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

Sustainable power-feeding solutions for 5G networks

Recommendation ITU-T L.1210

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.1210

Sustainable power-feeding solutions for 5G networks

Summary

Recommendation ITU-T L.1210 defines power-feeding solutions for 5G, converged wireless and wireline access equipment and networks, taking into consideration their enhanced requirements on service availability and reliability and new deployment scenarios, along with the environmental impact of the proposed solutions.

The minimum requirements of different solutions, including power-feeding structures, components, backup, safety requirements and environmental conditions, are also defined.

This Recommendation is applicable to the powering of both mobile and fixed access network elements, in particular equipment that have similar configurations and needs.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T L.1210	2019-12-22	5	11.1002/1000/14079

Keywords

5G powering, energy efficiency, hybrid cables, power backup, remote powering, smart energy, sustainable.

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Introduction

Mobile and fixed networks are evolving towards ultra-broadband, and with 5G are going to converge. The use of much broader frequency ranges of up to 60 GHz, where radio propagation is an issue, is going to impact network deployment topologies. In particular, the use of higher frequencies and the need to cover hot/black spots and indoor locations will make it necessary to deploy much denser amounts of radio nodes.

5G is introducing major improvements to massive multi-input multi-output (MIMO) antenna, Internet of things (IoT), low latency connection, unlicensed spectrum, as well as improvements to vehicle to everything (V2X) for the vehicular market. Support of some of these services will have a relevant effect on the power ratings and energy consumption of radio base stations.

A major new service area of 5G which will impact the powering and backup of radio base stations is ultra-reliable low latency communication (URLLC) as its support will increase the service availability demands by many orders of magnitude. Supporting such high availability goals will be partly reached through redundant network coverage, but a main support will have to come through newly-designed powering architectures. This will be made even more challenging as 5G will require the widespread introduction of distributed small cells. [b-ETSI TS 110 174-2-2] analyses any implications and indicates possible solutions to fulfil such high demanding availability goals.

There is a need to define sustainable and smart powering solutions, that are able to adapt to present mobile network technologies and that are able to adapt to their evolution. The flexibility would be needed at the level of power interface and power consumption, and be architecture tolerant to power delivery point changes including control-monitoring.

This means that it should include from the beginning appropriate modularity and reconfiguration features for local powering and energy storage and for remote powering solutions including power lines sizing, input and output conversion power and scalable sources.

A technical equivalent of this Recommendation is jointly developed by the European Telecommunications Standards Institute – Environmental Engineering (ETSI EE) as Standard [b-ETSI ES 203 700].

Recommendation ITU-T L.1210

Sustainable power-feeding solutions for 5G networks

1 Scope

This Recommendation defines power-feeding solutions for 5G, converged wireless and wireline access equipment and networks, while taking into consideration their enhanced requirements on service availability and reliability, new deployment scenarios, together with the environmental impact of the proposed solutions.

Also defined are the minimum requirements of different solutions, including power-feeding structures, components, backup, safety requirements and environmental conditions.

This Recommendation is applicable to the powering of both mobile and fixed access network elements, in particular to equipment with similar configurations and needs.

The future development of 5G networks will create a new scenario in which the density of radio cells will increase considerably, together with the increase of wireline network equipment, that are going to be installed in the vicinity of the users; thereby, this creates the need to define new solutions for powering that will be environmentally friendly, sustainable, dependable, smart and visible remotely.

The –48 VDC, up to 400 VDC local and remote power solutions defined respectively in [ETSI EN 300 132-2], [b-ETSI EN 302 099] and [ITU-T L.1200] will be considered as the Standards in force for power facilities, together with [IEEE 802.3] that concerns power over Ethernet (PoE).

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.64] Recommendation ITU-T K.64 (2016), *Safe working practices for outside equipment installed in particular environments*.

[ITU-T L.1001] Recommendation ITU-T L.1001 (2012), *External universal power adapter solutions for stationary information and communication technology devices*.

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

[ITU-T L.1221] Recommendation ITU-T L.1221 (2018), *Innovative energy storage technology for stationary use – Part 2: Battery*.

[ITU-T L.1222] Recommendation ITU-T L.1222 (2018), *Innovative energy storage technology for stationary use – Part 3: Supercapacitor technology*.

[ITU-T L.1350] Recommendation ITU-T L.1350 (2016), *Energy efficiency metrics of a base station site*.

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

[ETSI EN 300 132-1] 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)*.

[ETSI EN 300 132-2] ETSI EN 300 132-2 V2.16.1 (2019), *Environmental Engineering (EE); Power supply interface at the input of Information and Communication Technology (ICT) equipment; Part 2: –48 V Direct Current (DC)*.

[IEEE 802.3] IEEE 802.3-2018 (2018), *IEEE Standard for Ethernet*.

[IEEE 802.3bt] IEEE 802.3bt-2018 (2019), *IEEE Standard for Ethernet Amendment 2: Physical Layer and Management Parameters for Power over Ethernet over 4 pairs*.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 cell [b-ITU-T Q.1743]: Radio network object that can be uniquely identified by user equipment from a (cell) identification that is broadcasted over a geographical area from one UTRAN or GERAN access point. A Cell in UTRAN is either FDD or TDD mode.

3.1.2 macrocell [b-ITU-T Q.1743]: "Macrocells" are outdoor cells with a large cell radius.

3.1.3 microcell [b-ITU-T Q.1743]:"Microcells" are small cells.

3.1.4 picocell [b-ITU-T Q.1743]: "Picocells" are cells, mainly indoor cells, with a radius typically less than 50 metres.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 cloud RAN (**C-RAN**): A radio access network (RAN) where functions are partially or completely centralized, with two additional key features: pooling of baseband/hardware resources, and virtualization through general-purpose processors.

3.2.2 distributed RAN (**D-RAN**): This is a network development where radio access network (RAN) processing is fully performed at the site, as in 4G.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

5G fifth Generation

AAU Active Antenna Unit

AC Alternating Current

BBU Base Band Unit

BCS Battery Control System

BMS Battery Management System

BRAS Broadband Remote Access Server

BS	Base Station
C-RAN	Centralized or Cloud Radio Access Network
DC	Direct Current
DOD	Depth Of Discharge
DP	Distribution Point
D-RAN	Distributed Radio Access Network
DSLAM	Digital Subscriber Line Access Multiplier
E2E	End-to-End
EV	Electric Vehicle
FDD	Frequency Division Duplex
FWA	Fixed Wireless Access
GERAN	GSM/EDGE Radio Access Network
GND	Ground
GPON	Gigabit Passive Optical Network
HetNet	Heterogeneous Network
ICT	Information and Communication Technology
IoT	Internet of Things
LFP	Lithium Iron Phosphate
MCB	Miniature Circuit Breaker
MEC	Multi-access Edge Computing
MIMO	Multi-Input Multi-Output
mmWaves	millimetric Waves
MPPT	Maximum Power Point Tracking
NE	Network Element
O&M	Operation and Management
OLT	Optical Line Terminal
OPEX	Operating Expense
OTN	Optical Transport Network
PAV	Power Availability
PoE	Power over Ethernet
PON	Passive Optical Network
PSU	Power Supply Unit
PTC	Positive Temperature Coefficient
PTU	Power Transmitter Unit
PVC	Polyvinyl Chloride
RAN	Radio Access Network
RBS	Radio Base Station

REN	Renewable Energy
RF	Radio Frequency
RRH	Remote Radio Head
RRU	Remote Radio Unit
SDH	Synchronous Digital Hierarchy
SEE	Site Energy Efficiency
SELV	Safety Extra Low Voltage
SOC	Status Of Charge
SOH	Status Of Health
SOHO	Small Offices Home Offices
TDD	Time Division multiplexing
TTM	Time To Market
URLLC	Ultra-Reliable Low Latency Communication
UTRAN	Universal Terrestrial Radio Access Network
V2X	Vehicle to Everything
VAC	Volts Alternating Current
VDC	Volts Direct Current

5 Conventions

None.

6 5G networks

6.1 5G network general description

Figure 1 shows a general end-to-end schematic of a 5G network with interconnectivity between the different emerging technologies such as massive MIMO networks and cognitive radio.

It includes stationary and mobile equipment:

– Macrocell equipment base station (BS) for wide coverage: In most cases, they will be located in the same sites as the macro-BS of the previous mobile generations. The increased energy demand and the much higher availability need of the 5G equipment will pose tough challenges to the powering infrastructure and will likely require major upgrades, both in the power capabilities and the backup duration.

– Small cells: These cover a small geographical area in indoor/outdoor applications, typically to satisfy data traffic hotspots, black spots and to deliver services at very high frequencies (e.g., mmWaves), that could not be supported through macro-BS installations alone. Small cells can be subdivided into:

  - Microcells – normally installed outdoors. These are designed to support a large number of users in high data traffic areas, to solve coverage issues and to support very high frequency deployment. Capable of covering medium/large cells and suitable for application such as smart cities, smart metro, etc.
  - Picocells – normally installed indoors. These are suitable for enterprises, shopping centres, stadium applications, etc. for extended network coverage and data throughput.

- Femtocells – these are small mobile base stations designed to provide extended coverage for residential and small offices home offices (SOHO) applications. Poor signal strength from a mobile operator's base stations can be solved using femtocell implementation. Femtocells are primarily introduced to offload network congestion, extend coverage and increase data capacity to indoor users.

– Internet of things (IoT) devices and concentrators.

– In-network cloud distribution including edge computing.

Also, fixed wireless access (FWA) radio access solutions, typically in point-to-multipoint configuration with coverage across macro and small cells schemes, will contribute to the evolution of ultra-broadband future networks.

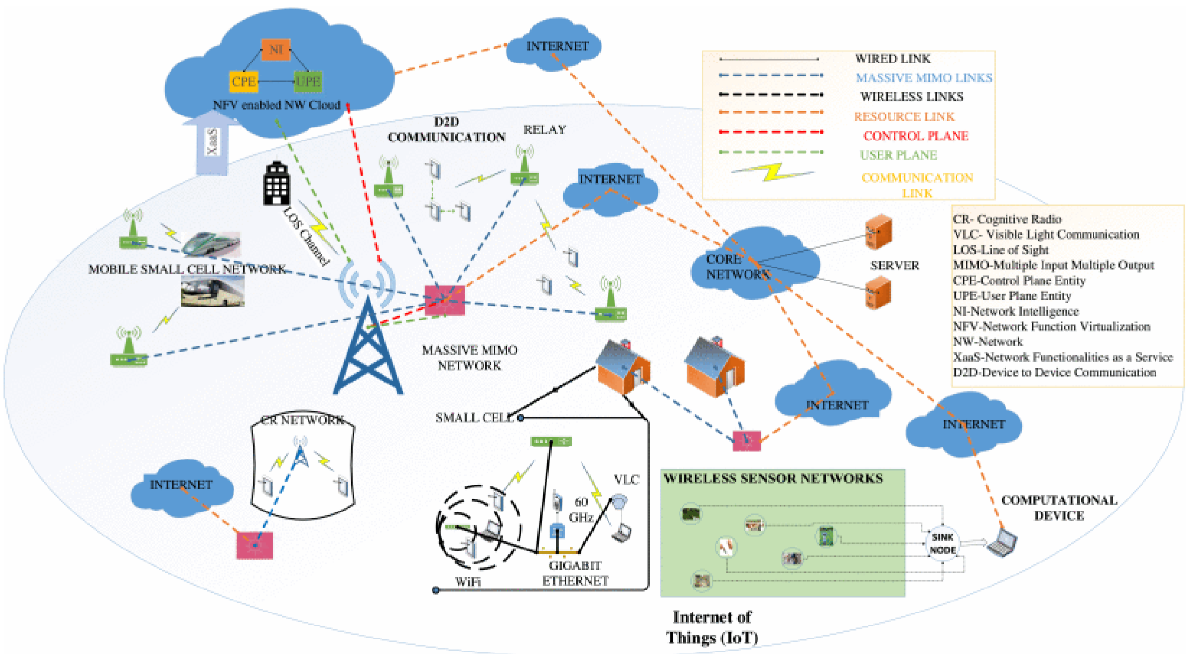

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Figure 1 – A general 5G cellular network architecture

6.2 Cells coverage and impacts on powering strategy

In the 4G era, a base station covers a radius of hundreds of metres, while a 5G base station operating at mmWave may cover only 20 to 40 metres, needing a much higher number of equipment to be spread out in the field to guarantee appropriate coverage. More dense deployment will also be needed to cover high traffic areas (e.g., stadiums) and indoors locations. This could result in much higher network development complexity and costs. In addition, the deployment of additional base stations is difficult and the site resources are not easy to obtain. Therefore, 5G networks will see a major development of small cells, in the form of small base stations as the basic unit for ultra-intensive networking, that is, small base stations with dense deployment. In the future, the most likely deployment mode for 5G base station construction will be low-frequency wide area coverage (macro-base station) + high-frequency deep coverage (micro base station), as shown in Figure 2.

Figure 2 (a) – Deployment mode of the 5G base station

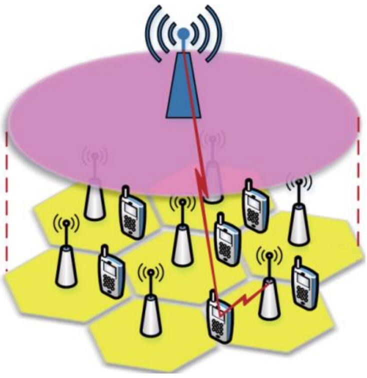


Figure 2 (b) – Micro-base station

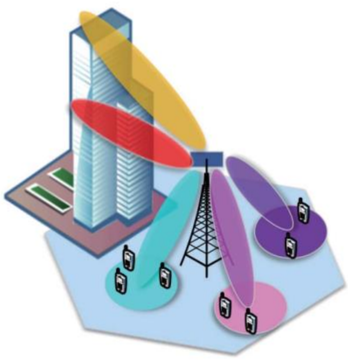


Figure 2 (c) – Macro-base station

The typical electrical power demand for radio base stations (macrocell, microcell and pico or femtocell), with correlation to aggregated radio frequency (RF) power, is listed in Table 1, together with the power needs of IoT, as they could be based on powering paradigms similar to those of the small cells.

Table 1 – Powering related characteristics of radio base station, small cells and IoT

EQUIPMENT	INSTALLATION			POW. CONSUMPTION		POWERING TYPE					Backhauling connection		Aggregated RF power	
	INDOORS Private premises	INDOORS Public sites and enterprises	OUTDOORS	TYP (W)	MAX (W)	BATTERY Duration (years)	Local mains	Remote power	PoE	mimimum BACKUP time	Wireline / Wireless	Connection flavour	MIN (W)	MAX (W)
WIRELESS														
COMPLEX MACRO BASE STATION (e.g. 2/3/4/5G - multiple freq, massive MIMO and multiple operators)			X	8000	24000		X			YES many hours	Wireline	Optical		many hundreds
SIMPLE MACRO BASE STATION (e.g. 2/3/4G - single freq and single operator)			X	3000	6000		X			YES few hours	Wireline / wireless	Optical / mmWave / high speed broadband		few hundreds
MICROCELLS			X	30	250		X	X		advised minutes	Wireline	Optical / high speed broadband	1	20
PICOCELLS (including FWA nodes)		X		10	50		X		X	advised minutes	Wireline	ETH/Optical	0,1	1
FEMTOCELLS	X			5	20		X			NO	Wireline	Any Broadband	0,01	0,1
WIRELINE														
VDSL2 DSLAMs			Cabinets	150	250		X	X		advised minutes	Wireline	Optical		
G.FAST			Cabinets	25	40			X			Wireline	Optical		
IoT														
Gas & water sensing, metering	X			very low		10					Wireless	LP WAN		
Surveillance camera		X	X	5	20		X	X	X	NO	Wireline	Any Broadband		
Environmental sensing (CO2, NOX, noise, particulate …)			X	2	10			X		NO	Wireless	LP WAN		

The most appropriate power architecture will depend on the site type, their coverage, location and distance from grid or from remote power sources.

The power source selection will depend on:

– local grid availability or connection cost and lead time, compared to remote powering;

– services availability (continuity) requirements;

– need to share the power infrastructure between operators;

– availability of renewable energy e.g., photovoltaic;

– possible power connection shared with other users such as street lighting equipment or electric car charging stations.

The power interfaces for each case are described in clause 7.

A possible solution using street lamp posts for small cell deployment can be found in [b-ETSI TS 110 174-2-2].

6.3 Type of 5G network and impacts on power load, power profile and feeding solution

Figure 2 shows base stations in possible 5G cellular network configurations; based on these figures it is possible to identify the 5G required power:

– per site to define the site power supply and AC grid connection requirement;

– for the remote powering cluster site dedicated to many sites in an area. This will depend on line distances and the maximum aggregated power limit considering the AC grid connection available to the cluster site.

The network can have homogeneous patterns based on 1 to 3 macrocell BS per km^2, while it can be more heterogeneous, i.e. heterogenous networks (HetNets), with 10 to 100 cells per km^2 ranging from macro to femtocells, with a possible evolution shown in Figure 3.

– To establish the local power system and the number of power access points either from AC grid or by DC remote powering it is necessary to define the power requirements and energy consumption of each site and the capacity of network element (NE) equipment. The cooling thermal limit and availability of local power can be a determinant parameter.

– To define remote power, the location and configuration is very important, as it will need to reuse existing pairs or existing ducts to install power cables (or hybrid powering/optical cable). In the case where this would turn out to be impracticable, building new buried or aerial lines can be considered, although this is going to be more expensive.

For all cases it is required to know the different types of 5G cells and NE power load profiles and its evolution on each site.

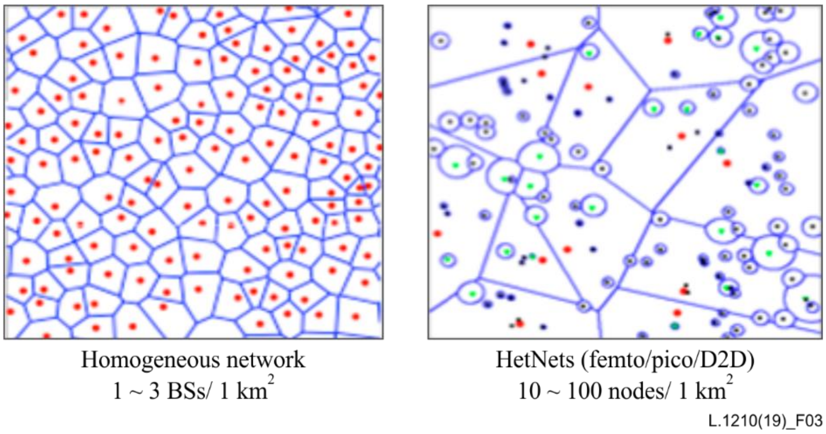


Figure 3 – Evolution of 5G cellular network configurations to HetNets

Figure 4 shows an estimation of possible power requests for a full radio site containing different bands for different development of 5G technologies.

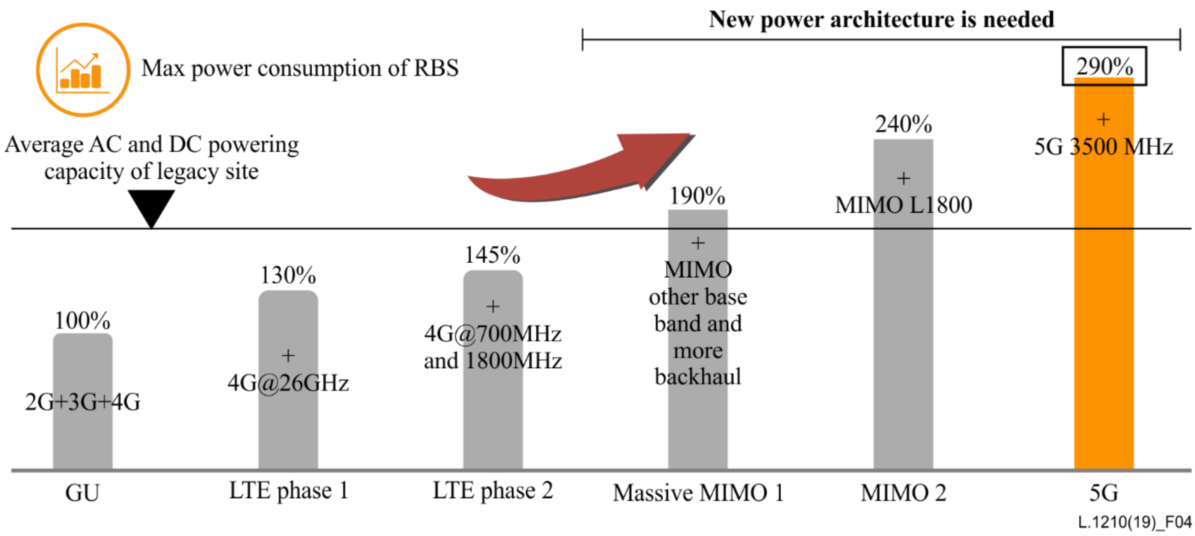


Figure 4 – Estimate of radio base station power site rating

7 Powering solutions

This clause defines requirements on 5G powering considering different site topology.

The 5G NE power interface voltages commonly used are listed below:

– ETSI EN 300 132-2 interface A for 40.5-72 VDC powering. The equipment of the remote radio unit / active antenna unit (RRU/AAU) is designed to work with the most common powering architectures found in telecommunication sites with operating voltages in the range –40.5-72 VDC. Feeding DC voltages within such a range enables the use of common and lower cost equipment. The use of voltages below 60 VDC incurs far less demanding safety requirements and eases installation and maintenance. However, within legacy telecommunications cabling, the need to limit the power losses resulting from the relatively high currents required restricts the maximum reach of this type of solution.

– ETSI EN 300 132-1 interface A1 for AC powering.

– ITU-T L.1200 interface P for up to 400 VDC powering.

– ITU-T L.1001 for low DC voltage 5 V or 12 V e.g., used for little 5G femtocells or picocells.

– IEEE 802.3 allows the same cable to provide both data connection and electric power to the devices. Sometimes referred to as power over Ethernet (PoE), [IEEE 802.3bt] specifies remote power feeding over 2 and 4 balanced pairs of cables of category 5 and above as specified in [b-CENELEC EN 50173-1]. In addition, [b-802.3cg-2018] specifies remote power feeding of a variety of 1 pair balanced cables. Both implementations use voltages of below 60 VDC. The power feeding of [IEEE 802.3bt] provides up to 71 W at the remote equipment using 4 balance pairs at a maximum distance of 100 m while [b-802.3cg-2018] delivers 14 W at 300 m and 2 W at 1000 m.

Clauses 7.1 and 7.2 consider the power requirement for:

- aggregation and core equipment room (clause 7.1);
- cloud radio access network (C-RAN) and distributed radio access network (D-RAN) site (clause 7.2).

7.1 Convergence and core room power supply

7.1.1 Scenario 1: –48 VDC power supply solution

Figure 5 shows a power-feeding distribution in the case using a –48 VDC power supply solution. The system needs to support –57 VDC power supply; it is defined in [ETSI EN 300 132-2] that the upper limit value of a –48 VDC system should be –57 VDC.

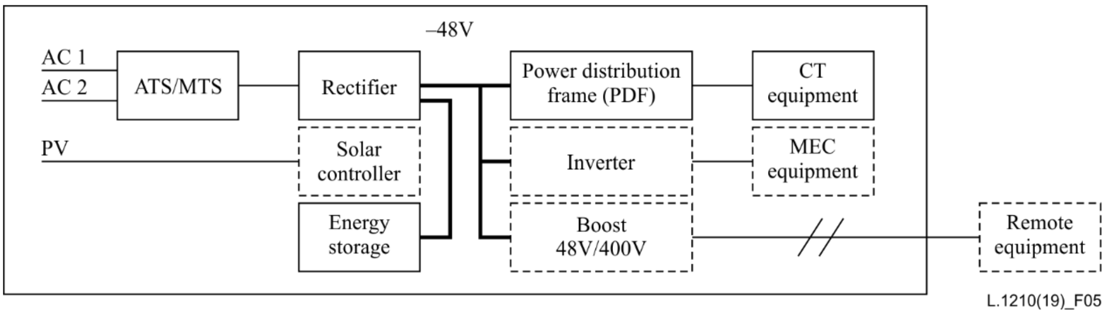


Figure 5 – Network diagram of –48 VDC power supply solution

NOTE 1 – AC2 can be a diesel generator or any other type of emergency generator.

NOTE 2 – Energy storage in some cases can be a fuel cell.

NOTE 3 – In some cases a wind generator can be used to replace a solar photovoltaic (PV) system or be used in conjunction with it.

7.1.2 Scenario 2: up to 400 VDC power supply solution

Figure 6 shows a power-feeding distribution in the case of using an up to 400 VDC power supply solution. The up to 400 VDC system decreases voltage drop on cable and allows for a much smaller cable size, which reduces cable investment and makes it easier to be installed.

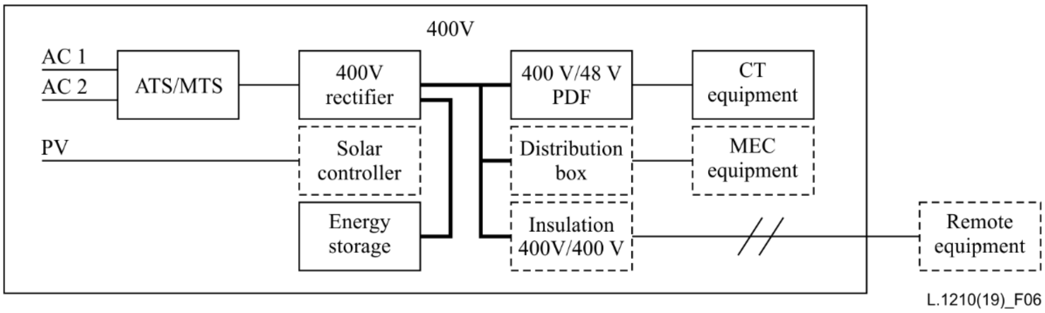


Figure 6 – Networking diagram of the up to 400 VDC power supply solution

NOTE 1 – AC2 can be a diesel generator or any other type of emergency generator.

NOTE 2 – Energy storage in some cases can be a fuel cell.

NOTE 3 – In some cases a wind generator can be used to replace solar photovoltaic (PV) system or be used in conjunction with it.

7.1.3 5G power supply solution for aggregation and core equipment room

Considering the changes in the power supply requirements of the 5G network for the core room and future evolution, the proposed power solution should have the following features:

1) Input and output voltage:
   - multiple energy input and multiple voltage output to meet information, communications and technology (ICT) integration needs;
   - multi-input: multi-type of AC energy inputs and solar (optional wind) energy input;
   - multi-output: 230 VAC, 400 VDC and other voltages output by adapting different power modules.
2) Lithium batteries:
   - Lithium replacing lead-acid battery is expected to reduce by more than a 60% the footprint to meet the space requirement of business expansion. Furthermore, the low dependency of lithium to the room temperature allows installing it in ICT rooms.
   - Lithium battery meets anti-fire requirement: ① battery material: at current stage of technology lithium iron phosphate is required for safety concern; ② safety management: abnormality of external charging voltage and current does not affect battery safety work; ③ flame-retardant: materials used in battery pack must meet UL 94-V0; ④ fire control: when the cell has a fire problem, the flame inside the battery pack must not leak outside, and the temperature of the battery pack outer surface must not exceed 120 °C.
   - Lithium discharge capability in parallel: When the modules are connected in parallel, the maximum discharge capacity can reach P*N without output power derating; P is the maximum discharge capacity of a single battery, and N is the number of batteries in parallel.
3) Green and efficient:
   - The system allows green energy (such as solar energy) access smoothly and gives it priority.
   - The system can output –57 VDC, which saves cable loss by 10%~20%.
4) Digital and intelligent management: The power system and the room environment information such as humidity and temperature can be managed by a remote network management system.

5) Additional safety requirement: Safety functions such as safe start up, insulation monitor and AC utility monitor are needed for enhancing the system safety.

Description:

- Safe start up: system automatically checks the cable route and remote load correctness in a safe voltage mode, then outputs a voltage up to 400 VDC for remote load.
- Insulation monitor for 400 VDC: monitors system insulation impedance, including + to GND and – to GND. Triggering alarm or cutting output when impedance is lower than defined threshold.
- AC utility monitor: detects AC voltage on the system. Triggering alarm or cutting output when impedance is lower than defined threshold.

7.2 Impact of 5G in C-RAN and D-RAN sites

7.2.1 Changes due to 5G implementation

The power consumption of 5G increases significantly compared with that of 4G. In the 5G era, for example, the estimated maximum power consumption for the 64T64R active antenna unit (AAU) could be 1 000 W-1 400 W, and the estimated maximum power consumption of the base band unit (BBU) could be approximately 1 200 W-1 500 W including also actual 3G and 4G cards.

Multiple bands in one site will be the typical configuration in 5G. The proportion of sites with more than five bands will increase from 3% in 2016 to 45% in 2023. As a result, the maximum power consumption of a typical site will exceed 10 kW, while in a site where there are more than 10 bands, the power consumption will exceed 20 kW. In the multi-carrier sharing scenarios, this figure will be doubled.

7.2.2 Construction and modernization challenges posed by 5G network evolution

- Grid reconstruction challenges

Grid connection sizing of the existing sites may be insufficient due to power consumption increasing when 5G accesses. Grid modernization is expensive and greatly slows down the pace of 5G deployment.

Over 30% of global sites need grid modernization. The time to modernize the grid could be about one year per site.

- DC power distribution challenges

A 5G single-band power distribution requires at least two 100 A inputs (or four 32 A and three 63 A inputs). For example, over 75% DC circuit breakers of a carrier in China are 63 A or smaller, which is insufficient for 5G access.

In a remote scenario with high-power AAU, a huge voltage drop on the cable would result in insufficient voltage input for AAU, which means the AAU fails to work normally.

- Power backup challenges

The investment of battery expansion would double when 5G accesses. In addition, the low energy density, heavy weight and a large volume of lead-acid batteries further aggravates the difficulty to deploy 5G especially on some rooftop sites with limited weight capacity and space availability.

- Cooling challenges

The heat consumption increases at the same pace as the power consumption. Thus, the heat dissipation capability of some sites needs to expand, which takes a long period of time and necessesitates expensive investment.

- Equipment room and cabinet space challenges

The remaining space in some existing cabinets is insufficient, thus a new cabinet is required for accommodating 5G devices. However, some sites have no extra space for adding new cabinets.

- Operation and Management (O&M) challenges

Higher electricity costs

The current electricity cost accounts for 1%–8% of the carrier's revenue. Since the increase in power consumption and electricity unit price brings much higher electricity costs in the 5G era, energy saving will be one of the core requirements of operators.

More complex maintenance

Diversified 5G services pose more requirements on energy assurance, which will increase the complexity of site maintenance. This is particularly true for when 5G ultra-reliable low latency communication (URLLC) services will have to be supported as such services will require five or more "nines" availability, i.e. 99.999% availability. More bands and higher frequency in 5G sites increases the number of equipment, complexity and manpower for O&M, leading to higher site maintenance costs.

Higher lease costs

The traditional solution for 5G deployment requires new power, batteries and cabinets. As a result, operators have to spend more on renting new rooms to allocate new equipment.

7.2.3 Problems to be addressed by 5G power systems

7.2.3.1 Low cost deployment

The power solution for 5G shall not increase its footprint to avoid high costs on site acquisition, and shall not modernize grids if possible, to reduce reconstruction costs.

7.2.3.2 Fast construction

The power solution for 5G shall be flexible and quickly deployed. For existing sites, the footprint and appearance of the power system should not be changed to avoid time and costs for site renegotiation. For new sites, the footprint should be minimized while the installation should be as simple and fast as possible.

7.2.3.3 Efficient and energy saving

Single-component energy-saving in the past does not meet the requirement for 5G. Full-link end-to-end saving in all components and subsystems must be considered based on both the whole site and the whole network to save on operating expense (OPEX).

7.2.3.4 Smooth evolution

The subsystems of the power solution can evolve to 5G smoothly with the same, or even less, initial investment as 4G construction.

7.2.3.5 Simple O&M

The complexity and cost of O&M greatly increases along with the double site quantity in the 5G era. Therefore, a simpler and efficient O&M method is required to replace the traditional low efficiency way.

7.2.4 C-RAN and D-RAN powering scenario

7.2.4.1 Networking diagram of powering scenario

Figure 7 shows a networking diagram on a non-remote powering scenario in the case of C-RAN.

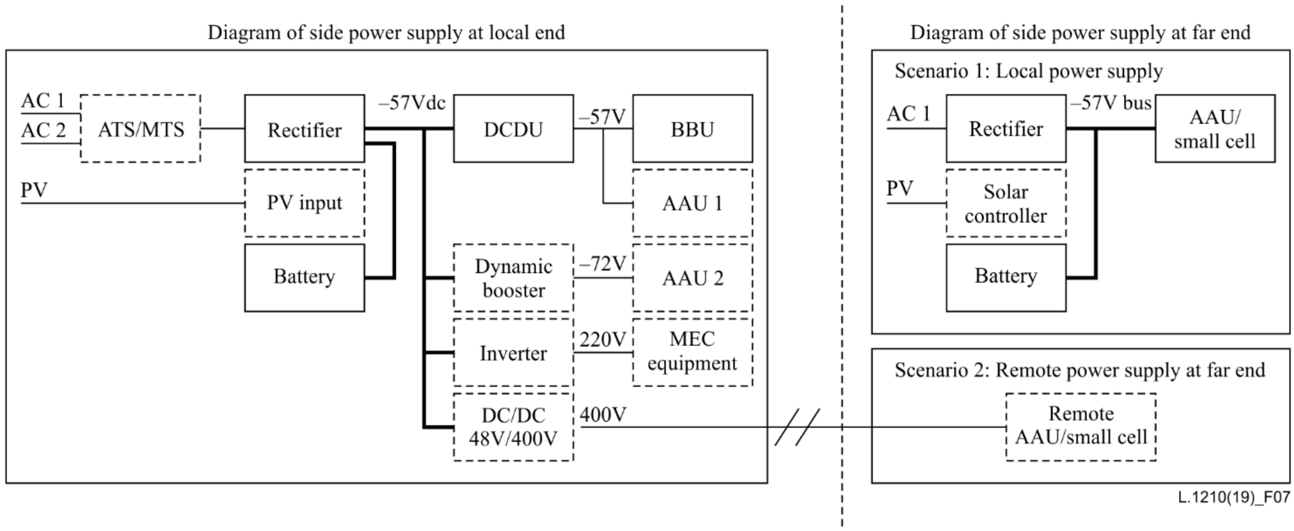


Figure 7 – Networking diagram of C-RAN powering scenario

NOTE 1 – AC2 can be a diesel generator or any other type of emergency generator.

NOTE 2 – Energy storage in some cases can be a fuel cell which supports constant 57 VDC output.

NOTE 3 – In some cases a wind generator can be used to replace solar photovoltaic (PV) system or be used in conjunction with it.

NOTE 4 – It is possible to use a mix of lead battery and lithium battery to take advantage of existing lead acid investment.

NOTE 5 – the remote AAU/small cell should be powered by a DC/DC down converter.

NOTE 6 – The distribution bar is a fixed –57 VDC voltage, energy storage is working at –57 VDC.

In the C-RAN site BBUs are installed centrally. The AAU is divided into two types, one of which is installed remotely and the other one is installed at the C-RAN site. There are two ways to power the AAUs which are remotely installed. One is remote power supply by the local end; the other is to take power directly from the far end.

Considering the requirements of future evolution, the C-RAN site will integrate multi-access edge computing (MEC) equipment, and the power supply system also needs to be smoothly evolved.

Figure 8 shows a networking diagram on a non-remote powering scenario in the case of D-RAN.

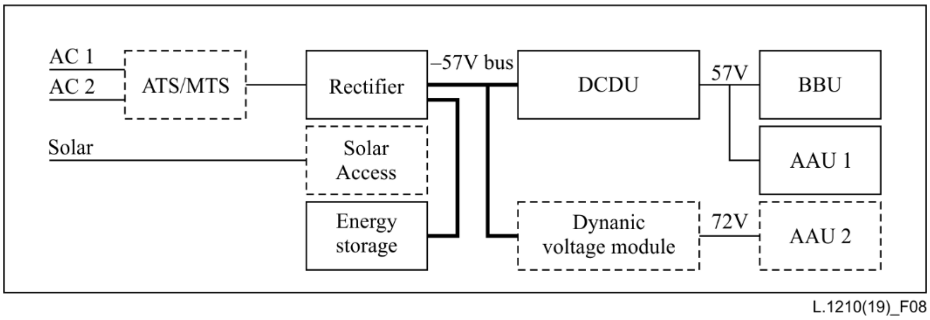


Figure 8 – Networking diagram on non-remote powering scenario in case of D-RAN

In the D-RAN site, a BBU and AAU are installed on site. Generally, there is no need to integrate MEC equipment, and there is no need for remote power supply.

7.2.5 5G power solution for C-RAN and D-RAN site

Considering the changes in the power supply requirements of the C-RAN and D-RAN site in the 5G network and the requirements for long-term evolution, it is recommended that the C-RAN and D-RAN power supply solution provides the following features:

1) Support multi-input and multi-output to satisfy the requirement of ICT convergence:

– Multi-input: multi-input of AC, up to 400 VDC input, and solar/wind access.

• The solar access module needs to be installed in the slot of the rectifier module. The number of rectifier modules and solar access modules can be flexibly configured according to the site requirements. The solar access module needs to support the maximum power point tracking (MPPT) function with a maximum efficiency of > 98% and an MPPT control accuracy of > 99.8%. When solar energy and grid power work at the same time, the system should automatically adjust the output of solar energy and grid power to ensure the priority of solar energy.

– Multi-output: –72 VDC, 220 VAC, 400 VDC, etc. (by configuring different modules).

According to Annex B of [ETSI EN 300 132-1] and shown in Figure 9, the –60 VDC is allowed for telecommunication base station use with normal service voltage up to –72 VDC.

The maximum power consumption of 5G AAU is significantly higher than that of 4G. Under the –48 V system, the maximum allowable power supply voltage of the system is –57 VDC, which can meet the AAU power supply distance of about 100 m. While some AAUs power supply distance will exceed 100 m, reaching to 200 m, this scenario will be supported by the optional –72 VDC interface. The use of voltages below 60 VDC incurs less demanding safety requirements and eases installation and maintenance [ITU-T K.64].

Annex B (informative): -60 V_{DC} systems

When equipment is added to existing -60 V_{DC} systems the requirements given in table B.1, deviating from the requirements of the present document, may be used.

NOTE: This variation may be necessary due to established national practice which cannot be changed for a long period of time, for instance when an existing network structure is based on -60 V_{DC} power feeding.

Table B.1

Nominal value of the supply voltage	-60,0 V_{DC}		
Normal service voltage range at interface "A"	-50,0 V_{DC}	to	-72,0 V_{DC}
Abnormal service voltage range at interface "A"	0 V_{DC} -72,0 V_{DC}	to to	-50,0 V_{DC} and -75,0 V_{DC}

Adapted from: [ETSI EN 300 132-2].

Figure 9 – Voltage definition for –60 VDC voltage

2) Be efficient

a) Rectifier efficient module:

D-RAN scenario: It is recommended that the standard of rectifier efficient modules be improved from 96% to 97% to balance the investment and efficiency requirements of massive D-RAN sites.

C-RAN (MEC) scenario: It is recommended to use a super high efficient 98% rectifier module to achieve more benefits, considering high power consumption of C-RAN.

b) Efficient cooling:

It is recommended to adopt a heat exchanger cooling system for the equipment cabin to save more energy than air conditioners and provide better environment protection (IP55) than direct ventilation. Battery cabins shall adopt suitable cooling systems accordingly for better energy saving and protection.

c) Efficient site:

The outdoor deployment solution is preferred as a site construction. In the cabinet scenario: The site energy efficiency (SEE) of the entire site, defined in [ITU-T L.1350], is improved by 10%+; the SEE to be in the blade power scenario is improved by +15%.

d) Efficient system:

Bus voltage boosting: Boost the bus voltage to 72 VDC, in line with [ETSI EN 300 132-2], maximally to match the AAU requirement when its power consumption increases, reducing the cable loss while satisfying the safety requirement of a –48 V system.

Intelligent boosting: For the AAU powering, the output voltage, of the power-feeding solution, can be adjusted intelligently based on the AAU efficiency curve and cable voltage drop to achieve the highest efficiency of the system composed by dynamic booster, cable connecting the AAU and AAU; these 3 items compose the power supply loop.

e) Solar module:

The solar access module needs to support the MPPT function with a maximum efficiency of > 98% and an MPPT control accuracy of > 99.8%.

f) Other active modules:

Other modules like DC/AC, DC/DC need be selected with high efficiency.

3) Green

a) Solar access (optional wind):

Accept solar energy access smoothly.

b) Fuel removal:

It is recommended to reduce or completely eliminate the use of diesel generators.

Site in off-grid scenario: Choose solar power supply as priority, diesel generator (D.G.) and solar hybrid power as second, D.G. and lithium battery hybrid power as the last option to avoid 24-hour D.G. running.

Site in a poor grid scenario: Agrid and lithium battery hybrid power solution is preferred. D.G. is only used for emergency. Other types of emergency generator can also be used e.g., fuel cell, gas engine, etc.

4) High density

Embedded power: (Power-feeding subracks)

a) Basic power density ≥ 7 kW/U (power distribution included).

b) Basic power capacity ≥ 24 kW (450 A), expandable to 36 kW (600 A) smoothly.

Power in cabinet: (complete power-feeding solution including batteries). The total outside height of the cabinet does not exceed 2 m.

a) The basic power supply capacity is not less than 24 kW, extendable to 36 kW.

b) The installation space for accommodating the telecommunication equipment (excluding the space for the power and the battery) is not less than 15U@24 kW/12U@36 kW. The basic cooling capacity for the TLC equipment is not less than 1 500 W, and can be expanded to 3 000 W maximum.

c) Battery capacity: ≥ 600 Ah.

Outdoor power system for pole/wall/tower mounting solution

a) A fan-free natural cooling design of the power system avoids routine maintenance.

b) Power system density: ≥ 333 W/L.

c) When the power modules systems are used in parallel, the output power of the parallel system shall be no of more than 2 power modules.

5) Intelligent: see clause 7.2.6

6) Additional safety requirements:

Adopting DC remote power supply safety functions such as safe start up, insulation monitor and AC utility monitor to enhance the system safety shall be present.

a) Safe start up: The system automatically shall check the cable route and remote load correctness in a safe voltage mode, then output voltage rises up to 400 VDC to the remote load.

b) Insulation monitor for 400 VDC: The system automatically shall monitor system insulation impedance, including + to GND and – to GND. The system shall trigger alarms or cut output when impedance is lower than the defined threshold.

c) AC utility monitor: The system automatically shall detect AC voltage on the system. The system shall trigger alarms or cut output when impedance is lower than the defined threshold.

7.2.6 Intelligent features for a C-RAN and D-RAN site

7.2.6.1 Intelligent peak shaving

Since the existing grid capacity could only satisfy the peak power of 2/3/4G, it needs to be expanded to meet the later peak power when 5G accesses. A grid expansion includes transformer modernization, power line reconstruction, big engineering and long time to market (TTM).

The 5G power shall be capable of cooperating with the energy storage system to shave the peak power when 5G accesses for minimizing the grid modernization and accelerating the 5G deployment.

Figures 10 and 11 show respectively the peak shaving functionality concept and an example of sizing.

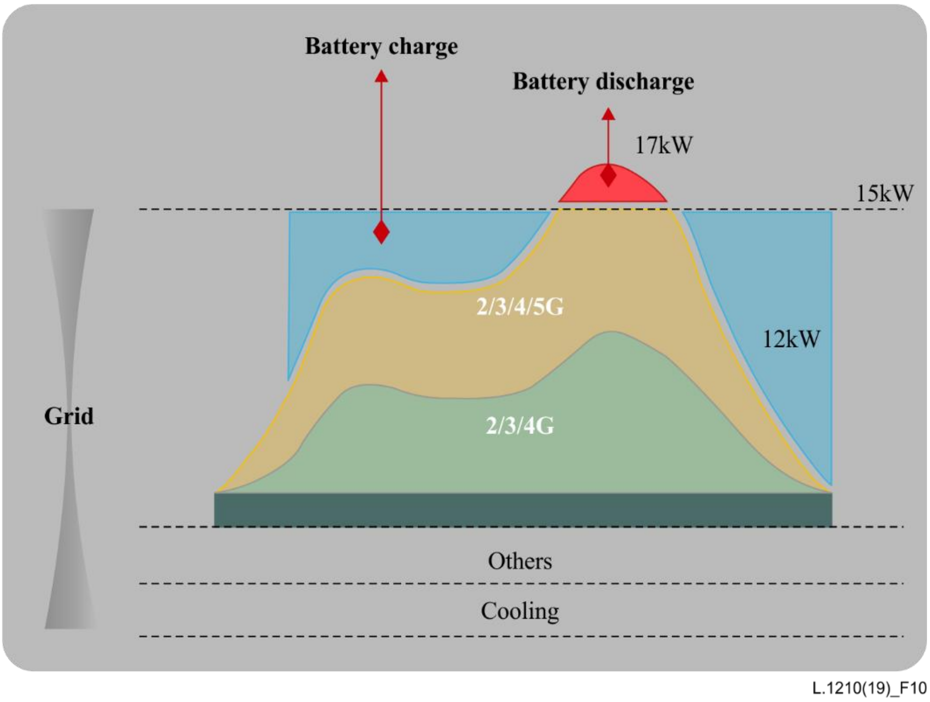


Figure 10 – Peak shaving of a radio site functionality

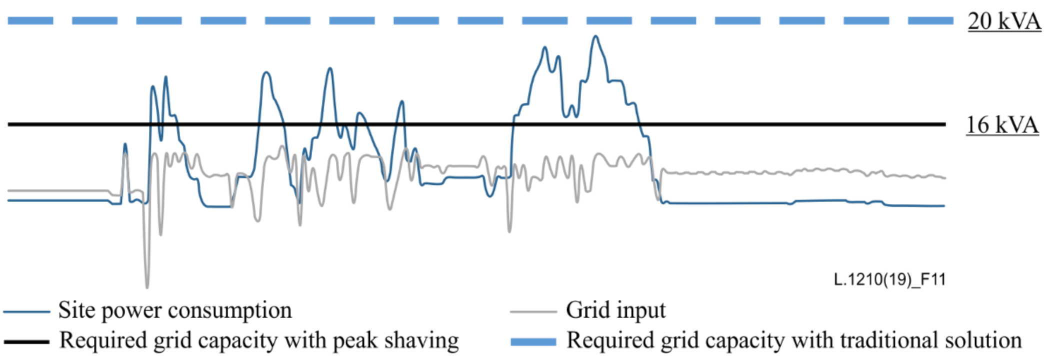


Figure 11 – Example of peak shaving of a radio site sizing

The capacity of the lithium battery for the peak shaving purpose should be designed according to the gap between peak load and grid limit, and also needs to consider the load changing model.

The battery capacity should be designed as reported below:

$$C = (P_{max} - P_{limit} * k1 * k2) * T * 1.25/48\ V * DOD \quad (1)$$

Table 2 shows a calculation example.

Table 2 – Example of backup capacity dimension

C: Capacity (Battery capacity for new peak)	$C = (P_{max} - P_{limit} * k1 * k2) * T * 1.25/(48\ V * DOD)$
P_{max}	Site peak maximum power
P_{limit}	Maximum site grid power
T	Peak duration
k1	Power system efficiency; common value: 0.94
K2	Derating coefficient of grid capacity; common value: 0.8 or 1

Table 2 – Example of backup capacity dimension

DOD	Battery depth of discharge; common value of lithium battery: 0.85
1.25	Safety coefficient (optional); consider based on the actual requirement

An example of battery capacity configuration for peak power under the following assumptions:

a) Existing grid power: 15 kW (enough for 2/3/4G peak power).

b) Peak power of 2/3/4G: 12 kW (including battery charging power).

c) Peak power of 5G access: 5 kW.

d) Peak time/day: 2 hours.

P_{max} = 12 + 5 = 17 kW

P_{limit} = 15 kW

T = 2 h

C = (17 000 W – 15 000 W*0.94*0.8)*2*1.25/(48*0.85) = 350 Ah

Working principle of battery for peak shaving

When a peak that is over the grid power appears, the battery will discharge to shave the extra peak that is beyond the grid's ability. The configured battery capacity, calculated using formula (1), is specific to peak shaving only.

Meanwhile, in order to ensure a reliable power supply and easy site maintenance, a software management platform should be deployed to real-time monitor in real-time the site running status for the operation of peak shaving, and provide early maintenance warnings and optimization suggestions.

The controller shall control the AC input to limit the power from AC below P_{limit} value.

NOTE 1 – The dimensioning of battery capacity needs to consider both the required backup time for the site, as well as the needed backup capacity for the peak shaving function.

NOTE 2 – There is no strict relationship between the miniature circuit breaker (MCB) capacity and the peak shaving function. The breaker capacity should match the specification of the power cable and the design of the battery charge and discharge current.

i.e.: I_charge/discharge ≤ I_MCB ≤ I_wire.

The specific selection refers to the breaker specification/manual from different breaker suppliers. Where I_charge/discharge is the charge or discharge battery current, I_MCB is the breaker trip current, I_wire is the cable maximum current.

7.2.7 Advance sleep/hibernation mode function

A rectifier sleep mode is also a way to maximize the power conversion efficiency of the overall DC power system.

The DC power system controller will automatically put asleep (based on configurable running conditions) one or more rectifiers in order to keep the system efficiency as high as possible.

This function could be useful if the power consumption is very low compared to the total installed power of the DC power system but unnecessary if the DC power system is equipped with the latest high efficiency rectifier modules (≥ 97%) and properly sized.

7.3 Intelligent management

In order to meet the ultimate business requirements of 5G networks, the standard of power reliability, site energy efficiency, O&M efficiency and site safety of the whole network should be much higher. 5G power systems should be able to provide more efficient management and maintenance on the basis of more intelligent software platforms, so as to be ready for 5G network evolution. As an evolutionary 5G power system, it should be equipped with the following four key management abilities.

7.3.1 Power availability management

The power availability value (PAV) refers to the site DC power supply reliability. It is a percentage of site online working time (total time except site shutdown time caused by various DC power supply outages) divided by total designed duration time. The calculation format is:

$$PAV = \frac{\text{Site designed working duration time} - \text{Site outage time}}{\text{Site designed working duration time}}$$

The management of PAV could be helpful for a precise investment to improve power supply reliability.

5G power should be capable of intelligent evolution to manage PAV comprehensively.

- 5G power should be able to manage the site power availability:

  All the key PAV relevant specifications of the power should be measured on the basis of ensuring a reliable power supply.

- 5G power should support PAV foresighted management:

  Besides system analysis to the site history power supply quality, 5G power should also be able to provide foresighted maintenance suggestions for upcoming potential risks. For example, it should analyse the real power backup capability of the energy storage system to provide maintenance suggestions in advance during early grid outages together with the consideration of load changing, so as to avoid site interruption and improve power supply reliability.

7.3.2 Site energy efficiency management

Site energy efficiency (SEE) is an indicator of site end-to-end (E2E) energy usage efficiency. When a particular sum of energy is provided to one site, only part of the energy goes to main devices while the rest is consumed by site-supporting devices such as lighting, cooling, power supply units (PSUs) and power distribution.

[ITU-T L.1350] defines site energy efficiency. SEE is the ratio between the total energy consumption of telecommunication equipment and the total energy consumption on site:

$$\mathrm{SEE} = \frac{\mathrm{E_{CT}}}{\mathrm{E_{TS}}} \times 100\%$$

The power consumption of a 5G network will increase dramatically. Precise management of site energy usage efficiency will help to reduce network energy bills and maintenance costs.

- 5G power solution should have the ability to manage SEE:

  5G power should monitor the energy consumption in detail including the total AC input, main device energy consumption, and every site subsystem's energy consumption. Then it should provide an SEE result, on the basis of detailed calculations. Through big data AI analysis, the system should identify the high-energy consumption and low SEE sites, and also give out the cause analysis. In this case, precise upgrading and investment suggestions could be made to improve the energy efficiency accordingly.

- SEE analysis together with traffic statistics:

  It is not accurate in some cases to judge one site's energy usage efficiency from the power side only. 5G power should consider energy efficiency together with traffic in the future, and pay attention to the energy consumption for every bit of traffic. The ultimate target is bit manages watt to reach high efficiency of bit/watt.

7.3.3 Remote maintenance

– The maintenance of ICT networks should develop towards automation and remote management, so as to improve network production capacity.

– The functionality provided will be able to:

  - Build comprehensive digital sensing ability

    The digital sensing ability of power is the basis to achieving remote and automatic maintenance. 5G power solutions should have a digital sensing ability.

  - Automatic O&M replaces manual O&M

    On the basis of thorough site digitization, traditional manual O&M is substituted by system automatic O&M, which could save large sums in operational costs.

  - Precise site maintenance reduces unnecessary site visits

    In the case of site situation close monitoring, the system provides remote trouble-shooting and cause analysis of malfunctions that have happened and potential risks. The target is to avoid unnecessary site visits and make only one visit to solve all the problems.

7.3.4 Intelligent security

Site quantities will increase in the 5G era and more attention should be paid to the security issue of site assets. 5G power should be equipped with an anti-theft ability to maximize site security and reduce the loss caused by theft.

- Comprehensive digitization is the basis of intelligent security

  It has been proved that the traditional physical anti-theft design cannot solve the theft issue. On the one hand theft is becoming more and more concealed and professional. On the other hand, there is a lack of effective management measures for self-stealing. The reason for these frequent theft issues is the profit chain.

  5G power should build a whole series of digital protection systems surrounding the power and site. For example, a digital lock of the battery that makes it useless if it leaves the site location; site access management automatically records abnormal site visits to avoid theft problems.

- 5G power should ensure site productivity security and asset security comprehensively by adopting innovative anti-theft features such as smart video, smart lock, smart alarm, and cloud and AI.

7.3.5 Intelligent energy storage system

Along with the power consumption increasing during the 5G evolution, the existing energy storage capacity for 2/3/4G is no longer sufficient. However, expanding the battery capacity using the traditional lead-acid battery faces severe challenges:

- limited space and weight capacity of numerous existing sites, including rooftop and greenfield sites, that in the future will lead to to high rental costs, expensive construction costs, long delays for site acquisition and even a lack of space for evolution;
- insufficient power supply distance for 5G equipment on towers due to big cable loss;
- over-capacity configuration in short time backup due to lead-acid battery's weak ability to output its capacity in a short time;
- natural short service life, expensive maintenance costs;
- long charging time.

Lithium batteries in line with [ITU-T L.1221], which can solve all the above problems, are essential for 5G evolution. A lithium battery shall contain the following capabilities to match 5G evolution:

- high density of no less than 25 Ah/U to realize space in-situ replacement for 5G access;
- constant voltage output to satisfy the long-distance power supply for 5G equipment on tower;
- no output power derating when in parallel connection to support large power and reduce battery and cabinet investment;
- the lithium battery needs to communicate with the power system and management system for remote management and control. The remote O&M includes visible battery parameters like voltage, current, temperature, status of charge (SOC), status of health (SOH), and remote test and customized report. The SOC detection deviation shall be less than 5% while the SOH detection deviation shall be less than 10%. The digital energy storage system also can be a solution and an example is shown in Appendix V;
- the lithium battery shall be lithium iron phosphate (LFP) and pass the safety tests such as the nail test, burning test, water-immersion test and thermal shock test based on the no fire and no explosion principle.

7.4 Renewable energy solution for 5G base stations

Different energy sources such as the grid, renewable energy and generators are connected to the input power panels of base stations in this solution. In order to maximize the utilization of renewable energy, the system will be controlled smartly to use the renewable energy first and it will choose the grid, battery storage system or generator based on the operational costs in different conditions considering the cost of the grid and others. An example showing the basic structure of the system is shown in Figure 12.

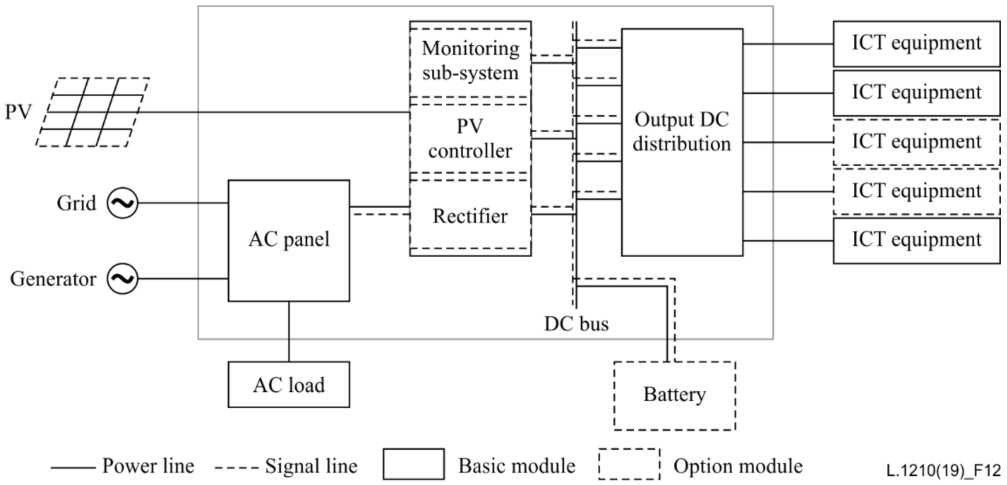


Figure 12 – Multiple energy source input system for 5G base station including renewable energy

When the capacity of the grid is not enough due to the increasing power of the 5G base station, then renewable energy such as a solar photovoltaic (PV) system, wind turbine and fuel cells could be a very good choice to increase the input power capacity to make sure the whole system can work well continuously.

7.5 Hybrid architecture scenario, with integration of power and optical networks

The power infrastructure is a critical point in 5G networks due to the high-density of "small cells", coupled with the high reliability requirements. So, innovative solutions will have to be developed, to achieve lower costs, higher efficiency and reliability goals.

A solution is the 5G hybrid cabling scenario, integrating power and optical networks as optical is the most common backhauling medium.

Local and remote powering are the two possible scenarios for power distribution. Local power implies a direct connection to the AC grid, feeding the cell in AC via a dedicated supply. An AC source could be obtained in different ways: AC grid, connecting to public lighting infrastructure, from private building, etc. Service reliability requirements will need the introduction of a back-up system: supercapacitor, when the need is only to cover micro-interruptions and lithium batteries to cover longer black outs.

While local powering solutions are well suited for current mobile and fixed access networks, cost and efficiency are becoming a main issue when a large number of distributed units are to be powered, in addition to the cost and time constraints for realizing the AC connection.

Furthermore, the impact on the deployment plan could be negatively impacted by the need to locate the cells in suboptimal locations due to the limited availability of connection points to the electric grid.

Remote powering solves most of these issues as:

- connection to AC grid is centralized (less numerous), in a central office or in external power concentrator;
- remote feeding using "up to 400 VDC" voltage reduces the cable dimension allowing the use of the same duct both for optical and power connections;
- to support the required service level, redundancy concepts are applicable, introducing power line duplication or power rings;
- centralized backup represents a more efficient solution with associated cost reductions.

Among the different back-hauling or front-hauling possibilities for future 5G networks, the one based on passive optical networks (PON) is a promising one. It is based on a tree architecture realized using passive optical splitters. The powering structure could efficiently replicate such communications structures.

As shown in Figure 13, a power layer overlays the optical one. The general principle is to reuse at maximum existing infrastructures as is already done for the deployment of optical access networks. This means that power components and cables must also be realized in order to fit these infrastructures (e.g., a power cable should be installable inside a micro-duct for fibre delivery) and hybrid copper-fibre cables have to be taken into consideration.

Basic concepts are:

- introduction of a power splitter where an optical splitter is present;
- usage of "up to 400 VDC" technology in the primary distribution segment;
- usage of safety extra low voltage (SELV) DC voltage to feed the equipment.

Figure 13 shows the hybrid architecture and Figure 14 shows a schematic of the architecture.

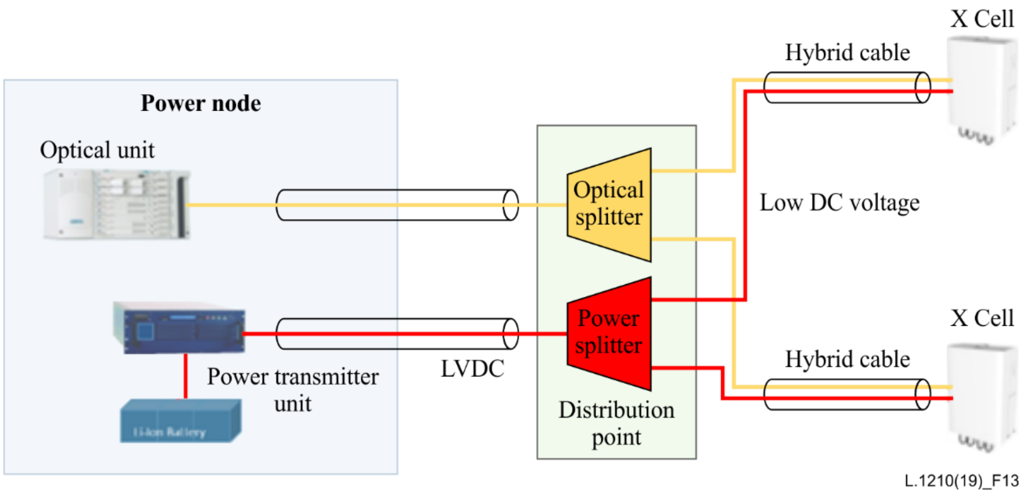


Figure 13 – "Power-optical" hybrid access architecture

Due to the density of small cells, an architecture based on direct connections from power nodes to the remote radio unit could be inefficient. One solution is the introduction of an intermediate distribution point splitting the power network into two different segments.

The first one, at a higher DC voltage, called the 'primary distribution', delivers the power from a power node to a distribution point. The second, at SELV levels, will feed, from the distribution point, the radio equipment remote radio units (RRUs). This will avoid colocation of the power node and optical unit, enabling cost-effective powering.

The expected small cell density suggests connecting a maximum of 8 RRUs to a distribution point at a maximum length of 2 km in the primary distribution and 300 m in the secondary direction with a capability of 100 W on the average RRU, or remote radio head (RRH), power requirement and 1 kW on the primary distribution.

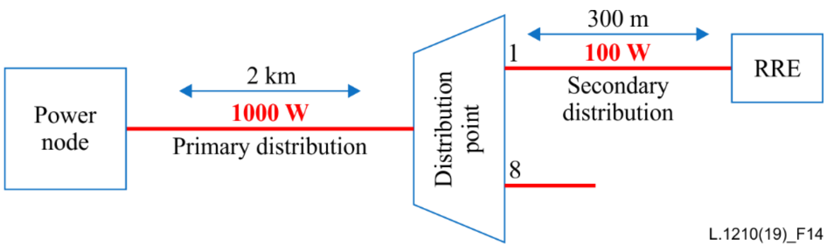


Figure 14 – Architecture schematic

A) Network architecture: primary distribution

Two different architectures are analysed, as detailed in Figure 15 and Figure 16.

A simple tree architecture solution where an AC/up to 400 VDC converter, called a power transmitter unit (PTU), implemented in a power node (PN) feeds a distribution point (DP) where a power splitter (PS) is located, together with an optical splitter (OS). The PN will be in a central office or will be located elsewhere depending the network demand.

This point-to-point architecture provides an efficient solution in terms of cost, simplifying the cabling aspect, but is not the most reliable solution, as a single fault could affect multiple RRUs.

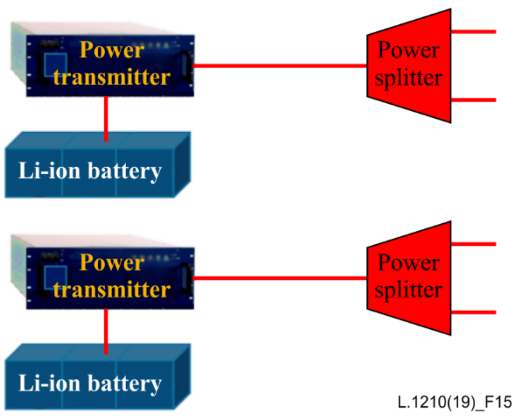


Figure 15 – Tree architecture

A second solution, based on ring architecture has higher reliability. Two PTUs are provided feeding the ring, one on the west side, the other on the east side. This architecture allows the feeding of several distribution points, having a limit only in the cable dimension and in the voltage drop. The PTUs act in a load sharing mode and communicate together in order to maintain alignment of their parameters.

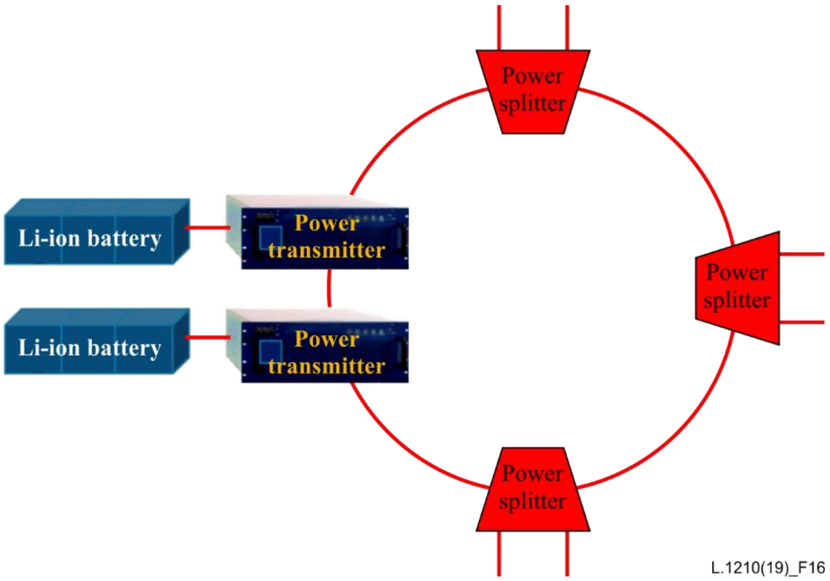


Figure 16 – Power ring architecture

B) Network architecture: secondary distribution

This segment connects the DP to the final equipment RRU. In order to compensate the drop on cables a voltage up to 60 VDC could be used, staying in the SELV range to simplify the safety aspect. The DP is typically installed in a dedicated box, with possible allocation at a cabinet, pole or underground. It mainly consists in a power splitter converting "up to 400 VDC" to SELV levels. An independent converter per RRU can be implemented to avoid influence between outputs in case of fault, increasing service availability as shown in Figure 17.

Redundancy on the input line can be obtained both through a 1+1 configuration or a power ring.

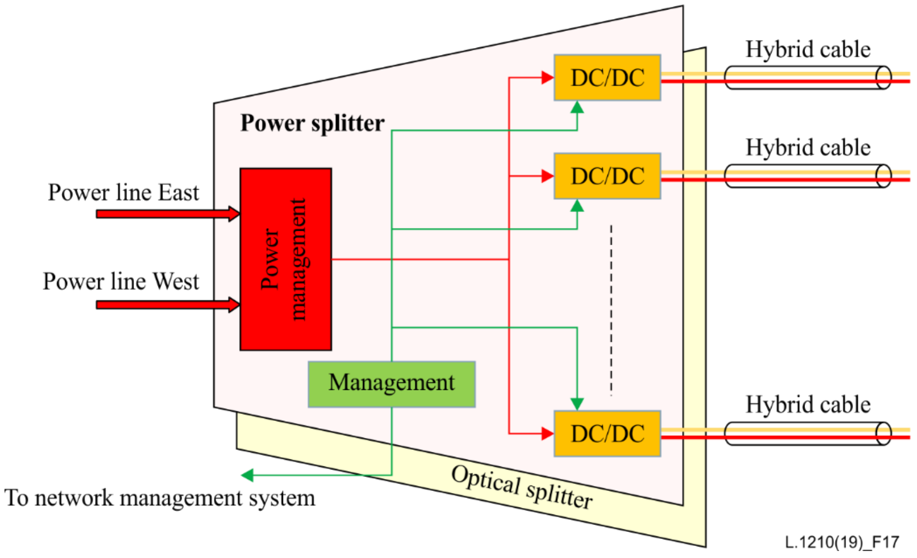


Figure 17 – DP structure

C) Maintenance and control

The characteristics of the power distribution network in terms of field distribution and high density recommends the introduction of management functions to track in real time the network status and carry out the appropriate maintenance activity [b-ETSI ES 202 336-12].

D) Back-up element

The back-up solutions are specified in the series of Recommendation for innovative energy storage selection and test methods overview in [ITU-T L.1220] in the case of batteries in [ITU-T L.1221] and in the case of super capacitors in [ITU-T L.1222].

E) Cables considerations

To implement the scenario described in the present clause, it is not strictly necessary to use new kinds of cables but it is possible to identify some optimal solutions to reduce the overall cost of deployment.

For example, in the primary distribution segment it would be opportune to opt for power cables that can be installed in existing telecommunication infrastructures (e.g., microducts installed to host optical cables).

The secondary feeding segment requires the adoption of a new generation of hybrid or composite cables, being able to carry both signals (through fibre optics) and electric power to supply the radio equipment. These cables are typically characterized by the presence of at least two or more electrical conductors and one or more optical fibres. As specified in [b-ETSI EN 301 605], some conductors could be required for earthing purposes.

It can be assumed that the leading transmission architecture will be the gigabit passive optical network (GPON), needing only one fibre; nevertheless, one extra fibre would be useful as a backup, for architectures using 2 fibres for upstream and downstream direction or for redundant paths. The outer dimensions of the hybrid cables should be small enough to be easily inserted, when required, into PVC microducts (about 10 mm diameter) and the outer jacket of the cable must be made of fire retardant material and resist atmospheric agents (rain, UV rays, ice, etc.). If the installation is mechanically stressful, the composite or hybrid cable must integrate a tensile high strength core, to be safely pulled or to resist external mechanical agents.

The sizes of the electrical conductors are dependent on the applications, that is to say, on the electric load and the distance to be covered. It can be envisaged that the distance should be in the order of 100 ÷ 1 000 m and the electric power around 100 ÷ 1 000 W, in relation to the appropriate distribution segment.

For electrical safety aspects related the adoption of "up to 400 VDC" voltages, the relevant safety standards apply and further details can be found in [ITU-T L.1200].

8 Energy efficiency

8.1 Power equipment energy efficiency

For the purpose of greater efficiency, greener technology and more savings, the efficiency of rectifiers for 5G power is recommended to be more than 97% from 20 to 80%, and more than 94% from 10 to 20% load rate. Load rate with less than 10% indicates an over-configured rectifier. Thus, considering less than 10% load rate is meaningless.

8.2 NE static and dynamic power requirement management and impact on powering

8.2.1 Low power mode management

The network element (NE) shall have a power level dependant to the telecommunication service load, in order to be able to put the power supply of unnecessary modules in deep low power mode. At no service load, the NE shall consume less than 10% of its maximum consumption.

The wake-up shall be sufficiently fast to allow operation without backup considering the hold-up time of the NE as defined at their interface A or A1 or A3.

8.2.2 Global efficiency target

Full standby mode: There shall be at network level a control of nodes activity, to be able to shut down unused nodes and wake them up when required.

8.2.3 Partial low power mode

The network should be able to dynamically drive nodes functionalities to their lowest energy consumption modes compatible with the required level of service.

9 Dependability, reliability and maintenance

The availability and reliability of the powering shall be defined in conjunction with the service and end-to-end network requirements with some margin allowing its evolution.

Table 7.2.2-1 of [b-ETSI TS 122 261] defines the main availability requirements of 5G services. The actual availability of 5G networks will depend on the service categories they are planned to serve.

Other major parameters for selecting and sizing the powering solutions are:

– AC grid availability, quality and time to restore from a grid failure;

– compatibility of a new powering system with an existing NE on the same site;

– power load evolution within the site and the NE configuration evolution (number and type of equipment, setting of the equipment, etc.);

– radio coverage and traffic type.

The availability and scalability requirement guide sets the requirements of power system architecture and sizing parameters, such as the following:

– Power supply and distribution redundancy, when considering remote powering, can be:
  - 1 line for 1 equipment.
  - n lines for 1 equipment.
  - 1 line for n equipment.
  - 1 powering ring which allows one fault in the ring through redundant paths.

– Energy storage autonomy for local powering or at remote powering cluster site level and possibly also on a remote site.

– Choice of power generators (grid, renewable energy, hybrid systems, etc.)

10 Safety

Safety of 5G installation shall follow relevant safety standards in force covering installation requirements and national rules.

11 Environmental impact

Environmental impact assessments of 5G powering solutions shall be conducted in line with the methodologies described in [ITU-T L.1410].

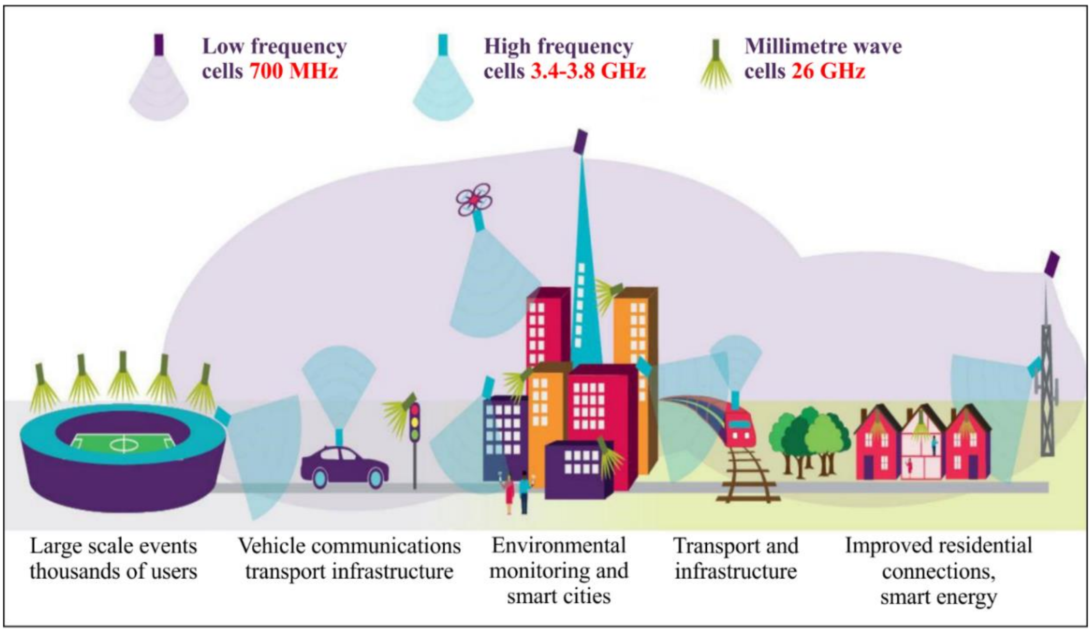
Appendix I

Which power requirement and where for 5G cells

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

This appendix provides information for understanding which power requirement is required and where.

Higher frequency would be used first in the range 700 MHz – 30 GHz (maybe later up to 300 GHz), offering a higher bandwidth than 4G, of up to 20 Gbps. At high frequency and bandwidth it is interesting to work with smaller cells than the macrocells used in previous 2G to 4G. As for 2G to 4G, low band up to 2 GHz are used for the coverage layer, but medium/high band (1 GHz to 6 GHz) increases capacity and very high bands (above 6 GHz) would be used for high traffic areas. At very high frequency the issue of efficient and low cost radio frequency electronics is still a critical point. See Figure I.1.



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Reproduced from [b-Ofcom 5G update]

Figure I.1 – 5G frequency subdivision

This leads to the following hypothesis for cell coverage and density:

– 0.1-0.3 km range small cells rather than 1 km range macrocells. This means a density of cell per km^2 multiplied per 10 to 100.

– The small cell (SC) will be installed far from existing grids or other power indirect connections such as bus stops or street lights (these indirect connections are less convenient as they are switched off during the day, so a battery would be required in the 5G cell).

The SC average power consumption range is in the range of tens of W to hundreds of W.

Another issue is the need and specification of energy backup for covering grid interruption or for optimizing remote power feeding by shaving the power peaks.

If only short interruptions are to be considered, it could be interesting to use a high-power supercapacitor or lithium battery in the ITU-T L.1220 series.

Appendix II

Method of optimization of equipment, power and energy

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

In order to reduce the number of cells and their powering issues and avoid an explosion in power consumption and costs, the following optimization method shown in Figure II.1, is proposed.

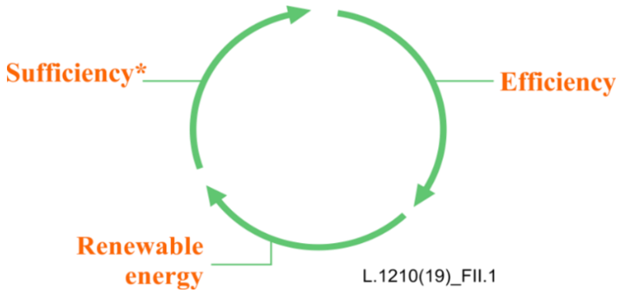

Figure II.1 – Optimization methodology

The method is circular and iterative. It is linked to circular economy targets. It is based on the following three improvement steps:

– function sufficiency is a way to optimize services and minimize functional requirement;

– energy and material efficiency is a way to optimize equipment in terms of impact on the environment, thermal management and electricity bill for operators while matching the required service;

– renewable energy is generally more enabled by the previous efforts as a lower power will reduce the size and cost of generators and energy storage.

The method is described as a circle because the starting step is not always the same.

The method is iterative, because each improvement step can impact the other e.g., by enabling solutions that were not possible before.

In some cases (bad grids, difficult remote powering), standalone energy will be chosen as a first entrance step. It is often desirable to avoid the use of fuel generators and all their issues (higher operational costs, fuel risks, noise, pollution, etc.) depending on the generator type. So renewable energy (REN) is chosen and it absolutely needs to optimize iteratively safe working practices for outside equipment installed in particular environments the power and energy next steps of the circle.

The iterative approach can be applied as follows:

– renewable energy is sized; if it is not enough, e.g., due to available site area or budget target;

– sufficiency is checked. A further functional review is done to reduce functions to what is considered sufficient (e.g., do I absolutely need a maximum bandwidth 24 hours per day and every day?);

– then it is checked if it opens new efficiency gains;

– then the REN is resized; and

– then other turns are done until the solution status is considered acceptable.

This can be done site by site or at the network level as the network optimal solution can be different for each site's optimal solution.

Appendix III

Example of powering requirement definition on site and remote powering area

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

This appendix considers the powering solution rather than the energy consumption of different network configurations, which is a completely different question especially when power is service load dependant, which is required to save energy.

Assuming different cells scale with the following power consumption as an example:

– macrocell site 2 to 8 kW for NE equipment, power station and cooling;

– microcell site up to 500 W;

– picocell up to 100 W;

– femtocell up to 20 W.

Different network configurations and the possible powering solutions can then be studied.

Case study of 1 km^2 homogeneous cell network

There will be very few small and very small cells.

The global power is at 80% for 1 to 3 macrocell sites and so for example less than about 15 kW/km^2, the microcell accounts for 3 kW.

Each macrocell site would be connected to the AC grid with a contract from 6 to 12 kVA, and a remote power of 3 kW can be fed to the few small cells from one macrocell site or existing central offices of the same area to accommodate the existing duct without major changes.

Case study of 1 km^2 cell Hetnet

The power could be used for 1 macrocell complemented by 10 to 100 small cells. For example, 1 macrocell of 5 kW + 5 microcells of 0,5 kW + 20 picocells of 50 W + 50 femtocells of 10 W.

The total power of all these 76 cells is then 9 kW/km^2.

It can be very interesting in this study case to power the small cells without an AC grid connection as the fees will be very expensive; about 4 kW by remote powering, from a cluster site, and the remaining few bigger sites on an AC grid.

In addition, it is highly probable that there will be much fewer than 76 lines as many sites would be gathered on the same main branches with ramifications to distribute small power to picocells and femtocells connected to the same branch (or bus) in the area of 1 km^2.

The macro or microcell site would be connected to the AC grid with a contract from 3 to 12 kVA; while the remote power of 9 kW can be fed to the few small cells from the macrocell site or from a cluster powering site or from existing central offices of the same area, to accommodate an existing duct without major changes.

Appendix IV

Example of required output voltage variation under correlation models between different loads and different cable lengths

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

This appendix considers the required output voltage variation under correlation models between different loads and different cable lengths, which are taken as references when evaluating whether existing cable deployment is acceptable for 5G AAUs working under a general voltage range and temperature conditions of 35°C.

Premise:

1) Consider the conductivity of copper cable being 57 m/Ω*mm^2, R = 2*L/S*σ, with resistivity 0.0175 Ω/m*mm^2 under temperature coefficient 0.00393Ω/°C.

2) The input voltage at the load end from 36 V to 57 V is considered as the general working range of the 5G AAU.

Figure IV.1 shows the results with regard to a 6 mm^2 copper cable.

Figure IV.2 shows the results with regard to an 8.2 mm^2 copper cable.

Figure IV.3 shows the results with regard to a 10 mm^2 copper cable.

Load (W) \ Cable Length (m)	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130
1700	48	48	57	57	57	57	57	57	57	57	57	72	72	72	72	72	72	72	72	72	72	72	72
1600	48	48	57	57	57	57	57	57	57	57	57	57	72	72	72	72	72	72	72	72	72	72	72
1500	48	48	48	57	57	57	57	57	57	57	57	57	57	72	72	72	72	72	72	72	72	72	72
1400	48	48	48	57	57	57	57	57	57	57	57	57	57	57	72	72	72	72	72	72	72	72	72
1300	48	48	48	48	57	57	57	57	57	57	57	57	57	57	57	57	72	72	72	72	72	72	72
1200	48	48	48	48	57	57	57	57	57	57	57	57	57	57	57	57	57	72	72	72	72	72	72
1100	48	48	48	48	48	57	57	57	57	57	57	57	57	57	57	57	57	57	57	72	72	72	72
1000	48	48	48	48	48	48	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57	72	72
900	48	48	48	48	48	48	48	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57
800	48	48	48	48	48	48	48	48	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57
700	48	48	48	48	48	48	48	48	48	48	57	57	57	57	57	57	57	57	57	57	57	57	57
600	48	48	48	48	48	48	48	48	48	48	48	48	57	57	57	57	57	57	57	57	57	57	57
500	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	57	57	57	57	57	57	57
400	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	57	57	57
300	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
200	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
100	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48

Figure IV.1 – Required output voltage variation under the correlation between load and cable length: 6 mm^2 copper cable

Load (W)	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130
1700	48	48	48	48	57	57	57	57	57	57	57	57	57	57	57	57	72	72	72	72	72	72	72
1600	48	48	48	48	57	57	57	57	57	57	57	57	57	57	57	57	57	72	72	72	72	72	72
1500	48	48	48	48	48	57	57	57	57	57	57	57	57	57	57	57	57	57	57	72	72	72	72
1400	48	48	48	48	48	48	57	57	57	57	57	57	57	57	57	57	57	57	57	57	72	72	72
1300	48	48	48	48	48	48	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57	72
1200	48	48	48	48	48	48	48	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57
1100	48	48	48	48	48	48	48	48	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57
1000	48	48	48	48	48	48	48	48	48	57	57	57	57	57	57	57	57	57	57	57	57	57	57
900	48	48	48	48	48	48	48	48	48	48	48	57	57	57	57	57	57	57	57	57	57	57	57
800	48	48	48	48	48	48	48	48	48	48	48	48	57	57	57	57	57	57	57	57	57	57	57
700	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	57	57	57	57	57	57	57	57
600	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	57	57	57	57	57
500	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	57
400	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
300	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
200	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
100	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48

Cable Length (m)

Figure IV.2 – Required output voltage variation under the correlation between load and cable length: 8.2 mm² copper cable

Load (W)	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130
1700	48	48	48	48	48	48	57	57	57	57	57	57	57	57	57	57	57	57	57	57	72	72	72
1600	48	48	48	48	48	48	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57	72
1500	48	48	48	48	48	48	48	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57
1400	48	48	48	48	48	48	48	48	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57
1300	48	48	48	48	48	48	48	48	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57
1200	48	48	48	48	48	48	48	48	48	57	57	57	57	57	57	57	57	57	57	57	57	57	57
1100	48	48	48	48	48	48	48	48	48	48	48	57	57	57	57	57	57	57	57	57	57	57	57
1000	48	48	48	48	48	48	48	48	48	48	48	48	57	57	57	57	57	57	57	57	57	57	57
900	48	48	48	48	48	48	48	48	48	48	48	48	48	48	57	57	57	57	57	57	57	57	57
800	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	57	57	57	57	57	57	57
700	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	57	57	57	57
600	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	57
500	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
400	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
300	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
200	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
100	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48

Cable Length (m)

Figure IV.3 – Required output voltage variation under the correlation between load and cable length: 10 mm² copper cable

Appendix V

Example of digital reconfigurable battery solution for 5G base stations

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

It is expected that there will be plenty of batteries to be adopted as various back-up power systems and renewable energy storage systems in 5G networks.

A digital reconfigurable battery system is illustrated in Figure V.1, where cell-level topology can be modified to accommodate cell characteristics and load efficiently. This ability is achieved by deploying power switches around battery cells and adjusting cell connectivity in a real-time fashion. A basic requirement of a battery control system (BCS) is that it should be capable of bypassing any cell, as well as adjusting the configuration of cells according to real-time operational conditions, such as cell status and load profile, while keeping a balanced cell status across the entire battery pack.

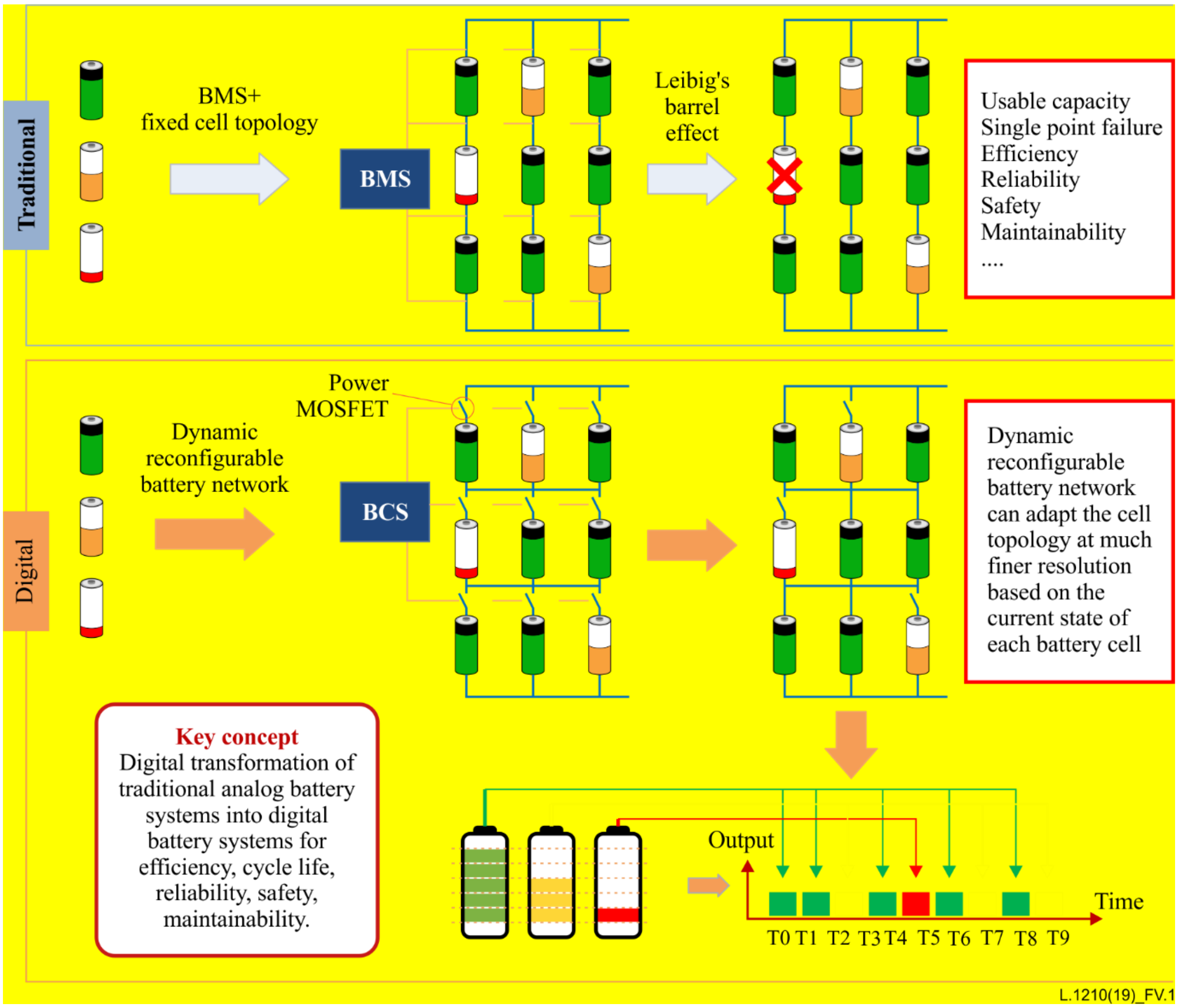

Figure V.1 – Architecture of digital reconfigurable battery system

Figure V.2 illustrates the system diagram of a typical digital battery system, where a switching circuit enables reconfiguration on cell-level topology within 10 milliseconds. As a result, power management and control in this system can be conducted dynamically at the cell level, array level, pack level and battery network level by means of the network and information. Higher energy efficiency, better safety and reliability can be achieved through proper management on cells and reconfiguration on cell topologies. Meanwhile, the system is capable of isolating arbitrary faulty cells, as well as achieving cell-to-cell balanced conditions, meaning that the lifespan of the system will become much longer than that of traditional battery packs with a fixed topology and the same number of single cells under the identical load and operational conditions. Furthermore, the distributed nature of such a system also paves the way for high utilization of repurposed electric vehicle (EV) batteries.

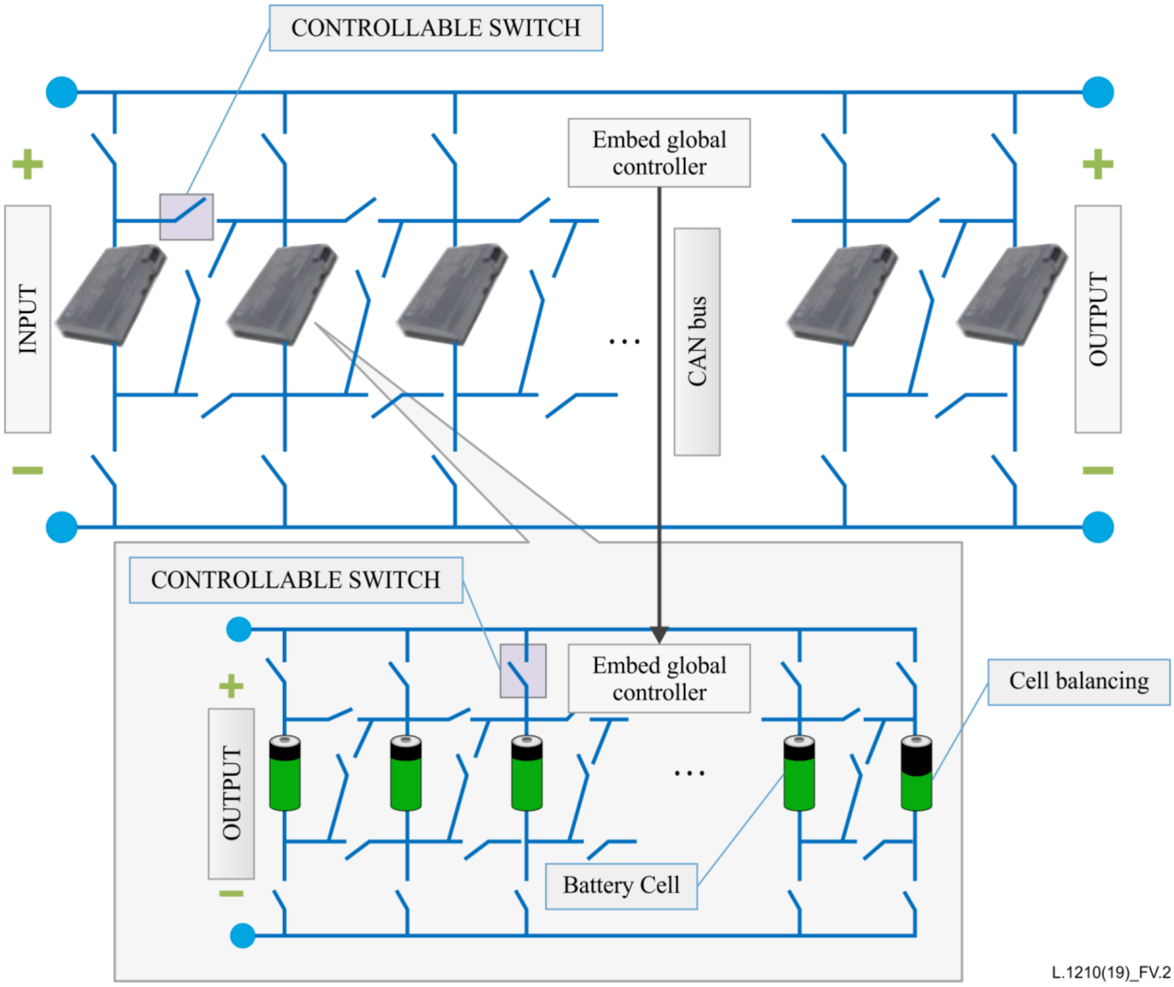

Figure V.2 – System diagram of digital reconfigurable battery systems

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