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Extended architecture of power feeding systems of up to 400 VDC

Recommendation ITU-T L.1204

ITU-T L-SERIES RECOMMENDATIONS

ENVIRONMENT AND ICTS, CLIMATE CHANGE, E-WASTE, ENERGY EFFICIENCY; CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF OUTSIDE PLANT

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Recommendation ITU-T L.1204

Extended architecture of power feeding systems of up to 400 VDC

Summary

Recommendation ITU-T L.1204 describes the extended architecture of power feeding systems of up to 400 V direct current (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. This Recommendation can be used also as an architecture reference model for future Recommendations e.g., on the performance of DC power feeding systems.

This Recommendation describes extended power feeding architectures using up to 400 VDC e.g., hybrid redundant DC and alternating current (AC) power feeding based on Recommendation ITU-T L.1201.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
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FOREWORD

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The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

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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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As of the date of approval of this Recommendation, ITU had not received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementers are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database at http://www.itu.int/ITU-T/ipr/.

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Introduction

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

The up to 400 VDC interface between the power feeding system and any information and communication technology (ICT) equipment connected to it is specified in [ITU-T L.1200]. This Recommendation specifies architectures 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 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 a −48 VDC power feeding system 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-CCSA YD/T 2378], [b-Tanaka, 2012], [b-Shuguang, 2012], [b-Marquet, 2013], and 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 alternating current uninterruptible power supply (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., in [b-Koomey, 2011].

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, 2004], [b-Han, 2007], [b-Tsumura, 2008], [b-Bauer, 2006] and [b-Liu, 2010].

Compared to a centralized −48 VDC architecture, a reduction of 10% to 50% in copper usage has been precisely recorded, while for a decentralized −48 VDC architecture, a reduction of 60% in battery sizes was reached [b-Tanaka, 2012].

Many studies show that there is a reduction in the initial set-up costs that can be as high as 20%, and a reduction in the running costs where savings could come from making fewer site interventions and trips. Also, there is, in general, less maintenance with modular rectifiers because the system is easier to operate with ICT equipment working 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.).

Due to the urgency to find a solution to the growing power problem, it is believed that interim solutions applicable in the short term could be considered. One of these is the use of up to 400 VDC only as means to transport energy from the 48 V energy system to the 48 V powered equipment. This could then evolve through the deployment of powered equipment able to be directly fed through an up to 400 VDC power feeding system.

For complementary information on power architectures specified in this Recommendation, it may be useful to refer to [b-ITU-T L.1300], [b-IEC 60896], [b-IEC TS 60479-1], [b-IEC 60950-1], [b-IEEE 1184], [b-IEEE 1491] and [b-ETSI TR 102 121].

Recommendation ITU-T L.1204

Extended 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 V direct current (VDC) at telecommunications centres, datacentres and customer premises [ITU-T L.1200]. This Recommendation aims to provide a reference of power feeding architecture 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 pure up to 400 VDC and hybrid power feeding systems with up to 400 VDC and alternating current (AC) power feeding systems;
2) requirements of the main basic elements for power feeding systems of up to 400 VDC, such as 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 [ETSI 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 (PSUs) in ICT equipment and renewable or distributed energy sources are outside of the scope of this Recommendation, but indications are given on their influence on the architecture of power feeding systems of up to 400 VDC.

This Recommendation describes extended power feeding architectures using up to 400 VDC e.g., hybrid redundant DC and alternating current (AC) power feeding based on [ITU-T L.1201].

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.20] Recommendation ITU-T K.20 (2016), *Resistibility of telecommunication equipment installed in a telecommunication centre to overvoltages and overcurrents*.

[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.*

[ITU-T L.1201] Recommendation ITU-T L.1201 (2014), *Architecture of power feeding systems of up to 400 VDC*

[ITU-T L.1202] Recommendation ITU-T L.1202 (2015), *Methodologies for evaluating the performance of an up to 400 VDC power feeding system and its environmental impact.*

[ITU-T L.1203]	Recommendation ITU-T L.1203 (2016), *Colour and marking identification of up to 400 VDC power distribution for information and communication technology systems.*
[ETSI EN 300 132-2]	ETSI EN 300 132-2 V2.4.16 (2016), *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), *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), *Environmental Engineering (EE); Monitoring and Control Interface for Infrastructure Equipment (Power, Cooling and Building Environment Systems used in Telecommunication Networks) Part 1: Generic Interface.*
[IEC 60364-1]	IEC 60364-1 (2005), *Low-voltage electrical installations – Part 1: Fundamental principles, assessment of general characteristics, definitions.*
[IEC 60364-4-41]	IEC 60364-4-41 (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 distributed power source [ITU-T L.1201]: 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.

3.1.2 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.

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

3.1.4 renewable energy [ITU-T L.1201]: This is mainly non-fossil fuel converted into electricity (e.g., solar energy, wind, water flow, biomass).

3.2 Terms defined in this Recommendation

None.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

AC Alternating Current

CPU Central Processing Unit

DC Direct Current

EMC Electromagnetic Compatibility

FC Fuel Cell

GHG	Greenhouse Gas
ICT	Information and Communication Technology
IMD	Insulation Monitoring Device
IP	Internet Protocol
MTTR	Mean Time To Repair
PDU	Power Distribution Unit
PSU	Power Supply Unit
PV	Photovoltaic
REST	Representational State Transfer
TCP	Transmission Control Protocol
UPS	Uninterruptible Power Supply
VRLA	Valve-Regulated Lead Acid
WG	Wind Generator

5 Conventions

The keywords "is required to" indicate a requirement which must be strictly followed and from which no deviation is permitted if conformance to this Recommendation is to be claimed.

The keywords "is recommended" indicate a requirement which is recommended but which is not absolutely required. Thus this requirement need not be present to claim conformance.

The keywords "is prohibited from" indicate a requirement which must be strictly followed and from which no deviation is permitted if conformance to this Recommendation is to be claimed.

The keywords "can optionally" indicate an optional requirement which is permissible, without implying any sense of being recommended. This term is not intended to imply that the vendor's implementation must provide the option and the feature can be optionally enabled by the network operator/service provider. Rather, it means the vendor may optionally provide the feature and still claim conformance with this Recommendation.

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 typical configuration of a power feeding system in the end-to-end power chain is shown in Figure 1, which 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 power distribution unit (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. Power supply units (PSUs) installed in the input of ICT equipment convert the power to operate loads, such as central processing units (CPUs) and peripherals in ICT equipment. The battery can be recharged using DC power by the same rectifier, which has charging control functions. Distribution power lines connect the battery to the rectifier, the rectifier to the PDU and the PDU to interface P.

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 taking into account user requirements and the features of the system configuration. The main items to consider in the choice of configuration for the up to 400 VDC power system are as follows:

– reliability and availability requirements;
– delay for intervention;
– simplicity of maintenance and the skill of maintenance staff: without or with voltage (hotplug);
– redundancy level inside ICT equipment.

NOTE 1 – [b-ITU-T L.1001] adapters with a DC power interface as defined in [ITU-T L.1200], also enabling ICT terminal devices powered by the DC power feeding system may be used in telecommunication or data communication rooms and in a tertiary office, even without a small dedicated AC UPS.

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

NOTE 3 – Reliability, availability and efficiency performance assessment are defined in [ITU-T L.1202].

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

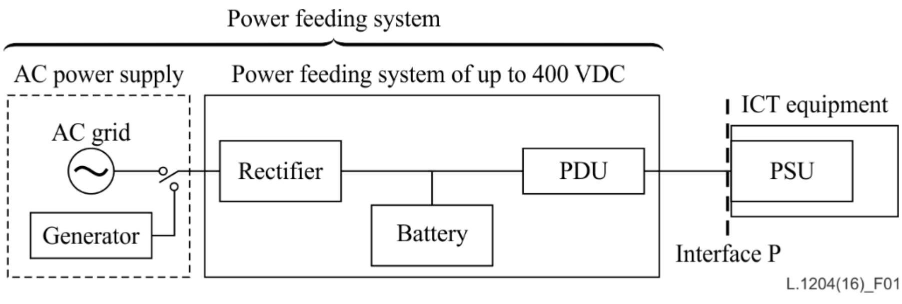

Figure 1 – Typical power feeding system configuration integrating a power feeding system of up to 400 VDC

6.1 Basic single DC power feeding system configuration

The simplest configuration of an up to 400 VDC power feeding system, as 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 the 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.

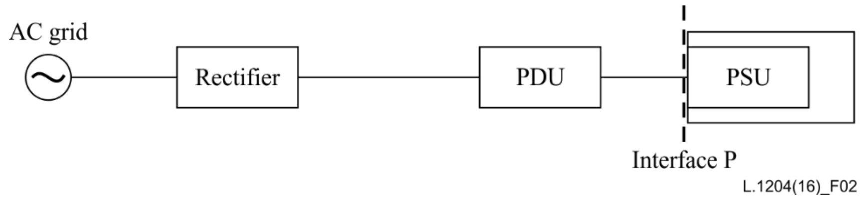

Figure 2 – Simplest system configuration of up to 400 VDC power feeding system

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.

The batteries provide power to interface P instead of the rectifier if the rectifier fails or the AC power supply is interrupted. The battery can be configured with redundancy that 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 complete loss of its backup function during a battery cell or battery string replacement.

If an AC backup generator is installed, the length of the battery-operating time is less critical. However, a battery's main function is to provide power during the starting time of the AC backup generator. Therefore, on installation of an AC backup generator, batteries should be also installed.

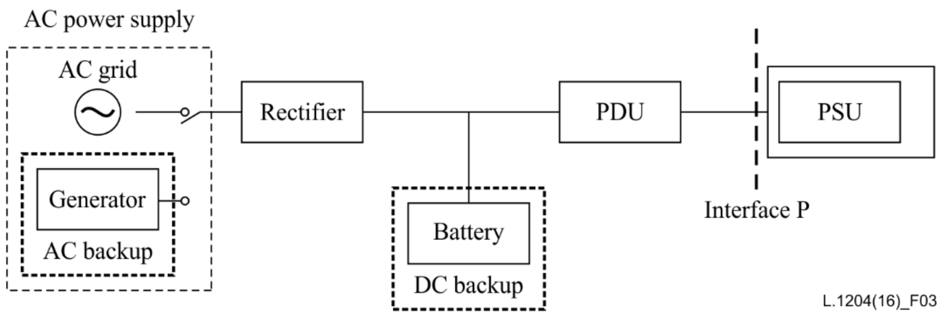

Figure 3 – Power feeding system of up to 400 VDC with backup solution

NOTE 1 – The AC power supply can be ensured by an 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 if one of the AC grid distribution paths fails. The same is possible from the AC backup generator.

NOTE 2 – It is also possible to have a DC backup generator coupled to 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 if AC power supply problems occur (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 that is useful if the AC power path to the rectifier's input fails (e.g., due to fire in the AC distribution).

NOTE 4 – Other configurations of power functionalities are possible where the battery is not directly connected to the DC output of rectifiers. Some configurations can optimize the rectifiers by removing charger function and are presented in Appendix IV with a separate charger for batteries and a voltage booster option.

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, they 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 with several battery strings as described in clause 6.3.1.

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 if a rectifier fails. This configuration can tolerate one rectifier failure without altering the power feeding mission and without battery discharge.

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

There can be several strings constituting the battery on Figure 4 in one or several cabinets working in parallel providing some additional redundancy.

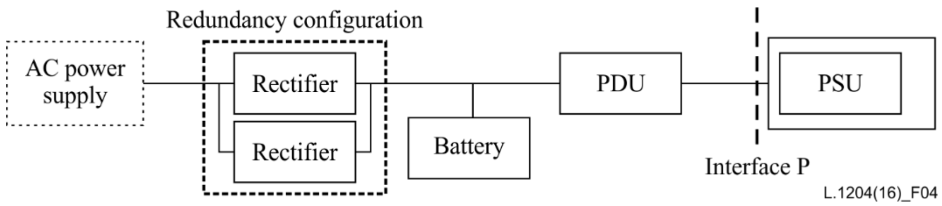

Figure 4 – Example of a system configuration with redundant rectifiers

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 separate DC power distribution paths to provide power to each PSU.

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

6.3.2.1 Power feeding system of up to 400 VDC 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. 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 are required.

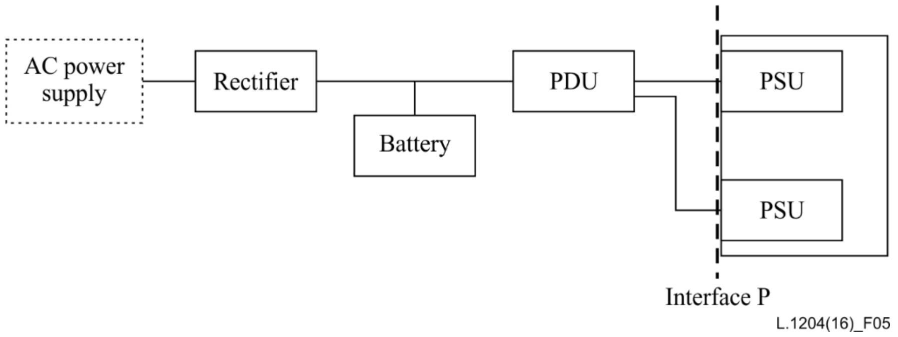

Figure 5 – System configuration with the redundant input of ICT equipment

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 short circuit (see clause 6.3.2).There is still redundancy of the distribution and PSU.

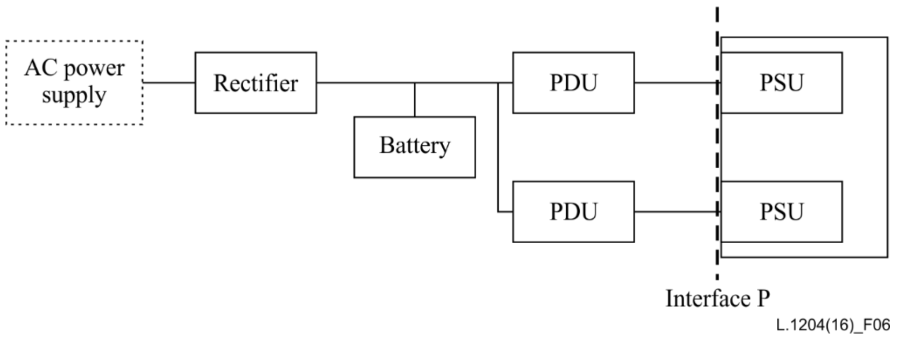

Figure 6 – System configuration with redundant PDUs for the redundant input of ICT equipment

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

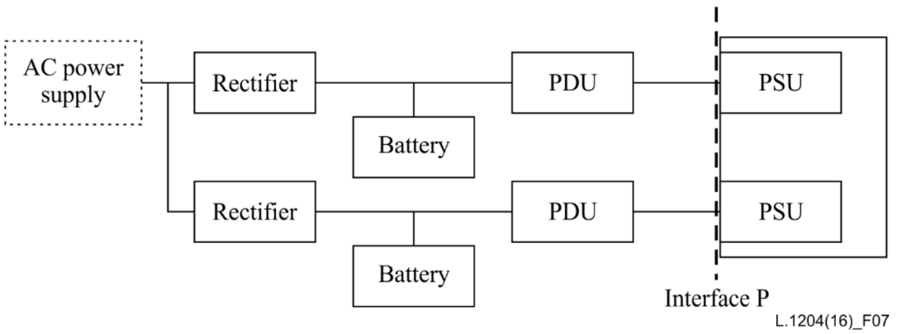

Figure 7 – System configuration with redundant rectifiers and DC distributions for the redundant input of ICT equipment

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.

Principally 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, although 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.

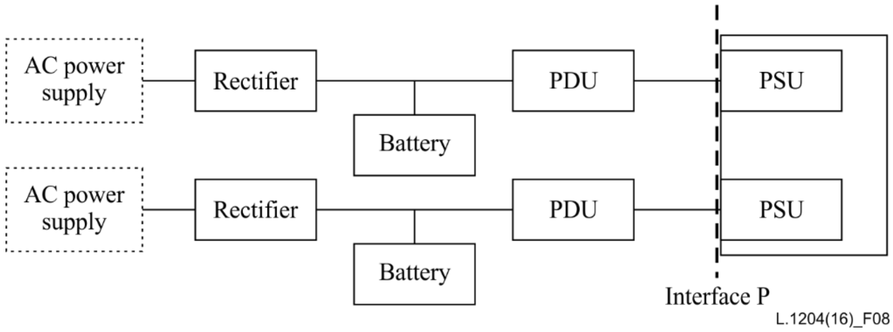

Figure 8 – System configuration with end-to-end redundancies of power feeding systems for the redundant inputs of ICT equipment

6.3.2.2 Hybrid power feeding system with up to 400 VDC and an AC power feeding system

When there are redundant PSUs on ICT equipment, asymmetric power chain configurations are possible, e.g., most of the time the AC grid can power a redundant power chain, while the AC backup can power the ICT by a single power chain. An AC and DC power feeding system configuration for redundant inputs of ICT equipment is shown in Figure 9. The AC chain without UPS can provide a higher efficiency than power through an UPS, assuming no high losses in the AC chain.

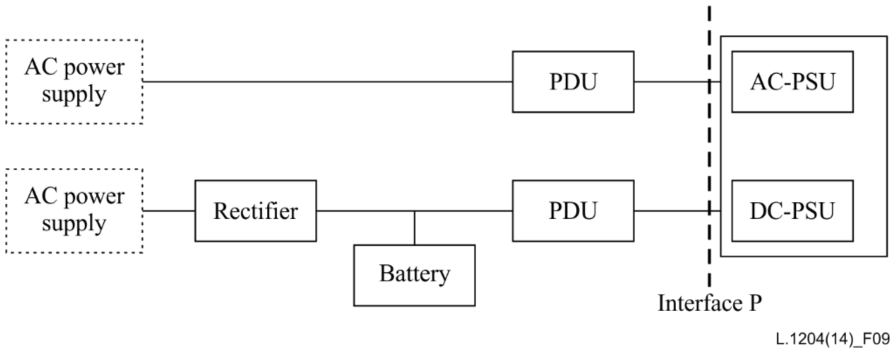

Figure 9 – AC and DC power feeding system configuration from two independent grids for dual-PSU ICT equipment

NOTE – DC-PSU, AC-PSU and universal input PSU are possible options in the configuration in Figure 9 and energy efficiency should be considered in further study.

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

All elements of power feeding system of up to 400 VDC shall comply with [IEC 60364-1].

To maintain safety and high reliability, the configuration of earthing and bonding is important. The earthing and bonding configuration affects the safety requirements of every element. The earthing and bonding method shall be chosen taking into account safety, system operation and the skill level of intervention personnel.

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

An IT system with an earthed high-ohmic mid-point terminal should be chosen to maximize safety. This is described as the preferable configuration in [ETSI EN 301 605].

NOTE – General safety issues are also described in [ETSI EN 301 605].

7.1.2 Electromagnetic compatibility

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

NOTE 1 – There are many EMC standards applicable. Normally, emission requirements are described in [b-CISPR 22] and immunity requirements are described in [b-CISPR 24]. The transition from [b-CISPR 22] to [b-CISPR 32] should be respected. National regulations override the content of this Recommendation.

NOTE 2 – The bonding defined in [ETSI EN 301 605] is intended to improve EMC for correct operation of the telecom or ICT equipment and systems.

7.1.3 Resistibility

Resistibility tests and levels are given in [ITU-T K.20]. 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 enhanced or special resistibility requirements.

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 commonly used. Other configurations are possible to reduce the voltage range and improve PSU efficiency, but care is necessary for reliability. These configurations are described in Appendix IV in detail.

A rectifier configuration should be chosen taking overall configuration features into account.

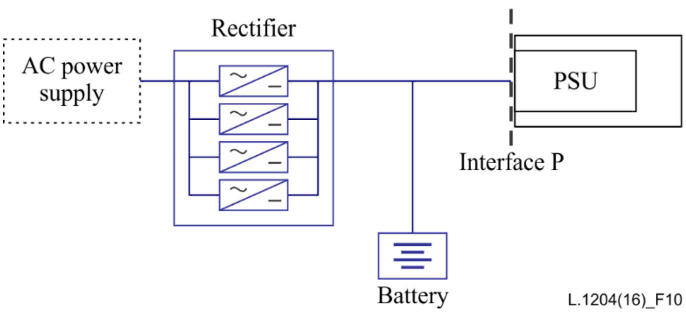

Figure 10 – Basic configuration of rectifier

7.2.2 Rectifier electrical characteristic

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

If a rectifier unit in a rectifier cabinet fails, other rectifier units should be able to operate safely and with high reliability.

A rectifier shall be isolated between the AC input and the DC output, unless there is an isolation transformer that isolates other earthing-configuration systems on the AC input side of the rectifiers. Earthing and bonding shall conform to [ETSI EN 301 605].

7.3 Power distribution unit 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 that are within the range specified in [ITU-T L.1200], while overcurrent protection is ensured by the protection devices.

7.3.1 Power distribution unit 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.

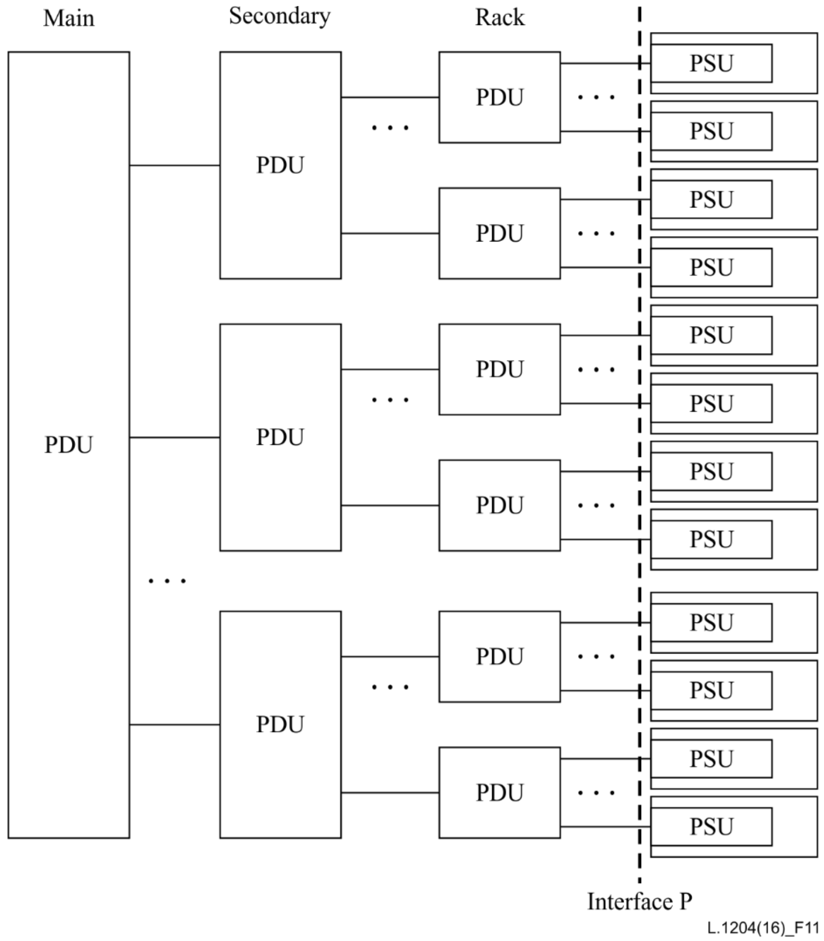

Figure 11 – Example configuration of multi-level PDU

NOTE – A detailed implementation example is given in Appendix III.

7.3.2 Protection device in a power distribution unit

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.

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, voltage at interface P changes as described in Appendix G of [b-ETSI EN 300 132-3-1].

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

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

NOTE 2 – The overvoltage can 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 (basic electrochemical units that produce the nominal voltage of the battery). The battery string, produces the voltage applied to interface P.

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

The required battery-operating time (discharge time) depends on different applications. The practical number of battery cells should be determined by taking into account, for example, the recovery of the AC grid, life expectancy, operation temperature and manufacturer's specification.

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 units of 2 V valve-regulated lead acid (VRLA) cells; this corresponds, for example, to 28 battery blocks of 12 V.

NOTE 2 – Battery size depends on such factors as cell type charge and discharge voltage, battery cell quantity, battery-operation discharge time and operating temperature.

NOTE 3 – There is a possibility of having dual storage technology (lead acid for long-term battery-operating time, lithium or supercapacitor 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 lifetime and characteristics

The performance and lifetime of battery cells are dependent on, for example, the different technologies (such as VRLA or lithium batteries), operating temperature, operating voltage and battery design. Temperature changes can affect battery performance, depending on battery technology. If the temperature under the operating conditions greatly affects battery performance, the use of charging techniques that can correct the floating and end of charge voltages for the influence of temperature may be required.

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

NOTE 2 – A VRLA battery self-discharges and is continuously recharged by a rectifier to keep its float voltage. The float voltage of a battery can be insufficient to maintain a full charge and an imbalance of the float voltage among battery cells can occur. In order to increase the health of the battery and maintain the desired float voltage, regular equalization of the battery charge (i.e., a higher voltage applied to the battery) is recommended for those batteries having 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 the use of the same battery string types, but 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 interconnect the battery, the rectifier, the PDU and the PSU. The distribution power lines may be single wires, cables or bus-bars.

The distribution power lines are quite important in power feeding systems. In addition, the selection of line protection devices is dependent on the area of cross-section of the conductor and allowable current. Therefore, specifications described in [IEC 60364-1] shall be referred to, specifically section 132.6 "Cross-sectional area of conductors" and section 132.7 "Type of wiring and methods of installation" of [IEC 60364-1] shall be used as reference. How the length and cross-sectional area of distribution power lines affect the voltage drop between the battery and interface P should also be considered.

Colouring and marking of the up to 400 VDC systems should follow the requirements specified in [ITU-T L.1203].

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 the 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 from 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 up to 400 VDC power feeding systems. 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 intervention personnel after reporting the failure to the remote monitoring system. When a failure occurs in monitoring entities before an alarm signal, 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. More details are given in Appendix I.

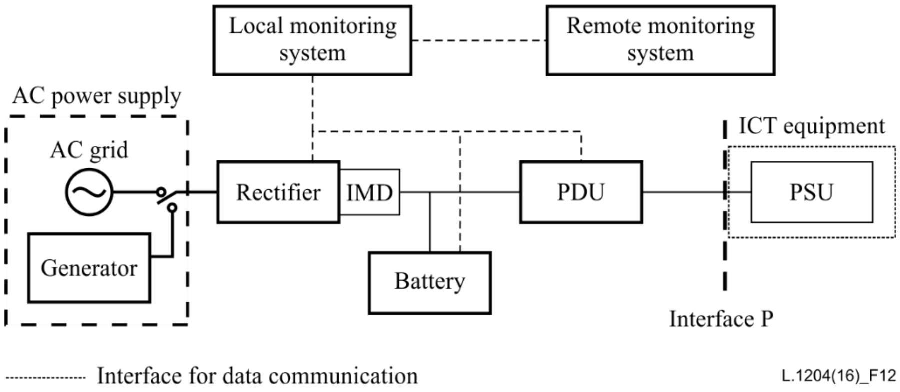

Figure 12 – Monitoring entities in a typical power feeding system of up to 400 VDC

NOTE 1 – AC grids and AC backup generators are outside the scope of this Recommendation. However, the AC source, e.g., a generator, should also be monitored.

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

8.2 Elements for monitoring

8.2.1 Rectifier

Rectifier information can be provided on 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 or visual signal that shall continue as long as the fault persists [IEC 60364-4-41].

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 as an option.

8.2.3 Battery

It is recommended that battery performance, such as output voltage and output current, be 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 over- or undervoltage occurs, the battery should signal the event. If there is a battery fuse, the battery also signals the state of the battery fuse.

More details are given in Appendix II.

NOTE – The internal resistance, impedance or conductance measurement of the batteries or cells connected to the DC power feeding system may provide additional information about the health of the battery. These signs of battery or cell ageing are still under study. For example, the internal resistance of a battery increases due to deterioration of internal conductance paths. During discharge, the increased internal resistance causes the old battery to reach the end of the discharge voltage faster 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. The requirement of the interface between the local monitoring system and the remote monitoring system is similar to that of the interface between sensors and the local monitoring system.

[ETSI ES 202 336-1] and subsequent parts should be used for the monitoring and control of the elements of the power feeding system.

NOTE – In [ETSI ES 202 336-1] and subsequent parts, the protocol is transmission control protocol/Internet protocol (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 representational state transfer (REST): get and post.

Appendix I

Example of monitoring data of a DC power system

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

Table I.1 shows an example of data gathered from five monitoring entities. "Monitoring information" specifies the state of the monitoring entities including the abnormal state and the state of failure. In the "Monitoring type" column, "data" means regularly measured data for maintenance in normal operation. "Alarm" indicates an abnormal state of the entities that requires protective action against failures or malfunctions of the entities. Some alarms require direct manipulation of the system before notifying the performance manager, because notification implies that a failure has occurred, such as a failure of the AC mains supply or rectifier. "Collection period" lists recommended durations for collecting data, but the period 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 the monitoring entities and manufacturers' requirements.

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 (remaining 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 health of a battery is regularly monitored to maintain its optimum operating condition. 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 includes, for example, 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). The data should be stored and regularly analysed to discover, before the battery fails, whether there are any abnormal conditions or undesired states of the battery. Based on the information gathered, the performance manager produces useful information to operate the battery in its best environment and to determine its expected lifespan, as well as determining when it should be replaced.

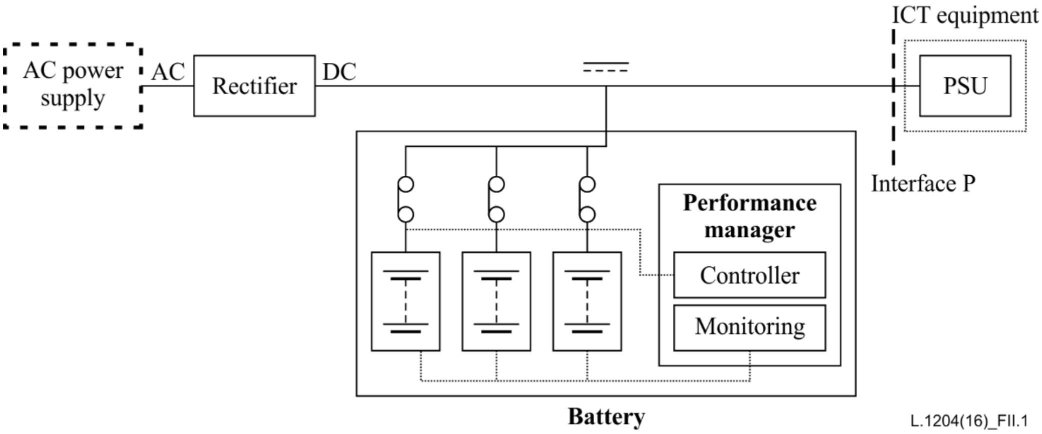

Figure II.1 – Battery configuration with performance manager

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 and distribution array cabinet in the larger capacity power supply system.

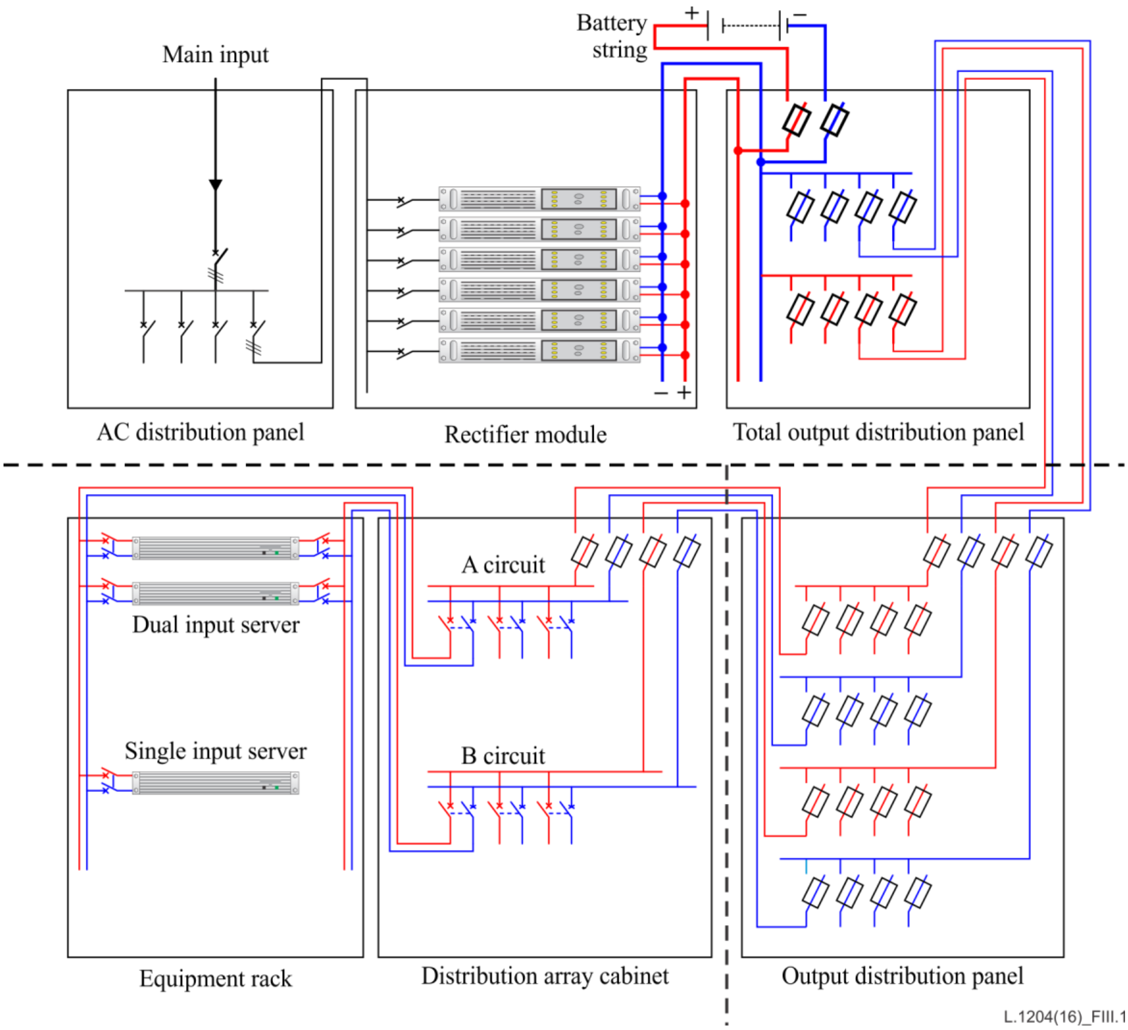

Figure III.1 – Three-level distribution structure

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

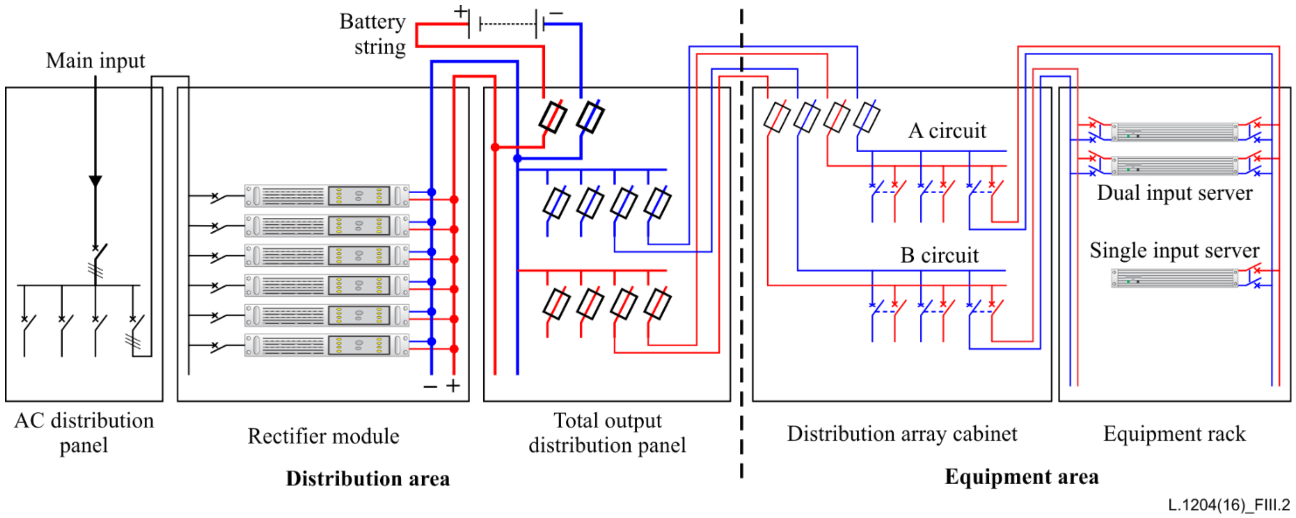

Figure III.2 – Two-level distribution structure

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. This basic configuration 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 voltage drop and generated heat in this low-voltage operation condition.

Figure IV.1 shows other configurations for 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. In addition, 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 needs to have a battery charger function. Redundancy of the charger results in high reliability.

b) Configuration with charger, diode, battery and booster

   This configuration includes an additional booster compared to configuration a). This allows a narrower operational voltage of the rectifiers, even if the battery is discharged. Therefore, if the capacity is the same, 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 results in high reliability.

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

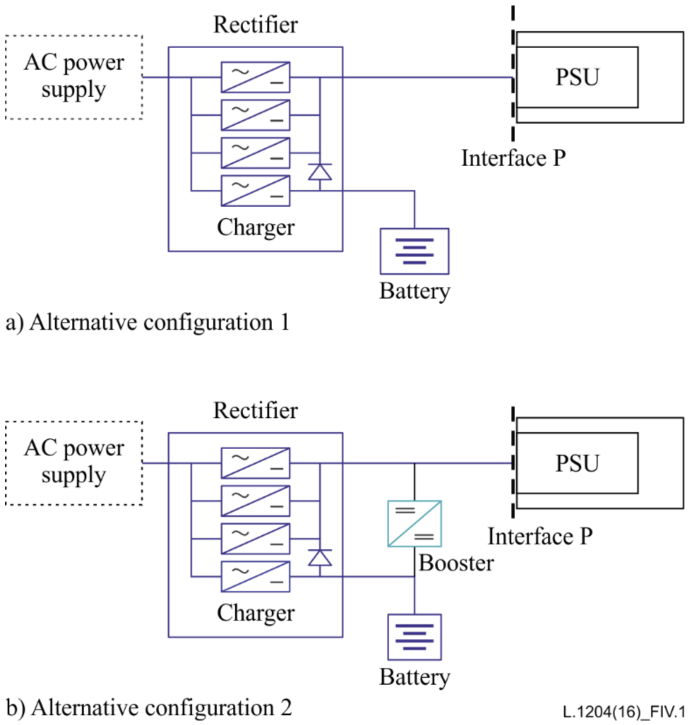

Figure IV.1 – Configurations of rectifiers/battery system

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 possible connection of renewable energy (e.g., photovoltaic (PV) and wind generator (WG)) and distributed power sources (e.g., fuel cell (FC)) to 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 connected to 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 for connecting renewable energy and distributed power sources to a power feeding system of up to 400 VDC powered by an 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 a 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 that lightning protection be taken into account, because some generators, such as PV and WG, are installed in the external environment.

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, through a rectifier to the battery without the need for the AC switchgear.

One advantage of this solution of connection in a DC power feeding system of the generators without AC switchgear is a very direct backup by the renewable energy and distributed power sources that could be much more reliable and have a much shorter mean time to repair (MTTR), by avoiding failure and delicate maintenance of the AC switchgear 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 energy produced cannot be sold with this configuration. It is applicable to redundant DC systems.

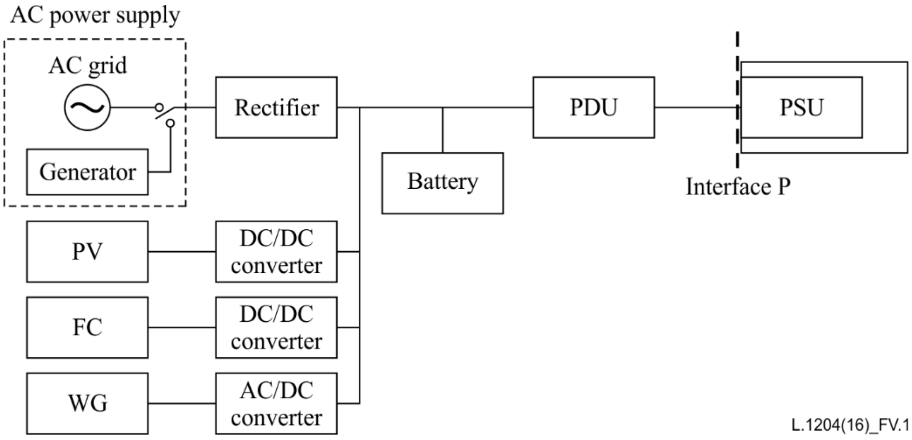

Figure V.1 – Direct connection in a DC power feeding system of PV, FC or WG generators to a DC power feed

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