Final draft ETSI ES 203 726 V1.0.0 (2022-06)

ETSI STANDARD

Environmental Engineering (EE); Progressive migration of Information and Communication Technology (ICT) site to 400 VDC sources and distribution

Reference
DES/EE-0260

Keywords
energy efficiency, power supply, site engineering

ETSI

650 Route des Lucioles
F-06921 Sophia Antipolis Cedex - FRANCE

Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16

Siret N° 348 623 562 00017 - APE 7112B
Association à but non lucratif enregistrée à la
Sous-Préfecture de Grasse (06) N° w061004871

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Foreword

This final draft ETSI Standard (ES) has been produced by ETSI Technical Committee Environmental Engineering (EE), and is now submitted for the ETSI standards Membership Approval Procedure.

Modal verbs terminology

In the present document "**shall**", "**shall not**", "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

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Executive summary

The present document gives explanation, requirements and guidance for increasing the use of up to 400 V Direct Current (400 VDC) power systems and the distribution to Information and Communication Technology (ICT) equipment. It includes 400 VDC remote powering up to 400 VDC of distributed ICT equipment, the option of interconnection of local renewable energy sources and their connection to DC power nanogrids and other users, extending the resilience capability of the telecommunication network and ICT sites to grid failures and climate change.

Introduction

Telecommunication network energy consumption and cost are increasing at a rate of several percentage points per year as reported in Trends in worldwide ICT electricity consumption from 2007 to 2012 [i.11]. The use of up to 400 V Direct Current (400 VDC) architecture (as presented in Table 1, Annex B and Annex C) can result in significant savings.

The use of up to 400 VDC solutions result in energy savings with higher efficiency and reduced distribution losses, reduction in maintenance cost due to higher reliability and lower unavailability, savings in space for power equipment in Information and Communication Technology (ICT) rooms (each square metre being of high cost) and, finally, more simplicity in site installation and development.

Different levels of saving and improvement result from a comparison of up to 400 VDC solutions to -48 V solutions (copper savings) or to Uninterrupted Power Supply (UPS) solutions (reliability, efficiency, easier installation). 400 VDC remote power can be beneficial.

As for the power system, energy savings in addition to those resulting from efficiency improvements depend on the load in the telecommunication or data centre. Energy efficiency should be evaluated at the system level, including the general distribution cabling and voltage conversion stages, as well as the internal power circuits inside the load downstream of the power interface, i.e. conversion architecture in the system (e.g. dual inputs, local back-up, AC/DC rectifier losses).

Indirect savings of up to 400 VDC solutions relate to lifecycle in the production and recycling phase as there should be less passage through copper and electronics as well as less battery usage for given output power and system dependability. Battery capacity and dependability savings are achieved by removing inverter losses if replacing AC UPS or by reducing -48 V distribution losses.

The present document specifies requirements for a safe migration of an existing site to a unified up to 400 VDC powering feeding system, power distribution and the power interface of telecommunication/ICT equipment. It includes requirements relating to the stability, cabling, earthing, as well as bonding and measurement, for the existing site.

The main significant components of up to 400 VDC equipment and additional progressive migration equipment are presented in Figures 2 and 3. These are schematic diagrams that do not show all the electrical arrangement details. The architecture under consideration complies with Recommendation ITU-T L.1204 [14] on electrical architecture, including energy storage defined in ETSI TS 103 553-1 [i.1] or Recommendation ITU-T L.1220 [i.2], technically equivalent, and with ETSI ES 203 474 [9] or Recommendation ITU-T L.1205 [15], technically equivalent, for DC coupling of a local Renewable Energy (REN) system on site or with DC nano/micro grid interconnecting sites with REN sources and storage or ICT equipment requiring remote powering. Smart DC nanogrids are under study as reported in Intelligent DC Microgrid Living Lab [i.12].

The migration simplifies the use of up to 400 VDC combined with REN and DC nanogrids and should extend resilience capability of telecommunication networks sites to grid failures and climate change.

The present document was developed jointly by ETSI TC EE and ITU-T Study Group 5. It is published respectively by ITU and ETSI as Recommendation ITU-T L.1207 [i.3] and ETSI ES 203 726 (the present document), which are technically-equivalent.

1 Scope

The present document defines solutions for progressive migration of Information and Communication Technology (ICT) sites (telecommunication and data centres) to up to 400 V Direct Current (400 VDC) distribution and direct use of up to 400 VDC powering ICT equipment from 400 VDC sources. The present document also defines different major use case options and migration scenarios, such as:

- migration to an up to 400 VDC of telecommunication site power solution;
- migration to an up to 400 VDC of data centre power solution;
- migration with up to 400 VDC power transfer between existing -48 V centralized sources to high power density -48 V equipment, such as routers;
- integration of up to 400 VDC remote powering;
- combined architecture with up to 400 VDC and AC sources and distributions possibly using hybrid power interfaces on ICT equipment.

For each of these, the present document describes many possible options and characteristics, such as:

- migration architecture with up to 400 VDC/-48 V conversion to power existing -48 V equipment using existing -48 V room distribution;
- conditions for tripping overcurrent protection devices without -48 V batteries;
- migration architecture with up to 400 VDC/AC inverter as an alternative to the AC UPS to power existing AC equipment;
- use of local up to 400 VDC for remote powering of ICT equipment;
- coupling up to 400 VDC systems to a local REN source or to a DC microgrid;
- possibility of conversion between battery and up to 400 VDC distribution, e.g. for long power distribution or short-circuit current or battery technology (e.g. lithium-ion).

The present document also gives a saving assessment frame reference to define the best migration scenario and its steps by considering energy, resource, environmental impact and cost savings based on functional aspects such as modularity, flexibility, reliability, efficiency and distribution losses, as well as maintenance evolution when migrating from -48 V or Alternating Current (AC) to up to 400 VDC solutions. This also includes consideration of load architecture evolution dependent on use cases (e.g. telecommunication site, data centres).

2 References

2.1 Normative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

Referenced documents which are not found to be publicly available in the expected location might be found at https://docbox.etsi.org/Reference/.

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The following referenced documents are necessary for the application of the present document.

[1] ETSI EN 300 132-1 (V2.1.1) (2019): "Environmental Engineering (EE); Power supply interface at the input to Information and Communication Technology (ICT) equipment; Part 1: Alternating Current (AC)".

[2] ETSI EN 300 132-2 (V2.6.1) (2019): "Environmental Engineering (EE); Power supply interface at the input of Information and Communication Technology (ICT) equipment; Part 2: -48 V Direct Current (DC)".

[3] ETSI EN 300 132-3 (V1.2.1) (2003): "Environmental Engineering (EE); Power supply interface at the input to telecommunications equipment; Part 3: Operated by rectified current source, alternating current source or direct current source up to 400 V".

[4] ETSI EN 300 253 (V2.2.1) (2015): "Environmental Engineering (EE); Earthing and bonding of ICT equipment powered by -48 VDC in telecom and data centres".

[5] ETSI EN 301 605 (V1.1.1) (2013): "Environmental Engineering (EE); Earthing and bonding of 400 VDC data and telecom (ICT) equipment".

[6] ETSI ES 202 336-2 (V1.1.1) (2009): "Environmental Engineering (EE); Monitoring and control interface for infrastructure equipment (Power, Cooling and environment systems used in telecommunication networks); Part 2: DC power system control and monitoring information model".

[7] ETSI ES 203 199 (V1.3.1) (2015): "Environmental Engineering (EE); Methodology for environmental Life Cycle Assessment (LCA) of Information and Communication Technology (ICT) goods, networks and services".

[8] ETSI ES 203 408 (V1.1.1): "Environmental Engineering (EE); Colour and marking of DC cable and connecting devices".

[9] ETSI ES 203 474 (V1.1.1): "Environmental Engineering (EE); Interfacing of renewable energy or distributed power sources to 400 VDC distribution systems powering Information and Communication Technology (ICT) equipment".

[10] ETSI TS 103 531 (V1.1.1): "Environmental Engineering (EE); Impact on ICT equipment architecture of multiple AC, -48 VDC or up to 400 VDC power inputs".

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

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

[13] Recommendation ITU-T L.1203 (2016): "Colour and marking identification of up to 400 VDC power distribution for information and communication technology systems".

[14] Recommendation ITU-T L.1204 (2016): "Extended architecture of power feeding systems of up to 400 VDC".

[15] Recommendation ITU-T L.1205 (2016): "Interfacing of renewable energy or distributed power sources to up to 400 VDC power feeding systems".

[16] Recommendation ITU-T L.1206 (2017): "Impact on ICT equipment architecture of multiple AC, -48 VDC or up to 400 VDC power inputs".

[17] Recommendation ITU-T L.1320 (2014): "Energy efficiency metrics and measurement for power and cooling equipment for telecommunications and data centres".

[18] Recommendation ITU-T L.1410 (2014): "Methodology for environmental life cycle assessments of information and communication technology goods, networks and services".

[19] IEC 60364 (all parts): "Low-voltage electrical installations".

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] ETSI TS 103 553-1 (V1.1.1): "Environmental Engineering (EE); Innovative energy storage technology for stationary use; Part 1: Overview".

[i.2] Recommendation ITU-T L.1220 (2017): "Innovative energy storage technology for stationary use - Part 1: Overview of energy storage".

[i.3] Recommendation ITU-T L.1207 (2018-05): "Progressive migration of a telecommunication/information and communication technology site to 400 VDC sources and distribution".

[i.4] ETSI EN 302 099 (V2.1.1) (2014): "Environmental Engineering (EE); Powering of equipment in access network".

[i.5] Recommendation ITU-T K.48 (2017): "EMC requirements for telecommunication equipment - Product family Recommendation".

[i.6] IEC 60950-1: "Information technology equipment - Safety - Part 1: General requirements".

[i.7] IEC 62368-1: "Audio/video, information and communication technology equipment - Part 1: Safety requirements".

[i.8] ETSI EN 300 132-3-1 (V2.1.1) (2012): "Environmental Engineering (EE); Power supply interface at the input to telecommunications and datacom (ICT) equipment; Part 3: Operated by rectified current source, alternating current source or direct current source up to 400 V; Sub-part 1: Direct current source up to 400 V".

[i.9] ETSI EN 300 386 (V2.1.1) (2016): "Telecommunication network equipment; ElectroMagnetic Compatibility (EMC) requirements; Harmonised Standard covering the essential requirements of the Directive 2014/30/EU".

[i.10] ETSI TR 100 283 (V2.2.1) (2007): "Environmental Engineering (EE); Transient voltages at Interface "A" on telecommunications direct current (dc) power distributions".

[i.11] Van Heddeghem W., Lambert S., Lannoo B., Colle D., Pickavet M., Demeester P. (2014): "Trends in worldwide ICT electricity consumption from 2007 to 2012". Computer Communications, 50, 64-76.

NOTE: Available at https://doi.org/10.1016/j.comcom.2014.02.008.

[i.12] Aalborg University: "Intelligent DC Microgrid Living Lab".

[i.13] Tsumura T, Takeda T, Hirose K (2008): "A tool for calculating reliability of power supply for information and communication technology systems". In Intelec 2008 - IEEE 30th International Telecommunications Energy Conference, 21.3, 6 pp., San Diego.

[i.14] Marquet D, Tanaka T, Murai K, Tanaka T, Babasaki T (2013): "DC power wide spread in Telecom/Datacenter and in home/office with renewable energy and energy autonomy". In Intelec 2013 - IEEE 35th International Telecommunications Energy Conference, Smart Power and Efficiency, pp. 499-504, Hamburg.

[i.15] Caltech Berkeley 2017 Vossos V, Johnson K, Kloss M, Khattar M, Gerber D, Brown R: "Review of DC power distribution in buildings: A technology and market assessment" pp.71.

[i.16] Schneider WP 118 Rasmussen N (undated): "High-efficiency AC power distribution for data centers". White Paper 128. Rueil-Malmaison: Schneider Electric. 19 pp.

[i.17] CE+T Intelec 2016 Frebel F. (eFFiciency research), Bleus P. Bomboir O. (CE+T Power, sa): "Transformer-less 2 kW non isolated 400 VDC/230 VAC single stage micro inverter". In Intelec 2016 - IEEE International Telecommunications Energy Conference, Austin.

NOTE: Available at https://ieeexplore.ieee.org/document/7749105.

[i.18] CATR Intelec 2012 Qi S, Hou F, Jing H: "Study and application on high voltage DC power feeding system for telecommunications in China". In Intelec 2012 - IEEE 34th International Telecommunications Energy Conference, pp. 9.1. 5, Scottsdale.

NOTE: Available at https://ieeexplore.ieee.org/xpl/conhome/6362321/proceeding.

[i.19] CAICT Intelec 2017 Qi S, Sun W, Wu Y: "Comparative analysis on different architectures of power supply system for data center and telecom center". In Intelec 2017 - IEEE International Telecommunications Energy Conference, pp. 26-29, Queensland.

[i.20] DCC+G Fraunhofer 2014 Wunde B: "380VDC in commercial buildings and offices". Presentation at Vicor Seminar 2014. 71 slides.

NOTE: Available at http://dcgrid.tue.nl/files/2014-02-11%20-%20Webinar%20Vicor.pdf.

[i.21] Fraunhofer Safety Intelec 2017 Kaiser J et al.: "Safety consideration for the operation of bipolar DC grids". In Intelec 2017 - IEEE International Telecommunications Energy Conference, pp. 327-334, Queensland.

[i.22] Fraunhofer Droop Intelec 2017 Wunder B et al.: "Droop controlled cognitive power electronics for DC microgrids". In Intelec 2017 - IEEE International Telecommunications Energy Conference, pp. 335-342, Queensland.

[i.23] Void.

[i.24] Fujitsu-NTT-Appliance coupler-Intelec 2017 Kiryu K, Tanaka T, Sato K, Seki K, Hirose K: "Development of appliance coupler for LVDC in information communication technology (ICT) equipment with having a protection of inrush current and arc". In Intelec 2017 - IEEE International Telecommunications Energy Conference, pp. 343-346, Queensland.

[i.25] level3-Eltek Intelec 2016 Ambriz A. (Level 3 Communications), Kania M. (Eltek): "A service provider's decision to move from 48V to 380V powering: The problem statement, technical assessment, financial analysis and practical implementation plan". In Intelec 2016 - IEEE International Telecommunications Energy Conference, Austin.

NOTE: Available at https://ieeexplore.ieee.org/document/7749117.

[i.26] NTT Intelec 1999 Yamashita T, Muroyama S, Furubo S, Ohtsu S: "270 V DC System - A highly efficient and reliable power supply system for both telecom and datacom systems". In Intelec 1999 - IEEE 21st International Telecommunication Energy Conference, PI 1-3. 5 pp., Copenhagen.

[i.27] NTT-f Intelec 2016 Hiroya Yajima, Kenichi Usui, Toshiyuki Hayashi (R&D and datacenter, NTT Facilities Japan): "Energy-saving effects of super computers by using on-site solar power and direct HVDC feeding systems". In Intelec 2016 - IEEE International Telecommunications Energy Conference, Austin.

NOTE: Available at https://ieeexplore.ieee.org/document/8214133.

[i.28] NTT-f Intelec 2011 Hirose K, Tanaka T, Babasaki T, Person S, Foucault O, Sonnenberg BJ, Szpek M: "Grounding concept considerations and recommendations for 400 VDC distribution system". In Intelec 2011 - IEEE 33rd International Telecommunications Energy Conference, 8 pp., Amsterdam.

[i.29] NTT Intelec 2012 Tanaka T, Hirose K, Marquet D, Sonnenberg BJ, Szpek M: "Analysis of wiring design for 380-VDC power distribution system at telecommunication sites". In Intelec 2012 - IEEE 34th International Telecommunications Energy Conference, 15.2. 5 pp., Scottsdale.

[i.30] OCP Orange: "400 VDC power feeding architecture", OCP 2017.

NOTE: Available at http://www.opencompute.org/wiki/Telcos.

[i.31] OCP Murata (2017): "Open compute power solutions". 4 pp.

NOTE: Available at https://www.avnet.com/wps/wcm/connect/onesite/584cd2d9-7c90-4465-83bc-15501e9bc430/Murata-ocp-EN-Brochure.pdf?MOD=AJPERES&CVID=lMbA3cq&CVID=lMbA3cq.

[i.32] Orange Intelec 2011 Marquet D, Foucault O, Acheen J, Turc JF, Szpek M, Brunarie J: "Pre roll-out field test of 400 VDC power supply: The new alliance of Edison and Tesla towards energy efficiency". In Intelec 2011 - IEEE 33rd International Telecommunications Energy Conference, 8 pp., Amsterdam.

[i.33] Orange Intelec 2016 Foucault O, Marquet D, le Masson S: "400 VDC Remote Powering as an alternative for power needs in new fixed and radio access networks". In Intelec 2016 - IEEE International Telecommunications Energy Conference, TS19.3, 9 pp, Austin.

[i.34] Orange Intelec 2017 Marquet D, Foucault O, Pichon JM,, Hirose K, Bianco C, Hockley R: "Telecom operators to accelerate the migration towards 400 volt direct current - Efficient powering for telecom/ICT equipment and coupling sites to smart energy microgrids". In Intelec 2017 - IEEE International Telecommunications Energy Conference, pp. 196-203, Queensland.

[i.35] Orange Intelec 1999 Marquet D, San Miguel F, Gabillet JP: "New power supply optimised for new telecom networks and services". In Intelec 1999 - IEEE 21st International Telecommunication Energy Conference, 25-1. 8 pp., Copenhagen.

[i.36] Orange Intelec 2005 Marquet D, Kervarrec G, Foucault O: "New flexible powering architecture for integrated service operators". In Intelec 2005 - IEEE 27th International Telecommunications Conference, pp. 575-580, Berlin.

[i.37] Schneider WP 151 Rasmussen N (undated): "Review of four studies comparing efficiency of AC and DC distribution for data centers". White Paper 151, Rueil-Malmaison: Schneider Electric, 12 pp.

[i.38] Schneider WP 127 Rasmussen N, Spitaels J (undated): "A quantitative comparison of high efficiency AC vs. DC power distribution for data centers". White Paper 127, Rev 2. Rueil-Malmaison: Schneider Electric, 23 pp.

[i.39] Telstra Intelec 2017 Yong M, Bettle D: "Deploying HVDC in existing network exchanges: Practical and financial benefits for telecommunications carriers". In Intelec 2017 - IEEE International Telecommunications Energy Conference, pp. 204-207, Queensland.

3 Definition of terms, symbols and abbreviations

3.1 Terms

For the purposes of the present document, the following terms apply:

abnormal service voltage range: range of steady-state voltage over which the equipment will not be expected to maintain normal service but will survive undamaged

NOTE: Available in ETSI EN 300 132-2 [2].

advanced battery: battery of more performant technology, e.g. lithium battery compared to mainly used legacy battery technology used in telecommunication and data centres, i.e. Valve-Regulated Lead-Acid (VRLA)

DC/DC converter: power electronic system that transfers energy from one DC voltage (level) to another DC voltage (level)

ICT equipment: device, in the telecommunication network infrastructure, that provides an ICT service

interface "A": terminals, at which the power supply is connected to the system block

NOTE: Available in ETSI EN 300 132-2 [2].

interface A1: interface, physical point, at which AC power supply is connected in order to operate the telecommunications and datacom (ICT) equipment

interface A3: interface, physical point, at which power supply is connected in order to operate the telecommunications and datacom (ICT) equipment

NOTE: Available in ETSI EN 300 132-1 [1].

load, load equipment: power consuming equipment that is part of a system block

normal operation: operation in typical environmental and powering conditions for telecommunications and datacom (ICT) equipment, power supply, power distribution and battery at normal service

normal service: service mode where telecommunications and datacom (ICT) equipment operates within its specification which includes a defined restart time after malfunction or full interruption

NOTE: Available in ETSI EN 300 132-2 [2].

normal service voltage range: range of the steady-state voltages over which the equipment will maintain normal service

NOTE: Available in ETSI EN 300 132-2 [2].

power supply: power source to which telecommunication and datacom (ICT) equipment is intended to be connected

NOTE: A power source can be at building level, room level, rack level or a unit inside ICT equipment that feeds power at a defined interface where it is required.

system block: functional group of telecommunications and datacom (ICT) equipment depending on its connection to the same power supply for its operation and performance

telecommunication centre: any location where telecommunications and datacom (ICT) equipment is installed and is the sole responsibility of the operator

NOTE: Available in ETSI EN 300 132-3-1 [i.8].

3.2 Symbols

Void.

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

4G	fourth Generation
5G	fifth Generation
AC	Alternating Current
AC ICT	AC Information & Communication Technology
AC UPS	AC Uninterruptable Power Supply
ATS	Automatic Transfer Switch
CAPEX	Capital Expenditure
DC	Direct Current
DCC	DC Components
DCC+G	DC Components and Grids
DoD	Depth of Discharge
EMC	ElectroMagnetic Compatibility
FTTx	Fibre To The x
HRMG	High Resistance Middle point Grounding
HVDC	High-Voltage Direct Current

ICT	Information and Communication Technology
IEC	International Electrotechnical Commission
IT	Information Technology
ITU-T	International Telecommunications Union - Telecommunication
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
MTBF	Mean Time Between Failures
MW	MegaWatt
NTT	Nippon Telegraph and Telecom
O&M	Operation and Maintenance
OCP	Open Closed Principle
OPEX	Operation Expenditure
PDU	Power Distribution Unit
PFC	Power Factor Correction
POL	Point Of Load
PSU	Power Supply Unit
PV	Photovoltaic
REN	Renewable Energy
TC	Technical Committee
TCO	Total Cost Ownership
UPS	Uninterruptible Power Supply
USA	United States of America
VAC	Volts Alternating Current
VDC	Volts Direct Current
VRLA	Valve-Regulated Lead-Acid
WP	White Paper

4 Present situation of a telecommunication or data centre powering solution and motivation for migration to up to 400 VDC

Figure 1 presents a mixed power system architecture with the various interfaces A, A3 and A3ac, and interconnection to an AC board and back-up engine generator, as it will appear during the migration period in most of legacy telecommunication operators' buildings.

Figure 1 shows the drawbacks of existing powering -48 V and AC Uninterruptible Power Supply (UPS) solutions, and where improvements should progressively be made when building new generation rooms or upgrading existing rooms with up to 400 VDC in telecommunication/ICT buildings.

The ICT power supply interfaces considered in the present document shall be ETSI EN 300 132-2 [2] for -48 V, ETSI EN 300 132-1 [1] for AC and Recommendation ITU-T L.1200 [11] or ETSI EN 300 132-3 [3] for up to 400 VDC.

The motivations for migration to up to 400 VDC solutions are to reduce the drawbacks of -48 V and AC solutions shown in Figure 1 by aiming for the ultimate target defined in the architecture shown in Figure 2, which offers the following advantages:

- Power architecture unification by progressively using a single up to 400 VDC power interface on loads. Different migration steps are possible, from less to more benefit, as described in clause 7.
- Simplification of architecture and maintenance (e.g. with more modular solutions) by using the up to 400 VDC architecture defined in Recommendation ITU-T L.1204 [14].
- Energy efficiency and energy cost reduction with dynamic saving modes as in 48 V that can be assessed by using a comparative evaluation specified in Recommendation ITU-T L.1202 [12]. More than 3 % can be saved on energy consumption and more than 80 % on material and labour cost, as assessed in Annex C.
- Lower copper and installation costs, progressive installation by modularity. Copper use could be decreased by a factor of 10, resulting in a simpler and faster installation, easier upgrades and the flexibility to adapt to new product developments. Integration of REN could be also simplified. Assessment is described in Annex C.

- Reliability and dependability improvement. The comparative evaluation of up to 400 VDC versus -48 V and AC interfaces shall be established by the methods specified in Recommendation ITU-T L.1202 [12].

NOTE 1: Compared to UPS installation at comparable prices, unavailability can be improved by a factor of 10, as reported in "*A tool for calculating reliability of power supply for information and communication technology systems*" [i.13] and *"DC power wide spread in Telecom/Datacenter and in home/office with renewable energy and energy autonomy"* [i.14].

- Lower life cycle environmental impacts (less copper, less complex equipment, longer lifetime, less number and capacity of battery use and more modularity, etc.). This shall be evaluated by the Life Cycle Assessment (LCA) environmental impact in compliance with ETSI ES 203 199 [7] or Recommendation ITU-T L.1410 [18], technical equivalent, assessment methods.

The up to 400 VDC loads architecture can have an impact on specific aspects not fully covered in the present document such as:

- more on site power generation in terms of solar and wind with local power storage to try to minimize power drawn from the grid when grid supply is used only as a backup source;
- excess renewable power generation sold back to the grid and utility supply selection in attempts to minimize utility cost;
- a possible future requirement for centre power autonomy that might make the most of the supply distribution system that is dormant most of the time.

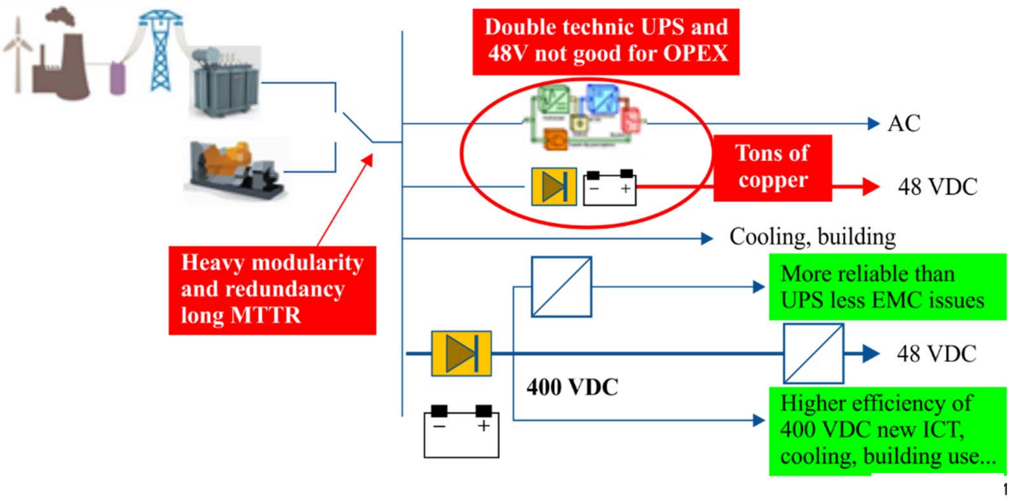

Figure 1: Legacy power architecture in common telecommunication or data centres at the start of migration to up to 400 VDC at level of power station, distribution and load equipment

NOTE 2: Text blocks highlighted in green indicate improvements and those in red drawbacks of existing solutions.

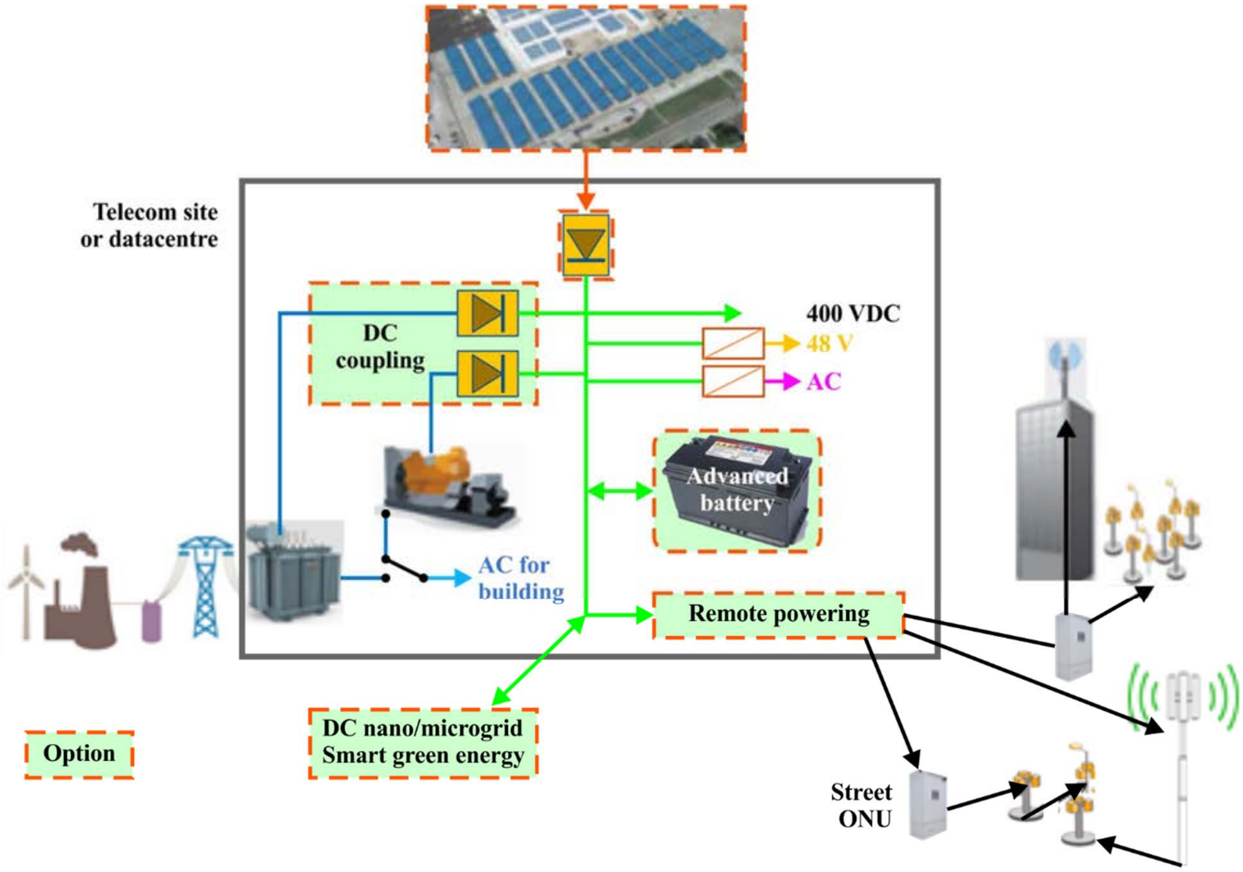

Figure 2: Expanded ultimate target migration to up to 400 VDC principle with all options

NOTE 3: The indicated power interface refers to standard up to 400 VDC Recommendation ITU-T L.1200 [11] or ETSI EN 300 132-3 [3], 48 V ETSI EN 300 132-2 [2], AC ETSI EN 300 132-1 [1], Remote Powering ETSI EN 302 099 [i.4].

As far as possible, a common approach is applied for telecommunication and data centres for local power distribution, but very high power in a data centre (multi-megawatt) might introduce some differences as presented in Annex B and clause 5.5.

The potential savings are at the levels of:

- power plant;
- distribution;
- loads.

The connection of a solar power system to up to 400 VDC local distribution presented in Figure 1 is not described in detail in the present document; it shall comply with ETSI ES 203 474 [9] or the technically equivalent Recommendation ITU-T L.1205 [15].

If data centres are looking to become more autonomous from the utility, this can also mean more emphasis on local site power solutions and the impact on electricity supply network has to be considered.

Depending on the battery usage approach, there can be an impact on the architecture depending on the strictness of the regulation for charge control, as discussed in clause 6.

There can be single or bidirectional flow on the DC nanogrid as presented in Intelligent DC Microgrid Living Lab [i.12].

In general, the migration steps towards up to 400 VDC solutions would be as shown in Figure 3, and described as follows:

- install a centralized up to 400 VDC power station, and up to 400 VDC distribution to ICT rooms on given sites or other user equipment (e.g. cooling);
- add up to 400 VDC/-48 or 400 VDC/AC front converter in a transition period;
- change existing -48 V or AC equipment Power Supply Unit (PSU) to up to 400 VDC PSU using dual input PSU ETSI TS 103 531 [10] or the technical equivalent Recommendation ITU-T L.1206 [16], one for -48 V or AC, one for up to 400 VDC or universal AC and up to 400 VDC input PSU.

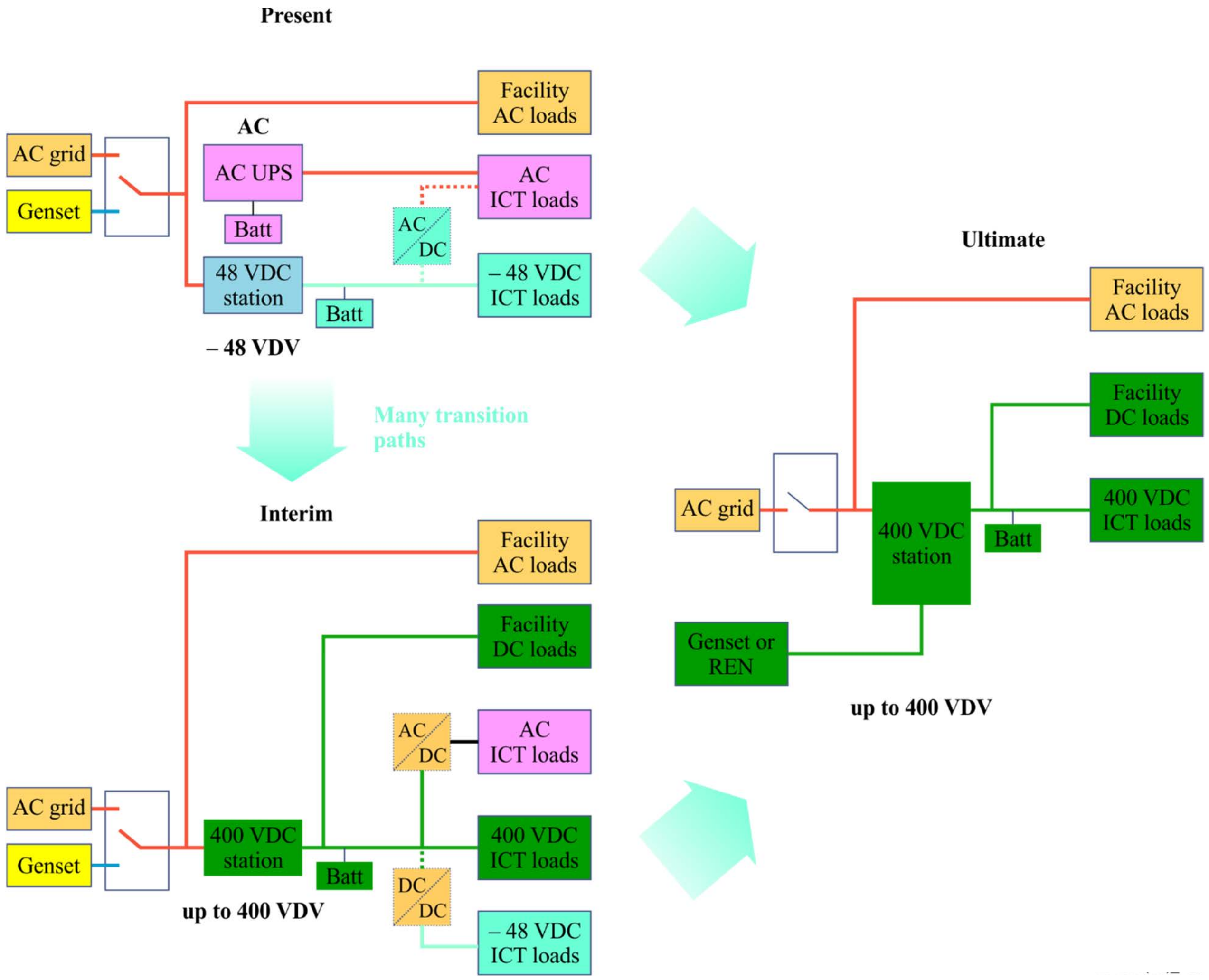

Figure 3: Possible transition paths to target inside a telecommunication or data centre

NOTE 4: The indicated power interface refers to standard up to 400 VDC Recommendation ITU-T L.1200 [11] or ETSI EN 300 132-3 [3], -48 V ETSI EN 300 132-2 [2], AC ETSI EN 300 132-1 [1], Remote Powering ETSI EN 302 099 [i.4].

Table 1 gives an overview of the potential improvements of migration case towards the up to 400 VDC target and additional options, such as Renewable Energy (REN). Some detailed assessment hypotheses are given in Annex C. The potential savings listed in Table 1 assume a sufficient market of up to 400 VDC systems for a realistic comparison (less than a factor of 10 in volume of installed equipment).

NOTE 5: The comparison is between legacy -48 V or AC UPS to pure up to 400 VDC target. The transition period with DC/DC converters (400/-48) or a DC/AC inverter (400/AC) is not assessed, as there are many different configurations and transition equipment that can be reused on several sites.

5 General evolution cases during migration

5.1 Present situation

The present legacy powering situation is shown in Figures 4 and 5 for data centres and telecommunication sites, respectively.

Clauses 5.2 to 5.6 give more details on the different power conversion stages required for existing interfaces of legacy architectures.

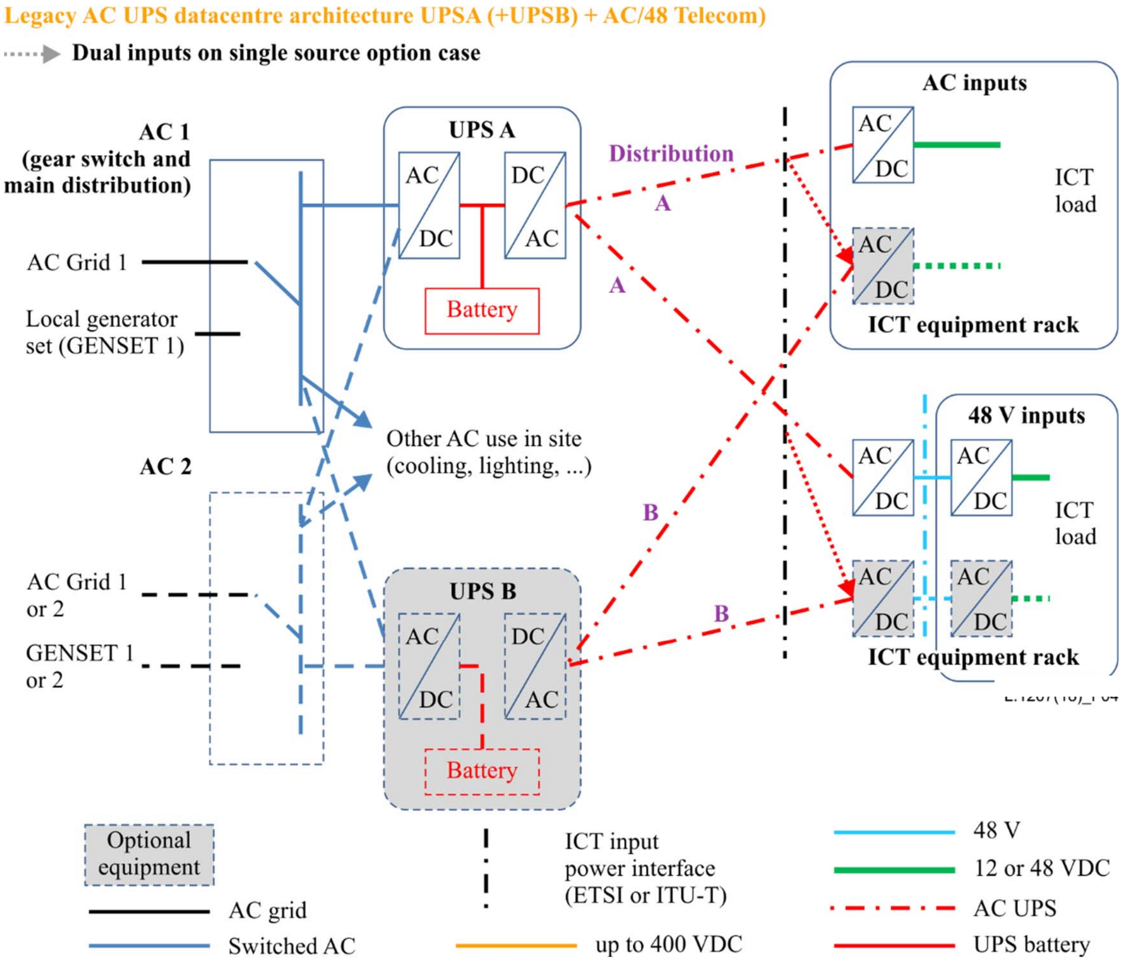

Figure 4: Typical AC UPS datacentre

Table 1: Assessment table of features and benefits of migration case towards up to 400 VDC

Indicative saving for migration	Energy efficiency or losses	Copper in cable, connectors, protective device	Reliability	Safety	Capital expenditure (CAPEX; including scalability and modularity)	Operation expenditure (OPEX; maintenance + energy savings)
-48 V to up to 400 VDC power source for same power		Less copper in cabinet and in power modules and distribution device	Higher mean time between failures (MTBF) when fewer power modules and distribution device		Lower CAPEX due to lower current and so higher power modularity corresponding to less equipment and less copper	Lower OPEX if less rectifier modules and distribution device
-48 V to up to 400 VDC distribution	1,4 % less losses in up to 400 VDC distribution (see note)	Cable section divided by 10 and so mass also compared to -48 V (see Annex C)	Same availability in -48 V and 380 V DC in double distribution	Better as Operation and Maintenance (O&M) work is done out of voltage in up to 400 VDC	-30 % on installation (as quoted on a 200 kW site) due to much less copper	
-48 V to up to 400 VDC equipment		1/10 + volume saving of power distribution in high density cabinets			Copper cost divided by 5 to 10	
AC UPS to up to 400 VDC power source	3 % if online UPS See Annex C: 96 % efficiency of a 380 VDC source compared to 93 % for AC UPS 1 % if offline UPS (no harmonic filter and 50 Hz transformers)		MTBF divided by 10 See Annex C: up to 400 VDC source simpler to maintain than AC UPS and less failure with no synchronized inverters and no by-pass	Higher in IT mode on DC side	-30 %	-30 % due to higher MTBF and simple maintenance not requiring costly contract
AC to up to 400 VDC distribution	1 %	Possible to divide by 5 (less section in 380 V compared to 230 V, and two wire cable without ground wire)		Higher with IT mode (HRMG)	-10 %	
AC to pure up to 400 servers PSU	3 % at load < 30 % Less saving if using universal AC and DC PSU		Higher MTBF with fewer components [no Power Factor Correction (PFC) stage in pure DC PSU]			
Renewable Energy (REN)	Grid saving: 5 % more without inverter		Better MTBF		10 % saving	
REN DC nanogrid	30 % [yearly with photovoltaic (PV)]		More resilience than grid			

Indicative saving for migration	Energy efficiency or losses	Copper in cable, connectors, protective device	Reliability	Safety	Capital expenditure (CAPEX; including scalability and modularity)	Operation expenditure (OPEX; maintenance + energy savings)
REN + Advanced battery	70 % (yearly with PV + battery)		Maximum resilience			
Remote powering			Higher MTBF and resilience without local site grid and battery			
NOTE: See Annex C.						

5.2 DC/DC converter related considerations

Figure 5 reflects the general case for powering legacy ICT equipment with possible redundant -48 V feeds and up to 400 VDC ICT equipment from single or redundant up to 400 VDC power plant. In general, up to 400 VDC will enable centralized power plant rather than decentralized close to the ICT equipment without inducing high losses and copper use compared to -48 V solutions.

The efficiency and losses are reduced by using up to 400 VDC distribution from an up to 400 VDC power system, but will be different depending on whether up to 400/48 DC/DC conversion is used.

Room centralized or rack level up to 400/48 conversion are possible. When a centralized up to 400/48 conversion cabinet is used in a room, the losses in -48 V cables are higher compared to losses in up to 400 VDC cables towards distributed up to 400/48 conversion racks in each ICT cabinet load.

Advantages of direct up to 400 VDC distribution and power feeding of ICT equipment are copper saving, better unavailability without up to 400/48 conversion, smaller footprint and more flexibility in installation with small cables.

Up to 400 VDC inputs will generally be fed in a different way to -48 V, by using power strips as in AC distribution. These plug strips can be connected directly to a room up to 400 VDC distribution frame or from a raised floor under distribution boxes.

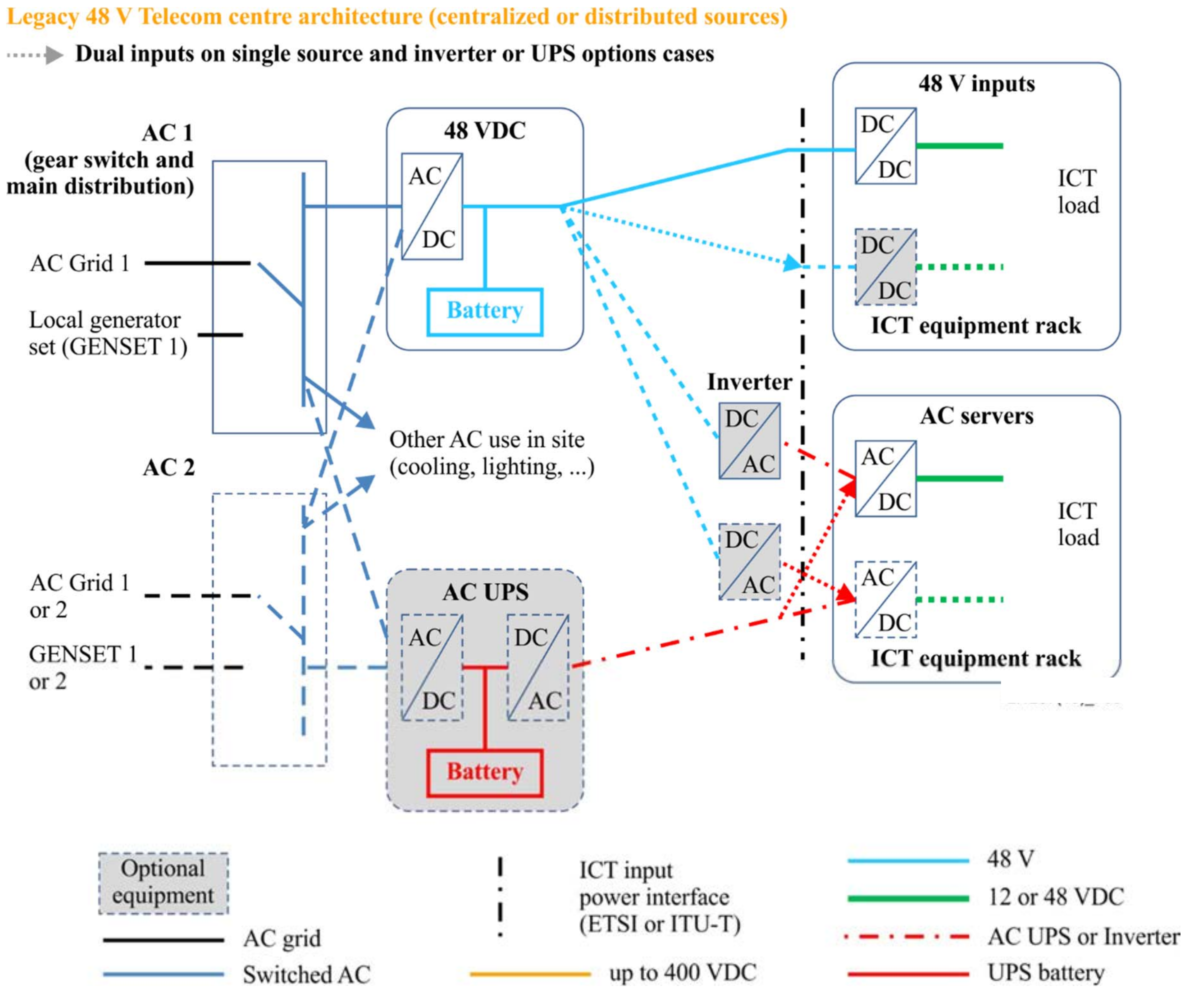

Figure 5: Typical telecommunication centre installation with ICT equipment having -48 V and AC inputs with optional redundancy indicated by dotted lines

A dual power input ICT system is possible with the dual up to 400 VDC input, hybrid up to 400 VDC and -48 V or AC, or with up to 400/48 or up to 400/AC (see Figure 6) as required. In that case, the dual input shall comply with ETSI TS 103 531 [10] or Recommendation ITU-T L.1206 [16], technically equivalent. The dual input can help to avoid difficulties to clear faults without a 48 V battery if a short circuit occurs in the distribution. It reduces the risk of short circuit fault propagation and can give very fast electronic protection in order to keep the voltage above the interface A ETSI EN 300 132-2 [2] abnormal service voltage range low limit without the help of a battery. See clause 10 for details.

NOTE: The need for a very fast protective device solution is required with or without double -48 V separate distribution, as some equipment uses only one input.

Discussion of and recommendations for up to 400 VDC batteries are given in clause 8.

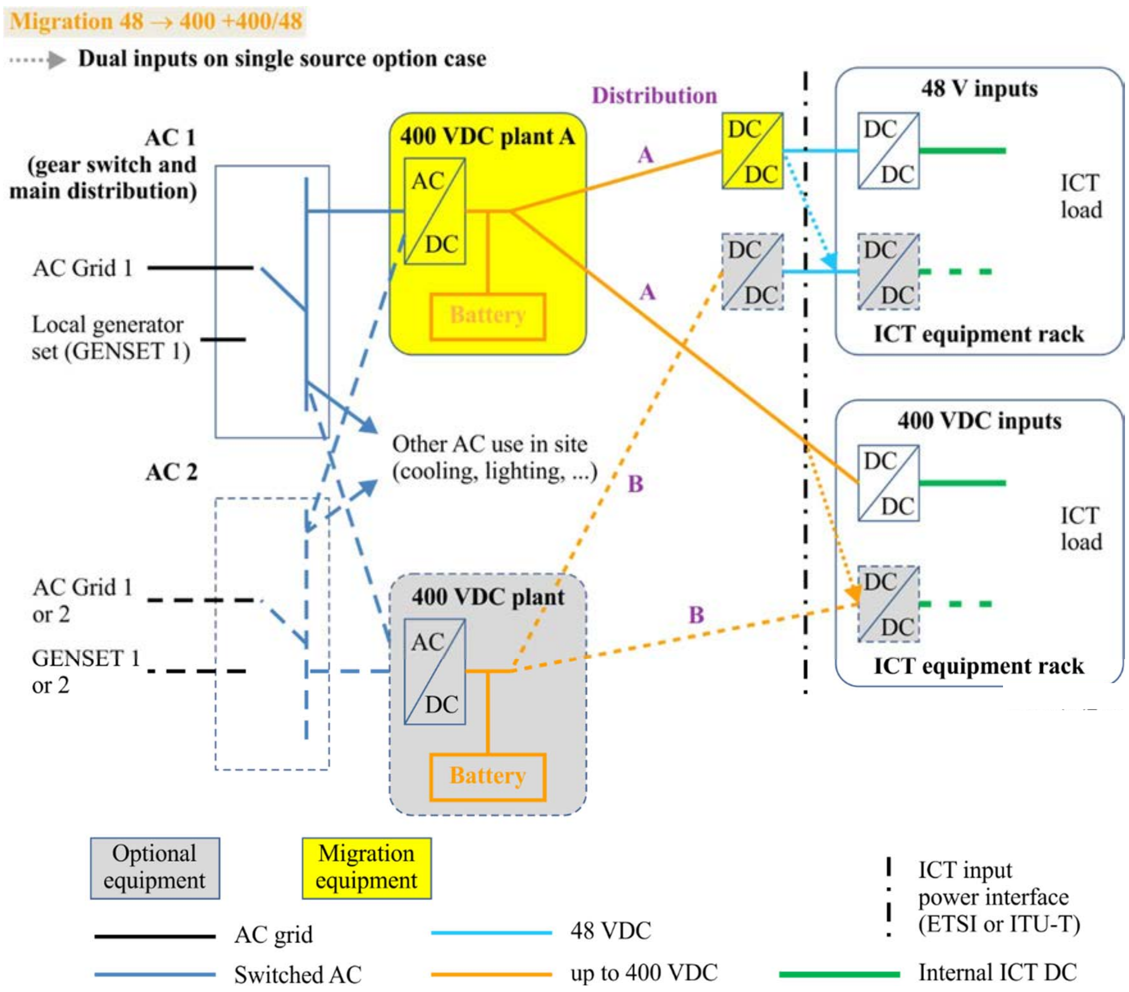

Figure 6: Migration to up to 400 VDC power system and distribution using 400/48 conversion

5.3 400/AC migration inverter consideration

Figure 7 reflects the general case of migration for legacy ICT equipment from AC UPS to up to 400 VDC distribution.

It is also possible to move towards hybrid architecture as defined in Recommendation ITU-T L.1204 [14] using ICT equipment with dual inputs in configurations DC and AC as defined in ETSI TS 103 531 [10] or the technical equivalent Recommendation ITU-T L.1206 [16]. In that case, the ICT equipment has one input powered by the AC grid and the other on a back-up up to 400 VDC station. This is an optimized replacement of a solution with AC grid power and back-up by AC UPS.

The general migration case is from legacy redundant UPS with manual bypass to up to 400 VDC solutions.

It can also be migration from modular -48 V inverters not always using manual bypass to up to 400 VDC solutions.

NOTE 1: When there was a single -48 V plant before migration, there is a single inverter system and AC bus with possibly double AC distribution at output.

The up to 400 VDC input of converter could be dual feeds inputs as defined in ETSI TS 103 531 [10] or the technical equivalent Recommendation ITU-T L.1206 [16].

Efficiency, reliability, maintenance and cost savings compared to UPS are listed in Table 1 and discussed in more detail in Annex C.

There may be further saving challenges by reducing power conversion stages in ICT equipment, such as using Point Of Load (POL) conversion at load directly from up to 400 VDC to the 1 V level of modern ICT components. Concerning migration of data centre architecture and equipment from AC UPS to up to 400 VDC architecture, clause 5.5 and Annex B contain additional requirements and information.

Migration of AC plug power strips to up to 400 VDC in cabinets in data centres is addressed in clause 5.2.

Discussion of and recommendations for up to 400 VDC batteries are given in clause 6.

NOTE 2: For a very high power datacentre, -400/400 front-end distribution has been considered, but this lies outside the scope of the present document.

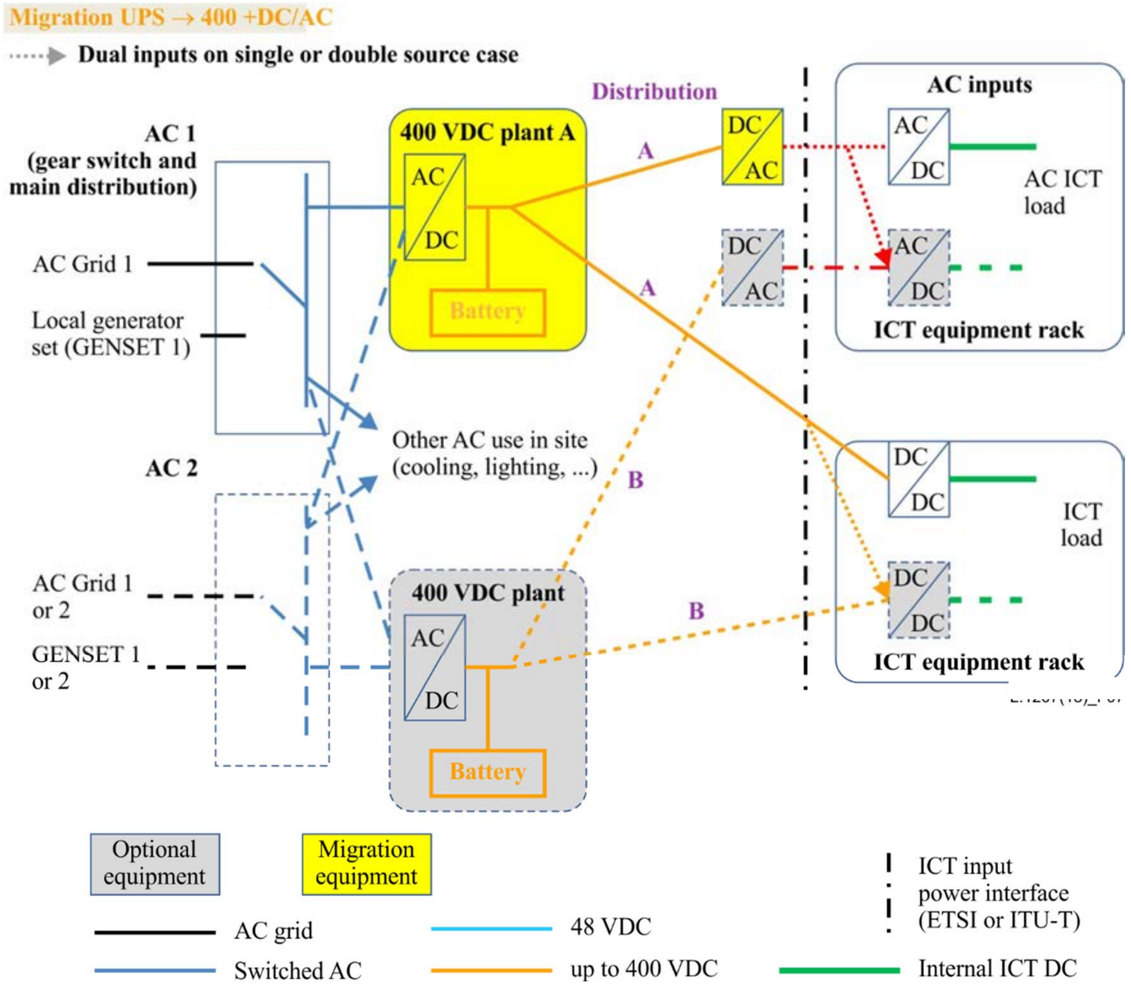

Figure 7: Migration to up to 400 VDC distribution with 400/AC inverter option

5.4 Long distance transport in -48 V/up to 400 VDC/-48 V in centre and multistep migration

There can be benefits in using copper in large buildings, due to cost and energy saving to distribute power using light cables up to 400 VDC rather than legacy -48 V heavy cables or bars.

The transition can then be multistep from situation A to D, as follows (see Figure 8):

A) replacement of -48 V distribution by up to 400 VDC distribution;

B) replacement of -48 V ICT equipment by up to 400 VDC ICT equipment;

C) replacement of a -48 V power station by an up to 400 VDC power station;

D) replacement of all -48 V equipment by up to 400 VDC equipment.

The galvanic insulation in B and C steps ensures proper fault condition management, as well as safety for loads and operational staff.

If there are already AC loads to power in the migration period, the migration solution using the up to 400 VDC distribution can be as described in clause 5.3.

The A and B configurations in Figure 8 use existing centralized -48 V plant to power existing -48 telecommunication equipment. Transporting power inside buildings using an up to 400 VDC system will save much copper weight and cost, and reduces energy losses.

Configurations A and B enable a fast and easy implementation by making use of the existing power plant, but they increase the conversion stages with the step-up -48/400. Consequently, consideration of reliability, efficiency and cost compared to direct migration with an up to 400 VDC power plant (as in configuration C and D) is necessary.

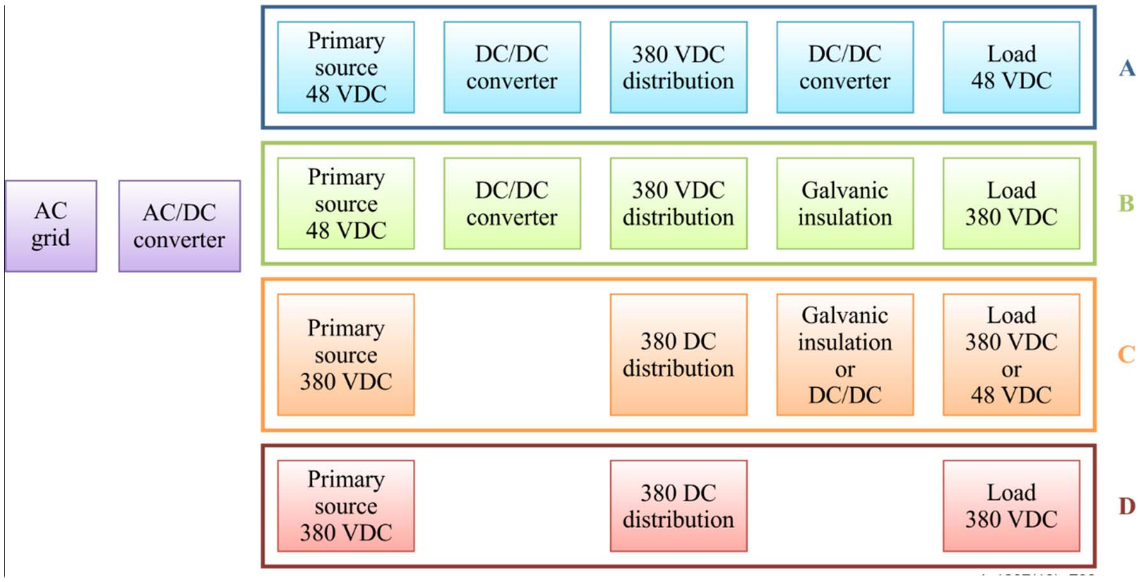

Figure 8: Multistep migration from -48 VDC power towards end to end up to 400 VDC architecture

For a transition period, there can be some advantage to maintaining the -48 V battery stack as on the input side of 48/400 conversion to DC UPS, especially when it is a high-capacity recently replaced -48 V battery. However, the reuse of the battery on another site requires consideration in the financial evaluation.

The solution covers both single ICT power feed interface or multiple feeds.

The object of configurations C and D in Figure 8 is to replace the -48 VDC source by an up to 400 VDC source and then use the different migration cases already dealt with elsewhere in clause 7.

Migration of AC plug power strips to up to 400 VDC in cabinets in data centres is addressed in clause 5.2.

Discussion of and recommendations for up to 400 VDC batteries are given in clause 6.

5.5 Combined migration cases

Figure 9 shows a general hybrid and combined solution when moving from a site equipped with AC ICT equipment with issues of migration, considering technical and O&M aspects.

An ideal approach for users would be an easy update to an existing system that gives the quickest benefits, with the potential for augmentation of the power system to support any IT expansion that works in harmony with the existing power solution. This can lead to a hybrid and combined solution.

The hybrid architecture with hybrid AC and up to 400 VDC feeds to ICT equipment shall be compliant with Recommendation ITU-T L.1204 [14]. The AC can be directly fed from a more or less filtered grid or from AC UPS in different power modes (e.g. offline, interactive, online) offering different levels of energy efficiency, AC quality and unavailability. This can be very cost effective if connected to a high-quality AC grid to use this combined architecture. Moreover, when using full distribution redundancy and hybrid dual feed PSU, both the reliability and efficiency can be very high.

NOTE: It can be very easy to implement by using universal input ICT PSU accepting AC and up to 400 VDC. The corresponding interface standard is under development.

The combined architecture would be up to 400 VDC and AC power feed distributions with sources in the same building and equipment rooms. The two power systems can operate from separate AC sources with the same up to 400 VDC battery, backed up or not.

The hybrid and combined systems can use the options of dual power inputs on and ICT equipment PSU as defined in ETSI TS 103 531 [10] or the technical equivalent Recommendation ITU-T L.1206 [16], which may be achieved by a combined cable power feed with selectable power management within ICT.

The issue of DC IT mode detection/localization and fault clearing procedure in coordination with AC distribution, which can be in another ground connection mode, is critical at the technical and operating level. This is covered in clauses 11 and 12 on earthing and bonding, and safety, respectively.

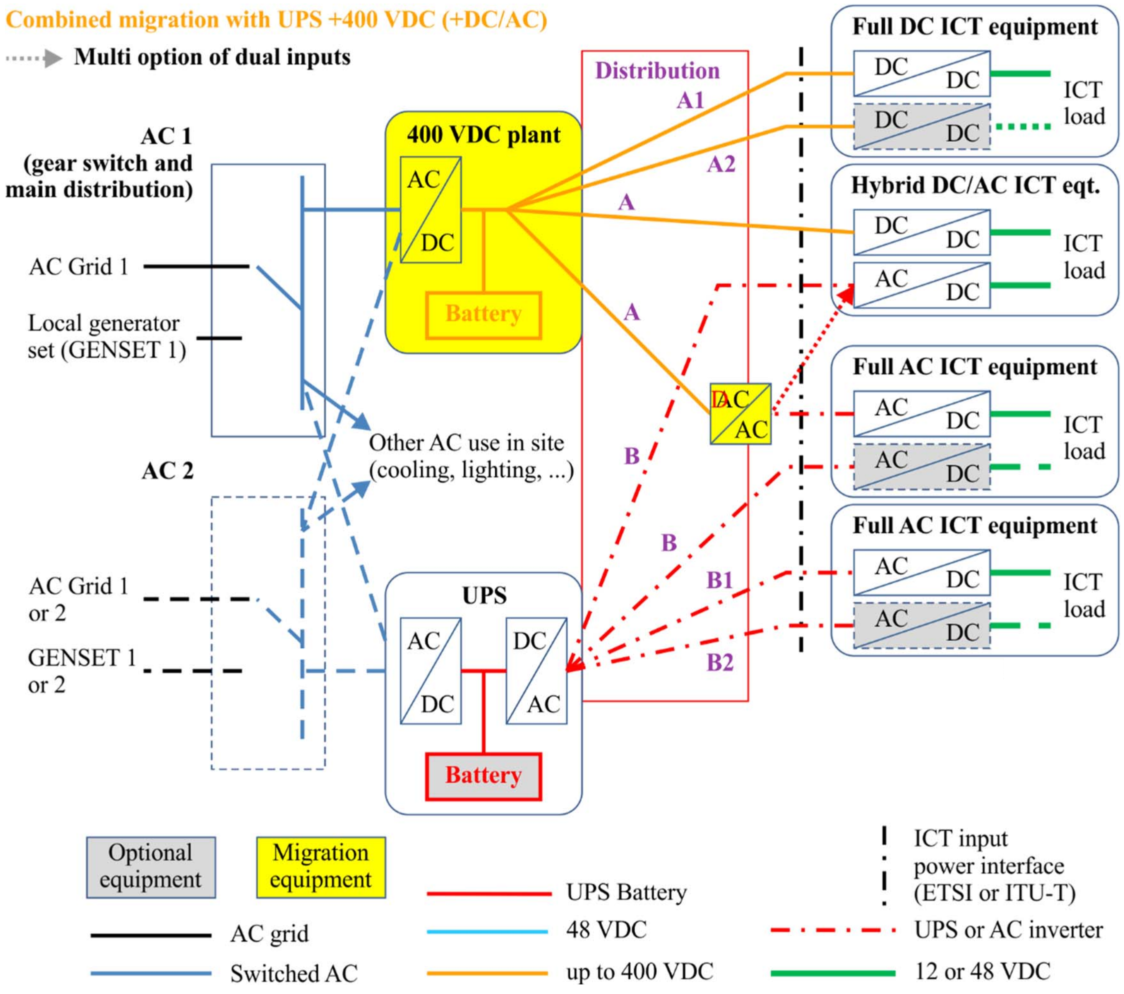

Figure 9: Combined migration architecture from -48 VDC or UPS towards combined up to 400 VDC and existing UPS architecture powering pure or hybrid dual power ICT inputs

An important question is whether a hybrid combined architecture gives benefits over a single interface up to 400 VDC or AC for a new building. A combined architecture can optimize the existing AC power feed by using up to 400 VDC distribution for system expansion.

A good future approach for a migration step towards up to 400 VDC would be a carefully thought out full system architecture. Future data centre power autonomy and use of local REN or connection to DC nanogrid for remote REN sources as defined in ETSI ES 203 474 [9] or in the technically equivalent Recommendation ITU-T L.1205 [15] should be considered.

Migration of AC plug power strips to up to 400 VDC in cabinets in data centres is addressed in clause 5.2.

Discussion of and recommendations for up to 400 VDC batteries are given in clause 8.

5.6 Grid/back-up generator 400 DC switch replacing AC mechanical switch

The DC coupling option shown in Figure 1 can be achieved by using the same up to 400 VDC rectifiers on both source AC grid and back-up generators. A static DC power transfer is obtained by using rectifiers on the output of a diesel generator coupled to a DC busbar powered by DC rectifiers.

Several papers Orange Intelec 2017 [i.34], Telstra Intelec 2017 [i.39], Caltech Berkeley 2017 [i.15] show a great interest in removing the Automatic Transfer Suite (ATS) by using a DC coupling solution.

This static DC transfer removes the main electromechanical switchgear and can improve reliability and maintenance by simple module hot replacement, compared to common switchgear heavy maintenance.

A static DC transfer can put a progressive load on the diesel back-up generator during the required heating period of the engine to get it ready to supply the full load reliably and without ageing stresses.

NOTE: This static switch solution can also be applied to 48 VDC systems.

6 Up to 400 VDC batteries

Operators find battery centralization advantageous for maintenance, charge/discharge/thermal management and safety, as there is always the risk of fire and toxic gas emission with VRLA or lithium batteries in an IT room.

In addition, centralization helps to maximize the available IT floor space to support the line of business or rent to tenants.

With some battery technologies (e.g. advanced batteries), there may be cost, reliability and lifetime advantages in building batteries with bigger cells, but this has to be balanced against the maintenance cost. It is much easier to replace lightweight battery modules (e.g. < 60 kg in the case of VRLA batteries rated 12 V 200 Ah or 2 V 1 000 Ah) and 48 V 200 Ah lithium ion rack).

There is a potential for lithium-ion batteries used in data centres to be optimized for high-capacity storage. Such batteries continue to deliver for longer periods.

On days when autonomy is not required, these batteries can replace local diesel generators and avoid the AC transfer switch or even DC switch by duplicated rectifier for DC coupling (see Figure 2).

In addition, optimization of battery sizing is higher at the centralized level when battery modularity is maintained, as the solution is more flexible for progressive battery installation, i.e. string by string (possibly cabinet by cabinet for up to 400 VDC).

Some further optimization can also be considered. For example, tight regulation of the 400 V power feed with its advantages would mean a controlled interface between the battery and the power feeding line (DC/DC), which could offer some flexibility on the battery block, module and string voltage used.

If data centres especially are looking to become autonomous from a utility, ideally they would move the converter from the battery stack to load distribution. Wider up to 400 VDC regulation at the load affects local power converter efficiencies.

In a battery test giving a state of health, capacity and charge level shall be provided. A test is simplified in a centralized system with fewer battery strings at a higher voltage than 48 V. For lithium, a test is simple, as it is integrated into each battery module and there is in general a concentration on a general supervision module. A Total Cost Ownership (TCO) saving might be observed when using lithium batteries compared to VRLA batteries, as described in Annex C.

The interconnection shall be interoperable and shall comply with ETSI ES 202 336-2 [6].

7 Migration of up to 400 VDC remote power to local up to 400 VDC power system

As shown in Figure 2, one target of migration is to power up to 400 VDC remote powering that complies with ETSI EN 302 099 [i.4] from up to 400 VDC power systems rather than from -48 V power systems.

Up to 400 VDC remote powering should develop massively in order to reduce installation delay due to grid connection of access network ICT equipment such as fourth generation (4G) or fifth generation (5G) mobile micro and macro radio cells, and for fixed access Fibre To The x (FTTx) cabinets. The remote power solution should avoid a lot of maintenance and cost as it avoids using batteries and it should be more reliable and resilient. Orange Intelec 2016 [i.33] provides details of configurations and opportunities of up to 400 VDC remote powering on power cable. Hybrid power and fibre optic cable can be used as shown in Figure 7. Remote power can be supplied to many sites from a cluster power site equipped with an up to 400 VDC power station unit coupled to a REN source.

8 Coupling renewable energy to existing buildings distribution with migration to up to 400 VDC

The coupling of REN to an up to 400 VDC system in new or existing buildings shall comply with ETSI ES 203 474 [9] or in the technically equivalent Recommendation ITU-T L.1205 [15], which describes architecture, requirements and power limits for safe and reliable interconnection in any situation. As these buildings may already be equipped with -48 V and AC distribution, the migration to up to 400 VDC is covered.

Data centres especially are looking to move towards autonomous power - minimal interface with a utility. This will put greater emphasis on solar/wind/battery power locally and maybe dictate the distribution of up to 400 VDC and best adoption.

9 Up to 400 VDC cabling, earthing and bonding in the migration period

In general, the earthing and bonding shall comply with ETSI EN 300 253 [4] for -48 V and AC distributions in buildings and ETSI EN 301 605 [5] when including up to 400 VDC distribution, in cohabitation with -48 V and AC distributions.

In general, the AC and DC building distribution shall comply with IEC 60364 [19].

The maximum voltage drop from an up to 400 VDC source output and operating equipment input should not be higher than 15 V at maximum power.

NOTE 1: There may be some additional voltage drop in the battery cabling and interconnection to the main DC distribution frame.

For redundant distribution by double path, the maximum load current corresponds to the power supply on a single path.

Voltage drop on multi-section: the sum of drops on every segment shall not be higher than the end-to-end voltage drop.

NOTE 2: In order to reach optimal cost of distribution, in normal operation the current density in power cable should be calculated at maximum load close to 4 A/mm^2 to avoid oversizing. This can affect the power distribution and the choice of protective devices with interrupting capacity adapted to the calculated battery short-circuit current.

For similar operation to a -48 V or AC system, the distribution is made with:

- main distribution frame on the source output;
- optional sub-distribution frame, e.g. in the equipment room;
- optional row sub-distribution;
- optional final cabinet by:
    - distribution interconnection boxes, e.g. on a raised floor; or
    - optional multisocket power strips in cabinets. In that case, the line shall be sized to sum the maximum power of all plugs or a circuit breaker shall limit the power to a lower value.

The approach for 400 VDC power feed will assume the possible reuse of existing cables in the building.

Any outdoor remote power feeding from the site should comply with ETSI EN 302 099 [i.4] to avoid disturbance to the building distribution.

10 Electrical safety requirements

Safety requirements are not covered by the present document.

The safety level shall not be altered during the whole migration period towards up to 400 VDC with cohabitation of different powering interface (-48 V, AC, up to 400 VDC).

Electrical installation and power supply safety is covered by relevant IEC standards.

NOTE 1: Information technology equipment safety is defined in IEC 60950-1 [i.6] for mains-powered or battery-powered information technology equipment, including business equipment and associated equipment, with rated voltage not exceeding 600 V. IEC 62368-1 [i.7] also specifies safety requirements for ICT equipment. Additional safety requirements might apply with the potential use of existing power feeding cable for outdoor use from a central office, e.g. in remote powering.

NOTE 2: Additional safety considerations may address perceived or otherwise hazards by future users that may not be immediately evident. Such considerations may necessitate adapted communication and training.

The protection of the distribution against very high battery short circuit current and possible local arcing by fast interruption of high currents is covered by safety certification and safety standards.

A study shall be available on these safety aspects and on how to avoid the destructive voltage transient effect when current interruption occurs. It shall contain an overall distribution study of the DC power system short circuit current, *Isc*, and appropriate protections containing:

- values of battery *Isc* with dependence on Depth of Discharge (DoD), temperature and ageing;
- circuit impedance calculations depending on the location of the short circuit: this can refer to ETSI TR 100 283 [i.10] on transient voltage evaluation when a protective device is tripped;
- details of protection for rectifier output to rectifier rack backplane, rectifier rack to DC power bus, rectifier cabinet to battery, main Power Distribution Unit (PDU) to local sub-PDU, etc. by reference to possible architecture specified in Recommendation ITU-T L.1204 [14].

The AC and DC distribution shall comply with ETSI ES 203 408 [8] or in the technically equivalent Recommendation ITU-T L.1203 [13] colours of cable and DC marking to avoid safety issues in particular in migration periods with combined AC and DC distribution in building rooms and equipment.

More information can be found in Fraunhofer Safety Intelec 2017 [i.21], Fraunhofer Droop Intelec 2017 [i.22], Fujitsu-NTTf-Appliance coupler-Intelec 2017 [i.24], DCC+G Fraunhofer 2014 [i.20].

11 Electromagnetic compatibility requirements at the input of telecommunication and datacom (ICT) equipment

ElectroMagnetic Compatibility (EMC) requirements are not covered by the present document. The same safety level shall be maintained throughout the migration period.

Improvements by a DC system and distribution when replacing AC UPS should be observed and evaluated.

NOTE: Telecommunication (ICT) equipment EMC is defined in Recommendation ITU-T K.48 [i.5] or ETSI EN 300 386 [i.9]; other EMC requirements for building power distribution are specified in relevant IEC EMC International Standards. Interference between distribution cabling is covered by the relevant ITU-T K series Recommendations.

12 Impacts on energy efficiency and other key performance indicators (environmental impact, life cycle assessment)

The right way to evaluate energy efficiency and other environmental impacts, e.g. by Key Performance Indicators (KPIs), is to refer to appropriate Recommendations and standards. Recommendation ITU-T L.1202 [12] shall be applied for comparative energy efficiency assessment, Recommendation ITU-T L.1320 [17] for assessing energy consumption, and energy efficiency KPI. ETSI ES 203 474 [9] or in the technically equivalent Recommendation ITU-T L.1205 [15]; Recommendation ITU-T L.1410 [18] or the technically equivalent ETSI ES 203 199 [7] are used to assess lifecycle environmental impact of up to 400 VDC solutions used for migration.

Annex A (normative): Power supply and interface considerations

When ICT converters are designed to operate from either up to 400 VDC or 230 V alternating current (230 VAC) supply, this may optimize and simplify the migration of the system towards DC. In addition, the converters use up to 400 VDC and 230 VAC common sockets/plugs. For optimal migration, the up to 400 VDC interface shall comply with Recommendation ITU-T L.1200 [11], the AC interface shall comply with ETSI EN 300 132-2 [2] and if equipped with dual inputs, the converter shall comply with ETSI TS 103 531 [10] or the technical equivalent Recommendation ITU-T L.1206 [16]. The design of a high-efficiency AC rectifier is one of the considerations for increased efficiency of data centres as it allows the AC transformer to be removed.

Information current at the time of publication suggests that for new data centres an up to 400 VDC system is the obvious choice; however, for the older AC installation, the best approach needs detailed study. Data centres configured with AC power systems that are looking at a rip out and replacement policy could better optimize their power system with quick gain updates that offer immediate energy improvements, and address any future system expansion with the up to 400 VDC distribution solution, i.e. move these older systems forward as combined power distribution solutions.

Consideration should also be given to forthcoming trends in data centres of carbon footprint reduction and more autonomy from power utilities that will affect, in ways difficult to evaluate, future up to 400 VDC distribution solutions.

Consideration should also be given to ongoing developments in the USA and its attempts to improve energy efficiency of data centres. One potential immediate impact could be systems directly powered from a 480 VAC utility or using 690 VDC systems.

Regarding the lower power telecommunication legacy -48 VDC system, the argument for up to 400 VDC migration is very clear due to high savings in copper, increased installation simplicity and flexibility, smaller footprint and expenditure reduction.

Annex B (informative): information on some papers on up to 400 VDC migration solutions, advantages and implementation decision and process

Some papers on up to 400 VDC migration solutions, advantages and implementation decision and process coming from IEEE Intelec conference are listed in the present document; they give more information about the comprehensive work for progressive migration from legacy power interface solutions, e.g. AC from DC source to new DC user loads or from DC source to existing AC user loads. This also includes work on DC distribution.

CE+T Intelec 2016 [i.17] shows the difficulty in studying small efficient inverters from DC source to AC at low cost. The best solution would be to avoid this conversion by immediate change of the user-load to DC interfaces; however, this is not yet possible and this study proposes a transitional DC/AC converter solution close to the servers.

NTT-f Intelec 2016 [i.27] shows the necessity to move from 48 V distribution to a higher voltage with very high power density of new telecommunication core equipment of some 10s of kilowatts per cabinet, i.e. some 100s to 1 000 A requiring difficult copper bar installation at a high cost.

level3-Eltek Intelec 2016 [i.25] shows the efficiency and simplification of using an up to 400 VDC power interface for the introduction of REN in the power chain with less conversion between AC and DC compared to legacy AC distribution solutions with AC UPS. This is in line with Recommendation ITU-T L.1205 [15].

Fraunhofer Intelec 2016 [i.23] shows the interest in correctly modelling electrical fault propagation that will be a challenge in the progressive migration to up to 400 V DC power architectures to limit failures to a partial local impact on the system.

This paper [i.23] also includes the introduction of more REN and services oriented to smart grid or smart energy that introduce another level of complexity in keeping system stability with variable sources and more control loops due to new grid interactions.

In addition to the latest information, some comparative studies of improvements of DC systems over the original AC systems are provided in the bibliography. IEEE Intelec papers and Schneider WP 118 [i.16], Schneider WP 127 [i.38], Caltech Berkeley 2017 [i.15] fully analyse the possibility of using DC technology within the replaced AC system, some White Papers (WPs) being quite objective as they also list progress in AC system solutions.

The full transformation of data centres is included in the "Open compute" approach OCP Murata [i.31], OCP Orange [i.30] that designs for energy efficiency, including the 277 VAC power distribution, which eliminates one transformer stage, and includes the comparison with the use of a single voltage (12,5 VDC) power supply designed to work with 277 VAC input and 48 VDC battery backup. Finally, many rollouts of up to 400 VDC are reported in:

- "A tool for calculating reliability of power supply for information and communication technology systems" [i.13];
- Orange Intelec 2011 [i.32], NTT-f Intelec 2011 [i.28], NTT Intelec 2012 [i.29], CATR Intelec 2012 [i.18];
- "DC power wide spread in Telecom/Datacenter and in home/office with renewable energy and energy autonomy" [i.14];
- Orange Intelec 2016 [i.33], Orange Intelec 2017 [i.34], CAICT Intelec 2017 [i.19].

Annex C (informative): Details on some saving assessment of migration to up to 400 VDC

C.0 Overview

This annex gives details of the savings identified in Table 1 (energy, copper, costs, electronic), and improved reliability and lifetime. Much information can be found in:

- NTT Intelec 1999 [i.26], Orange Intelec 1999 [i.35], Orange Intelec 2005 [i.36];
- "A tool for calculating reliability of power supply for information and communication technology systems" [i.13];
- Orange Intelec 2011 [i.32], NTT-f Intelec 2011 [i.28], NTT Intelec 2012 [i.29] CATR Intelec 2012 [i.18];
- "DC power wide spread in Telecom/Datacenter and in home/office with renewable energy and energy autonomy" [i.14];
- Orange Intelec 2016 [i.33], Orange Intelec 2017 [i.34], Schneider WP 118 [i.16], Schneider WP 127 [i.38], Schneider WP 151 [i.37], Caltech Berkeley 2017 [i.15].

C.1 Energy efficiency

Compared to UPS, the benefits are as follows:

- The omission of the inverter stage as equipment is DC powered from batteries. Real improvements have been made on the latest UPS systems efficiency so that the saving difference is limited to 1 to 3 % with up to 400 VDC as there are fewer conversion stages in the new three phase UPS solutions compared to the older ones.
- A better management of dynamic saving modes similar to 48 V, where the useful operating source modules (rectifiers) can be dynamically adapted to the load with no issues of phase synchronization compared to AC inverters in parallel operation. There is much less risk of power interruption because the battery systems are always connected to load power distribution compared to UPS where the AC power backup depends on the reliability of the complex synchronized DC/AC inverters. A comparative evaluation of reliability is provided in Recommendation ITU-T L.1202 [12].
- However, end load AC/DC PSUs are larger than comparable DC/DC converters and DC/DC may save up to 15 to 20 % space in ICT load racks.

Compared to 48 V system:

- there may be in the long term a gain in rectifier conversion efficiency as rectifiers work at much lower current at output and also a gain on equipment PSU as there may be no rectifier and PFC stage as they work at the same power at lower current at the input;
- the main savings are on copper and energy loss in cables in addition to reduced costly footprint in ICT rooms.

C.2 Energy cost reduction

More than 3 % savings can be achieved on energy consumption.

Site measurements have shown that for high-reliability data centre with redundant online UPS, with not enough modularity in installation due to use of a big AC UPS module for cost optimization, the efficiency is in general low for some years before reaching a high load in the server room.

The site can start with 10 to 20 % load on UPS for one or two servers with an end-to-end overall efficiency of 87 % and finally attain 94 % when the load reaches 35 % on UPS.

In fact, current UPSs do not tolerate without interruption an output overload as high and long, as the overload that an up to 400 VDC system can tolerate when equipped with an on-line battery at the output. These on-line batteries can generally accept high-energy peak demands.

Load estimates should take into account:

- 10 % for peak power;
- reserve for operation of old and new servers for the same service, during replacement.

NOTE: Reserve is for out of voltage maintenance of one UPS chain, while keeping UPS unit redundancy on the other [e.g. installation of 4,8 MW UPS in 2 × (2+1) 800 kW units for powering about 1,6 MW]. This is completely different with up to 400 VDC power chains, as efficiency will stay higher than 97 % from 20 to 80 % load on the rectifier, full installation is sized in 2*N* and progressively installed. So rectifier load remains at 30 to 40 % with end to end efficiency of 95 %.

C.3 Saving on material, area in ICT room and labour

Some studies report more than 80 % savings on material and labour cost by migration to up to 400 VDC mostly due to the following:

- Copper and cabling reduction (see clause C.4), it can reach 30 % saving between up to 400 VDC and -48 V systems).
- Power system and battery centralization avoiding the use of costly ICT room area compared to 48 VDC and local AC inverters. In addition, some studies show a total cost of ownership over 10 years reduced by about 10 % for lithium ion batteries over the more traditional VRLA batteries.
- Simpler system giving similar reliability with less redundancy.
- No need for AC harmonic filtering systems, AC phase balancing and neutral protection.
- More progressive installation due to higher modularity and thus scalability of the up to 400 VDC solutions.
- More flexible installation due to smaller section cable and more power modularity of up to 400 VDC systems.
- More compact up to 400 VDC power and distribution especially compared to 48 V and so there is the possibility of saving a lot of area and difficult work in operational ICT rooms for power system and distribution evolution.

C.4 Less copper and installation cost, progressive installation by modularity

C.4.0 Overview

- For a given power P and voltage U, $I = U/P$.
- Joule cable loss = $RI2$.
- So at constant joule losses, using $U2$ rather than $U1$, R can be increased by a factor of $(U1/U2)^2$.
- In practice, the value is between $U1/U2$ and $(U1/U2)^2$, for example.
- Copper is reduced with voltage increase by the ratio of the rated voltage, e.g. factor 4 for 12 V compared to 48 V for telecommunication equipment (see Figure C.1).

- And factor 1 to 2 for up to 400 VDC compared to common single phase 230 V AC servers.
- Another aspect is that, as equipment installation can be more modular at low cost than for big AC UPS units, there can be also a progressive installation of the distribution, but this saving is more complex to assess.
- It is observed that DC power distribution offers a 10 % copper saving over an AC (400 VAC L-L/230 VAC L-N) distribution.

Figure C.1: Estimation of copper saving comparing -48 V and up to 400 VDC

C.4.1 Reliability and dependability improvement (comparative evaluation using Recommendation ITU-T L.1202)

Compared to a UPS installation providing similar power and autonomy at similar prices, unavailability can be improved by a factor of 10, when considering reliability calculations according to Recommendation ITU-T L.1202 [12].

C.4.2 Lower life cycle environmental impacts

Reduced LCA impacts come from cost saving as in clause C.4.1, i.e. less copper, less complex equipment, longer lifetime, less battery use, as well as more modularity and flexibility.

The evaluation should be made using LCA Recommendation ITU-T L.1410 [18] or the technically equivalent ETSI ES 203 199 [7].

C.4.3 Solar power input to power distribution

400 VAC distribution at load would increase the complexity of autonomous data centre power as local battery/solar/wind would require inverter interfaces (AC UPS).

However, tight regulation for up to 400 VDC feed may also add complexity to potential solar interfaces, so comparison is not obvious.

C.4.4 Open innovation

The possible future use of 480 VAC may improve system efficiency, although this presents challenges as far as efficient load rectification is concerned, and ask whether this is a future development, and whether adopting up to 400 VDC will limit future updates. Some advocate future DC systems potentially at 690 VDC. However, currently the majority of players push towards a trend to intermediate voltage allowing optimization by massive industrialization and cost reduction by using Recommendation ITU-T L.1200 [11] or ETSI EN 300 132-3 [3].

Other voltages need further research.

History

Document history		
V1.0.0	June 2022	Membership Approval Procedure MV 20220820: 2022-06-21 to 2022-08-22