment from overcurrent problems. In addition, protection devices are required for voltage change at other power interfaces "P" which are within the range specified in [ITU-T L.1200], while overcurrent protection is ensured by the protection devices.

7.3.1 PDU configuration

A PDU can be configured in a multi-level way as illustrated in Figure 11. The main PDU provides power to several secondary PDUs. Secondary PDUs provide power to small-sized PDUs in a server rack. A PDU at each level of the power chain may have a different level of power capacity, volume, protection and reliability.

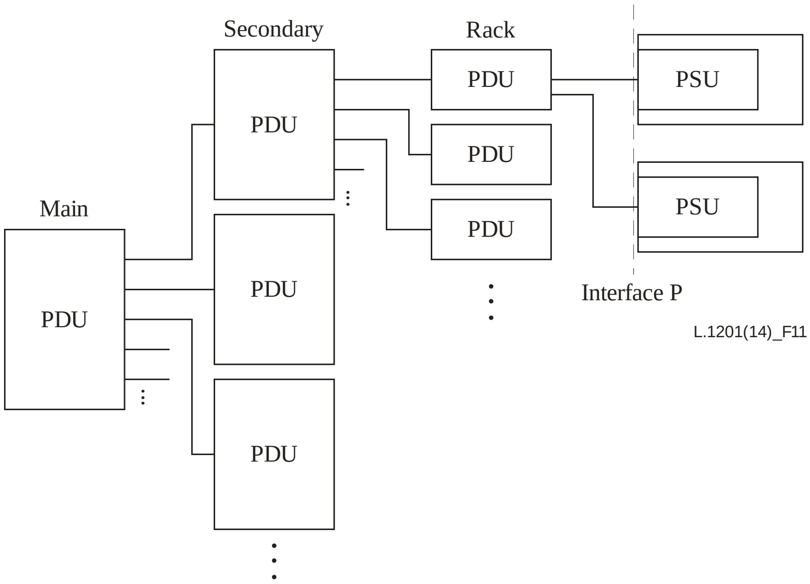

Figure 11 – Example configuration of a multi-level PDU

7.3.2 Protection device in PDU

Protection devices should be in series with the output power distribution lines of the PDU. The line circuit protection type (protection of the positive line only, of the negative line only, or of both lines) shall be determined by the earthing configuration.

NOTE 1 – If the earthing configuration is the IT system, the protection devices should be in both the positive and negative lines.

The rated voltage of the protection devices shall match the DC voltage range specified in [ITU-T L.1200]. Protection devices should meet the requirements for the capacity of different loads. If multi-level PDU configuration is used, protection coordination should be taken into consideration for high reliability.

When there is a short circuit and a current interruption occurs, the voltage at interface P changes as described in Appendix G of [b-ETSI EN 300 132-3-1].

Therefore, protective devices should make the voltage at the interface P of other equipment be within the ranges specified in [ITU-T L.1200], when the protection devices interrupt the overcurrent circuit.

NOTE 2 – The overvoltage would be affected by cable wiring and other causes. Therefore, it is important to consider system configurations when protection devices are evaluated. In Appendix G of [b-ETSI EN 300 132-3-1], overvoltage conditions are analysed in detail.

7.4 Battery requirements

7.4.1 Battery configurations

A battery consists of a group of battery strings in parallel.

A battery string is a serial connection of battery cells (a basic electrochemical unit, which account for the nominal voltage of the battery). The number of battery cells in a battery string, which account for the nominal voltage of the battery, is the required number of cells to support the given voltage applied to interface P.

Battery strings in parallel are effective for providing the appropriate capacity to loads for backing up the repair time of failed elements and for providing redundancy for greater reliability.

The required battery-operating time (discharge time) depends on standby applications. The practical number of battery cells should be determined by taking into account the battery-operating time loss, life expectancy, operation temperature, manufacturer's specification, and so on.

For battery sizing it is necessary to consider the output voltage of a rectifier, as well as the battery-operating time.

NOTE 1 – As a principle, the number of battery cells can be calculated by dividing the rated operating voltage by the floating voltage, e.g., 380/2.26 = 168 cells of 2 V VRLA battery; this corresponds for example to 28 battery blocks of 12 V.

NOTE 2 – Battery size depends on cell types, charge and discharge voltage, battery cell quantity, battery-operation discharge time, operating temperature, and so on.

NOTE 3 – There is a possibility of having dual storage technology (lead acid for long-term battery-operating time, lithium or super capacitor or flywheel for power), but further research is required as it may not be developed enough to have received enough feedback on its safety and operation.

7.4.2 Battery lifespan and characteristic

The performance and lifespan of battery cells are dependent on the operating temperature, operating voltage, battery technologies, and so on. The temperature change can affect battery performance depending on battery technology. If the temperature under the operating conditions largely affects battery performance, it may be required to use charging techniques which can correct the influence of temperature on the floating and end of charge voltage.

NOTE 1 – Some battery technologies have a wide temperature window for operation with respect to the lead acid battery technology such as valve-regulated lead acid (VRLA) battery technology, which implies that the battery performance and lifespan are less affected by the operating temperature.

NOTE 2 – In normal battery operation using VRLA technologies: The battery has self-discharged and is continuously recharged by a rectifier to keep its float voltage. The float voltage of a battery could be insufficient to maintain a full charge and an imbalance of the float voltage among battery cells could occur. In order to increase the health of the battery and keep the desired float voltage, regular equalization of the battery charge (i.e., a higher voltage applied to the battery) is recommended for some batteries; they have a large difference of float voltage due to their characteristics. The function of limiting the charge current is required and charge current limitation should not be affected by the load when the rectifier charges the battery.

NOTE 3 – There may be other requirements for the battery. Battery cells in a battery string should be identical with regard to capacity, voltage, type and manufacture. A better matching of technology and capacity of the battery cells avoids imbalance issues due to the difference in impedance. The same consideration applies to battery strings in a parallel arrangement. Some manufacturers allow using the same battery string types even if they are of different ages; this can be useful for partial replacement, string by string at the end of life.

7.5 Distribution power line requirements

Distribution power lines connect the battery to the rectifier, the rectifier to the PDU and the PDU to the PSU. The distribution power lines may be single wires, cables, bus-bars.

The distribution power lines are quite important in power feeding systems. In addition, the selection of line protection devices would be dependent on the area of a cross-section of conductor and allowable current. Therefore, specifications described in [IEC 603 641] shall be referred to, specifically section 132.6 "Cross-sectional area of conductors" and section 132.7 "Type of wiring and methods of installation". The length and the cross-sectional area of distribution power lines would also be considered as to how they affect the voltage drop between the battery and interface P.

Both the positive power line and negative power lines of the 'up to 400 VDC' systems should be distinguished with power lines of –48V DC systems and AC system power.

8 Monitoring power feeding systems of up to 400 VDC

In order to detect occurrences of abnormal conditions, such as low-voltage and overvoltage, over-temperature, insulation or ground faults, power feeding system conditions should be monitored and managed. In addition, a monitoring function is effective for discovering potential failures before they occur. Monitoring functions are also the key operational role for maintaining the best performance.

8.1 Configuration for monitoring

The configuration of a power feeding system of up to 400 VDC with monitoring systems and monitoring entities is illustrated in Figure 12. In cases where an IT system is used for reasons of continuity, an insulation monitoring device (IMD) shall be provided to indicate the occurrence of a fault from a live part to exposed-conductive-parts or to earth.

Performance-related parameters of monitoring entities should be regularly measured. An abnormal state of the entities, which may be a signal of failure should be reported to the operators of the power feeding systems of up to 400 VDC. The local monitoring system should analyse the measured data and alarms to discover potential failures before they occur. Criteria to issue a failure based on the analysis of measured data and alarms should be managed. They may be dependent on the manufacturer's specification. These actions can be performed automatically by the monitoring system or manually by a person after reporting it to the remote monitoring system. When a failure occurs in monitoring entities before an alarm signals, the failed entity should be automatically replaced with backup power sources such as a generator or a battery without interruption. After replacing the failed elements with the backup elements, the entity should be fixed or replaced with a new entity by separating it from the power feeding system. Abnormal states should be reported to the remote monitoring system.

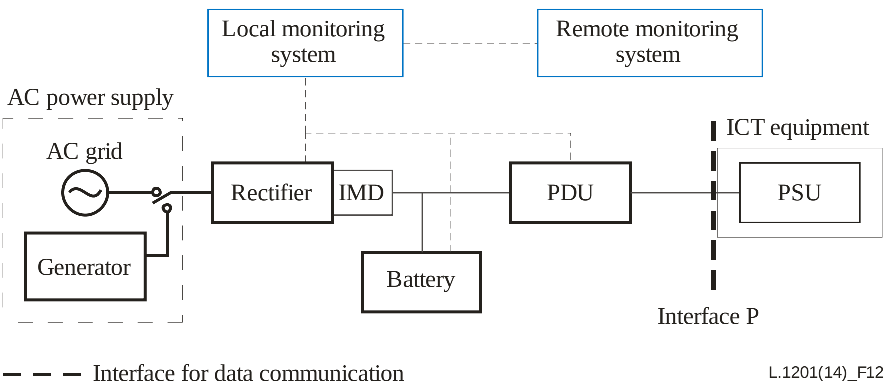

Figure 12 – Monitoring entities in a typical power feeding system of up to 400 VDC

NOTE 1 – An AC grid and AC backup generator are out of the scope of this Recommendation. However, the AC source such as a generator should be also monitored.

NOTE 2 – IMD is specified in [b-IEC 61557-8].

8.2 Elements for monitoring

8.2.1 Rectifier

The rectifier information can be provided by the rectifier cabinet.

The following items should be measured: AC input voltage (option), DC output voltage and rectifier module output current. It should also remotely signal the following items; abnormal input (out of range input voltage can be signalled by logic states), the state of the rectifier module (on/off state, limiting output capacity or not), and normal/abnormal condition.

If an IMD is provided, it shall initiate an audible and/or visual signal which shall continue as long as the fault persists. [IEC60364-4-41].

8.2.2 PDU

The following items should be measured; the state (e.g., on/off state, faults) of the protection device, which is mainly required for PDUs powering critical equipment, and output voltage and output current (optional).

8.2.3 Battery

It is recommended that battery performance such as output voltage and output current are monitored.

In order to check the health of the battery, the following battery parameters should be monitored: battery voltage, charging and discharging battery current, equalizing/floating/testing charge mode, and possibly internal impedance, e.g., resistance.

If overvoltage or under-voltage occurs, the battery should signal the event. If there is a battery fuse, the battery also signals the state of the battery fuse.

NOTE – The internal resistance, impedance or conductance measurement of the batteries or cells connected on the DC power feeding system may provide additional information on the health of the battery. These signs of the battery or cells ageing are still under research. For example, the internal resistance of battery increases due to deteriorated internal conductance paths. During discharge, the increased internal resistance causes the old battery to reach the end of the discharge voltage quicker than a new battery.

8.3 Management interface and network

Measured data, which contains states and operating conditions of management entities, should be delivered to the local monitoring system without loss or errors. In order to deliver measured data and alarms generated at sensors on monitoring entities to the local monitoring system, a communication interface should be provided between sensors and the local monitoring system. The local monitoring system should have an interface with the remote monitoring system for reporting the measured and analysed data in real time. A requirement of the interface between the local monitoring system and the remote monitoring system is similar to a requirement of the interface between sensors and the local monitoring system.

Some parts of a series of ETSI standards, [ETSI ES 202 336-x] and [ETSI ES 202 336-1] should be used for the monitoring and control of the elements of the power feeding system.

NOTE – In these standards, the protocol is TCP/IP, http > V1.1 and data for monitoring and control are exchanged using XML language, while the procedure is based on a simplified command of REST: get and post.

Appendix I

Example of monitoring data of DC power system

(This appendix does not form an integral part of this Recommendation.)

This appendix presents a table giving an example of data gathered from monitoring entities. There are five monitoring entities. 'Monitoring information' specifies the state of the monitoring entities including the abnormal state and the state of failure. In 'Monitoring Type', data implies regularly measured data for maintenance in normal operation. Alarm implies an abnormal state of the entities that require a protective action against failures or malfunctions of the entities. Some alarms require direct manipulation of the system before notifying this to the performance manager because this implies that a failure has occurred, such as a failure of the AC mains supply or rectifier. 'Collection period' is a recommended duration for collecting data but it can be varied depending on the environment and importance of the management entities. Besides the listed information, there will be additional data and alarms to be collected depending on the features and specifications of monitoring entities and a manufacturer's requirement.

Table I.1 – Measurement parameters and monitored information

Monitoring entity	Monitoring information	Monitoring Type	Collection period
AC mains supply	Output voltage	Data	Regularly
	Output current	Data	Regularly
	Circuit breaker state	Alarm	Immediately
	Failure of AC mains supply	Alarm	Immediately
Generator	Fuel gauge (remained diesel volume)	Data	Regularly
	Under threshold of fuel	Alarm	Immediately
	Failure of generator	Alarm	Immediately
Rectifier	Output voltage	Data	Regularly
	Output current	Data	Regularly
	Failure of rectifier	Alarm	Immediately
Battery	Full charge, end-discharge voltage	Data	After operation
	Voltage (cell, cell module, battery)	Data	Regularly
	Over/under threshold voltage	Alarm	Immediately
	Full charge, end-discharge current	Data	After operation
	Current (cell, cell module, battery)	Data	Regularly
	Over threshold current	Alarm	Immediately
	Cell temperature	Data	Regularly
	Over/under threshold cell temperature	Alarm	Immediately
	Resistance (internal cell, inter-cell)	Data	Regularly
	Electrolyte level	Data	Regularly
	Cycle of discharge/charge	Data	After operation
	Battery fuse state	Alarm	Immediately

Table I.1 – Measurement parameters and monitored information

Monitoring entity	Monitoring information	Monitoring Type	Collection period
PDU	Output voltage	Data	Regularly
	Output current	Data	Regularly
	Over/under threshold voltage/current	Alarm	Immediately
	Protection device state	Alarm	Immediately

Appendix II

Battery performance monitoring and management

(This appendix does not form an integral part of this Recommendation.)

The state of a battery's health is regularly monitored to maintain the best operating condition of the battery. A performance monitoring and management system consists of sensors to gather battery state information, a manager to check the health of the battery, and a controller to ensure that battery operation is in the best condition. Figure II.1 shows a battery configuration with a monitoring and controlling system in a DC power feeding system. The measured data is cell/battery and ambient temperature, cell/battery voltage and current (float, discharge/charge, ripple), the number of cycles of discharge and recharge, the depth of discharge per cycle, resistance (internal, interconnection between cells/strings), and so on. The data should be stored and regularly analysed to discover whether there are any abnormal conditions or undesired states of the battery, before the battery fails. Based on the information gathered, the performance manager produces useful information to operate the battery in its best environment and it determines the expected lifespan of the battery and when it should be replaced.

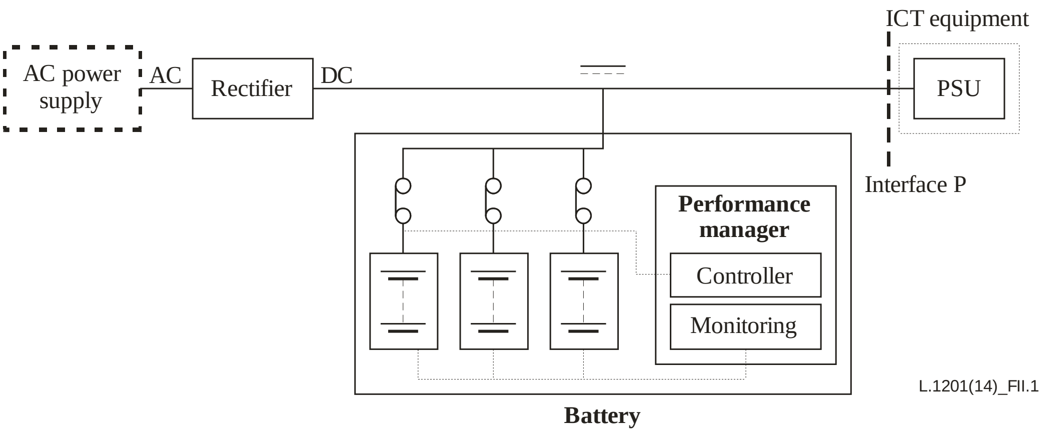

Figure II.1 – Battery configuration with performance manager

Appendix III

Power distribution unit configuration

(This appendix does not form an integral part of this Recommendation.)

Figure III.1 shows the three-level distribution structure: DC output total distribution panel + DC distribution panel + distribution array cabinet in the larger capacity power supply system.

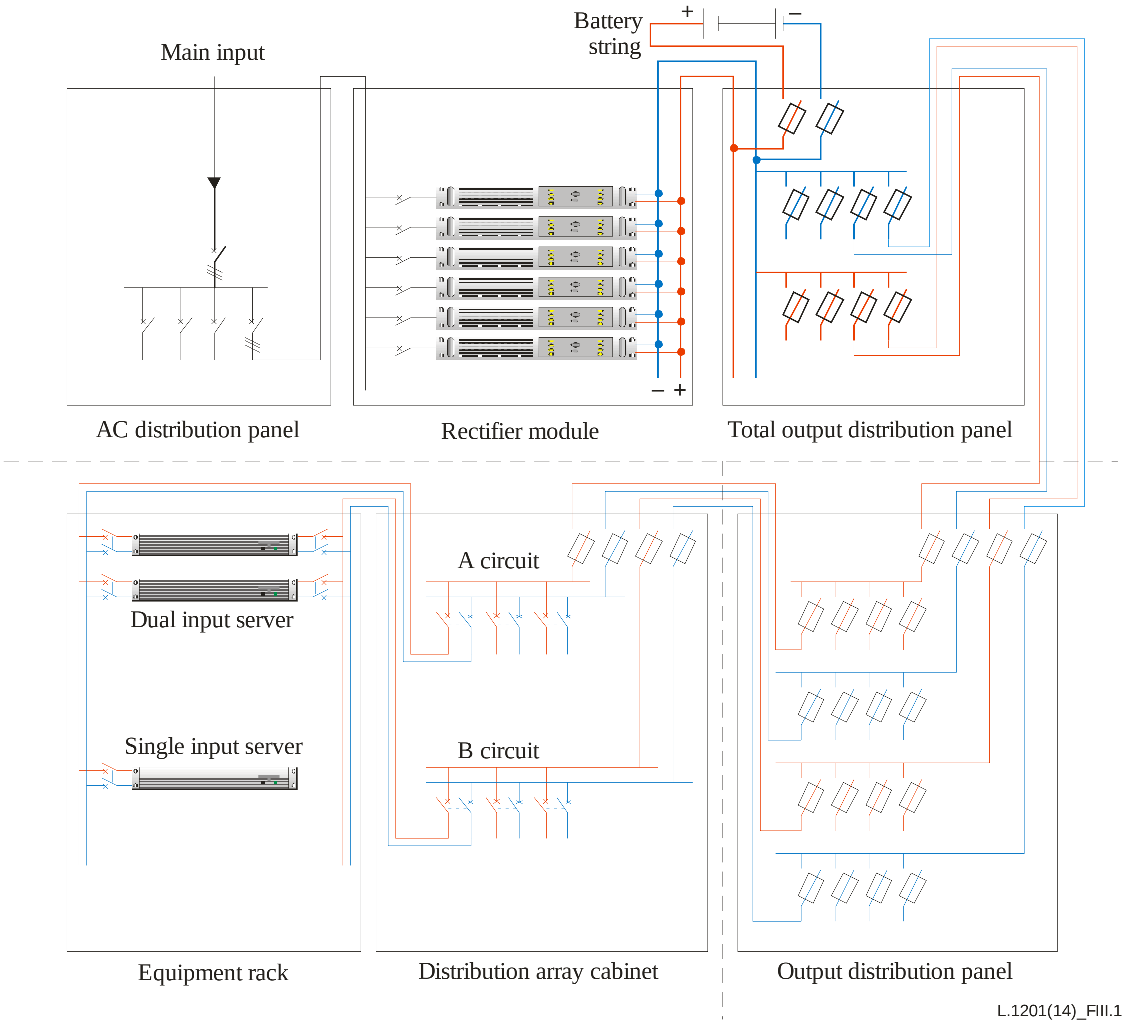

Figure III.1 – Three-level distribution structure

Figure III.2 shows the two-level distribution structure: DC output total distribution panel and distribution array cabinet.

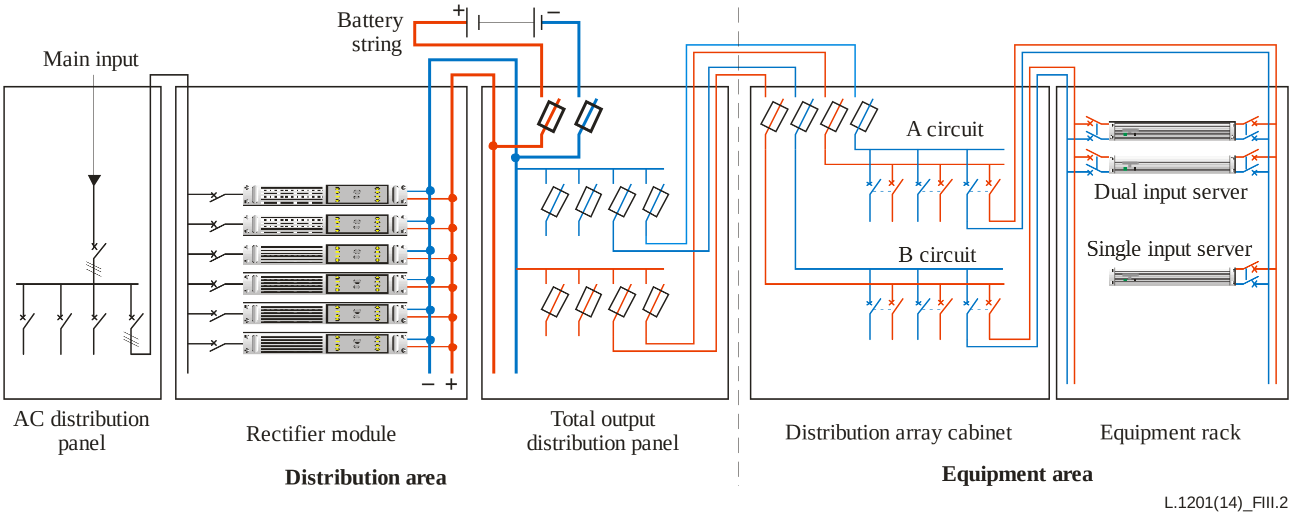

Figure III.2 – Two-level distribution structure

Appendix IV

Alternative rectifier configuration

(This appendix does not form an integral part of this Recommendation.)

This appendix describes some possible configurations of rectifiers:

The basic configuration of rectifiers is shown in Figure 10. It is the most reliable because it is simpler than any other configuration. There are no diodes, chargers and boosters and there is a redundancy of the charger function. However, the drawback is that after a battery discharge, the DC voltage determined by the battery voltage is much lower than the battery floating voltage which results in a higher current at constant power ICT load (common case). This higher current flowing through PDUs and power distribution lines is impacting the design by increasing the cross-sectional area of distribution power lines and rated current of protection devices, in order to reduce the voltage drop and generated heat in this low voltage operation condition.

Figure IV.1 shows other configurations of the rectifier. The features of the configurations are as follows:

(a) Configuration with charger, diode and battery

This configuration rapidly provides the system with a nominal output voltage after battery discharge of the battery. In addition to this, most of the rectifier units separated by a diode from the battery do not need to have a battery charger function. Only the rectifier unit connected to the battery need to have a battery charger function. Redundancy of the charger is better for high reliability.

(b) Configuration with charger, diode, battery and booster

This configuration includes an additional booster compared to configuration (a). It allows a narrower operational voltage of the rectifiers, even if the battery is discharged. Therefore, in the case of the same capacity, power distribution lines between the rectifier and PSU can be sized with a smaller cross-sectional area than the basic configuration and configuration (a). Redundancy of the booster is better for high reliability.

In the double DC power chain, alternative configurations (a) and (b) would be even less critical.

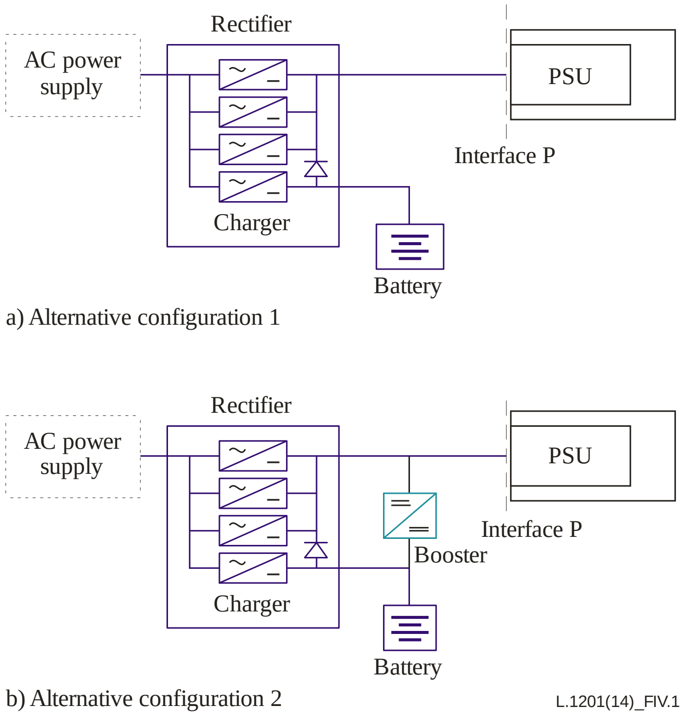

Figure IV.1 – Configurations of the rectifier/battery system

Appendix V

Configuration of power feeding systems of up to 400 VDC with renewable energy and distributed power sources

(This appendix does not form an integral part of this Recommendation.)

This appendix describes the possible interconnection of renewable energy (e.g., photovoltaic (PV) and wind generator (WG)) and distributed power sources (e.g., fuel cell (FC)) with up to 400-VDC power feeding systems.

To reduce CO_2 emissions and dependency on the AC grid, renewable energy and distributed power sources can be applied for power feeding systems of up to 400 VDC. PV and other green energy sources are elements that have grown from such basic power systems.

There are several possibilities to interconnect renewable energy and distributed power sources with a power feeding system of up to 400 VDC powered by the AC grid.

Figure V.1 shows renewable energy and distributed power sources connected directly in DC to a power feeding system of up to 400 VDC. The DC and AC power sources power the power feeding system of up to 400 VDC through a DC/DC or an AC/DC converter that adjusts the output of the power source to the input specification of the PDU. The DC/DC and the AC/DC converters should include the battery charging function in coordination with the rectifier.

When many power sources are connected to a DC power feeding system, it is important to monitor voltage stability, stray currents and current flows for the various operation modes (e.g., battery charge/discharge operation, rectifier start-up operation). It is recommended to consider lighting protection because some generators such as PV and WG are installed outside.

NOTE – Though this is not depicted in Figure V.1, the AC backup generator (generally a diesel generator) could be connected in a DC system via a rectifier to the battery without the need of the AC switch gear.

One advantage of this solution is that connecting the generators in DC without AC switch gears is a very direct backup by the renewable energy and distributed power sources in a DC power feeding system which could be much more reliable and have a much shorter mean time to repair (MTTR), by avoiding failure and delicate maintenance of the AC switch gear and AC system. This solution is efficient because there is only one conversion stage between a renewable energy source and the power feeding system of up to 400 VDC.

This solution is worthwhile as most of the energy produced by the ICT equipment operating with DC power is self-consumed and because the produced energy cannot be sold with this configuration. It is applicable to redundant DC systems.

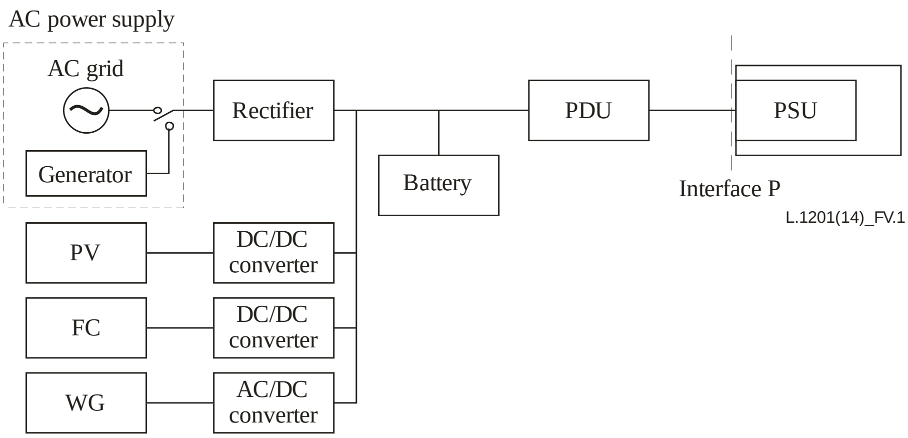

Figure V.1 – Direct connection in DC of PV, FC or WG generators to a DC power feeding

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