

# ETSI ES 203 700 V1.2.1 (2025-09)



**Environmental Engineering (EE);  
Sustainable power feeding solutions for 5G network**

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**Reference**

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RES/EE-02110

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**Keywords**

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5G, cable, energy efficiency, hybrid, power,  
remote, sustainability

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**ETSI**

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# Foreword

This ETSI Standard (ES) has been produced by ETSI Technical Committee Environmental Engineering (EE).

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

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

The present document is applicable to powering of both mobile and fixed access network elements, in particular on equipment that have similar configurations and needs.

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# Introduction

Mobile and fixed networks are evolving towards ultra-broadband, improved performance and coverage; with 5G and beyond, are going to converge. The use of much broader frequency ranges, up to 60 GHz, where radio propagation is an issue, is going to impact the 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 amount of radio nodes.

5G is introducing major improvements on Massive MIMO, IoT, low latency, unlicensed spectrum, and with V2x for the vehicular market. Support of some of these services will have a relevant effect on the power ratings and the energy consumption at the radio base station.

A major new service area of 5G and beyond impacting the powering and backup will be the 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. ETSI TS 110 174-2-2 [i.5] analyses the implications and indicates possible solutions to fulfil such high demanding availability goals.

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

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.1210 [i.7] and ETSI ES 203 700 (the present document), which are technically equivalent.

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# 1 Scope

The present document defines power feeding solutions for 5G, converged wireless and wireline access equipment and network, taking into consideration their enhanced requirements on service availability and reliability, the new deployment scenarios, together with the environmental impact of the proposed solutions.

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

The present document is applicable to powering of both mobile and fixed access network elements, in particular on equipment that have similar configurations and needs.

The 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 to the users, thereby creating the need to define new solutions for powering that will be environmentally friendly, sustainable, dependable, smart and visible remotely.

The -48 V DC, up to 400 V DC local and remote power solutions defined respectively in ETSI EN 300 132-2 [2], ETSI EN 302 099 [i.10] and ETSI EN 300 132-3 [3] or Recommendation ITU-T L.1200 [i.13] will be considered as the standards in force for power facilities, together with IEEE 802.3 [i.18] (PoE).

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# 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.

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- [1] [ETSI EN 300 132-1 \(V2.1.1\) \(03-2019\)](#): "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 \(V2.6.1\) \(04-2019\)](#): "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 \(V2.3.1\) \(01-2023\)](#): "Environmental Engineering (EE); Power supply interface at the input of Information and Communication Technology (ICT) equipment; Part 3: Up to 400 V Direct Current (DC)".
- [4] [ETSI ES 203 199 \(V1.3.1\) \(02-2015\)](#): "Environmental Engineering (EE); Methodology for environmental Life Cycle Assessment (LCA) of Information and Communication Technology (ICT) goods, networks and services".
- [5] [IEC 60695-11-20](#): "Fire hazard testing - Part 11-20: Test flames - 500 W flame test method".

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- [i.1] Recommendation ITU-T Q.1743 (09/2016): "IMT-Advanced references to Release 11 of LTE-Advanced evolved packet core network".
- [i.2] ETSI ES 202 336-12: "Environmental Engineering (EE); Monitoring and control interface for infrastructure equipment (power, cooling and building environment systems used in telecommunication networks); Part 12: ICT equipment power, energy and environmental parameters monitoring information model".
- [i.3] ETSI EN 301 605 (V1.1.1) (10-2013): "Environmental Engineering (EE); Earthing and bonding of 400 V DC data and telecom (ICT) equipment".
- [i.4] ETSI TS 122 261: "5G; Service requirements for next generation new services and markets (3GPP TS 22.261)".
- [i.5] ETSI TS 110 174-2-2: "Access, Terminals, Transmission and Multiplexing (ATTM); Sustainable Digital Multiservice Cities; Broadband Deployment and Energy Management; Part 2: Multiservice Networking Infrastructure and Associated Street Furniture; Sub-part 2: The use of lamp-posts for hosting sensing devices and 5G networking".
- [i.6] Recommendation ITU-T K.64 (06/2016): "Safe working practices for outside equipment installed in particular environments".
- [i.7] Void.
- [i.8] EN 50173-1: "Information technology - Generic cabling systems - Part 1: General requirement", (produced by CEN).
- [i.9] IEEE 802.3cg™: "IEEE Approved Draft Standard for Ethernet Amendment 5: Physical Layer Specifications and Management Parameters for 10 Mb/s Operation and Associated Power Delivery over a Single Balanced Pair of Conductors".
- [i.10] ETSI EN 302 099: "Environmental Engineering (EE); Powering of equipment in access network".
- [i.11] ETSI TS 103 553-1: "Environmental Engineering (EE); Innovative energy storage technology for stationary use; Part 1: Overview".
- [i.12] Recommendation ITU-T L.1001 (11/2012): "External universal power adapter solutions for stationary information and communication technology devices".
- [i.13] Recommendation ITU-T L.1200 (05/2012): "Direct current power feeding interface up to 400 V at the input to telecommunication and ICT equipment".
- [i.14] ETSI TS 103 553-1 (V1.1.1) (08-2019): "Environmental Engineering (EE); Innovative energy storage technology for stationary use; Part 1: Overview".
- [i.15] ETSI TS 103 553-2 (V1.1.1) (11-2021): "Environmental Engineering (EE); Innovative energy storage technology for stationary use; Part 2: Battery".
- [i.16] ETSI TS 103 553-3 (V1.1.1) (01-2020): "Environmental Engineering (EE); Innovative energy storage technology for stationary use; Part 3: Supercapacitor".
- [i.17] Recommendation ITU-T L.1350 (10/2016): "Energy efficiency metrics of a base station site".
- [i.18] IEEE 802.3™-2018: "IEEE Standard for Ethernet".



- [i.19] IEEE 802.3bt™-2018: "IEEE Standard for Ethernet Amendment 2: Physical Layer and Management Parameters for Power over Ethernet over 4 pairs".
- [i.20] A. Gupta, R. K. Jha: "[A Survey of 5G Network: Architecture and Emerging Technologies](#)".
- [i.21] CableFree: "[5G Frequency bands: Spectrum Allocations for Next-Gen LTE](#)".

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## 3 Definition of terms, symbols and abbreviations

### 3.1 Terms

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

**cell:** radio network object that can be uniquely identified by a user equipment from a (cell) identification that is broadcasted over a geographical area from one UTRAN or GERAN access point

NOTE 1: A Cell in UTRAN is either FDD or TDD mode.

NOTE 2: As defined in Recommendation ITU-T Q.1743 [i.1].

**cloud RAN:** RAN functions are partially or completely centralized with two additional key features: pooling of baseband/hardware resources, and virtualization through general-purpose processors

**distributed RAN:** network development where RAN processing is fully performed at the site as in 4G

**macro cells:** outdoor cells with a large cell radius

NOTE: As defined in Recommendation ITU-T Q.1743 [i.1].

**micro cells:** small cells

NOTE: As defined in Recommendation ITU-T Q.1743 [i.1].

**pico cells:** cells, mainly indoor cells, with a radius typically less than 50 m

NOTE: As defined in Recommendation ITU-T Q.1743 [i.1]

### 3.2 Symbols

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

|          |             |
|----------|-------------|
| C        | Celsius     |
| kW       | Kilo Watt   |
| L        | Litre       |
| l        | Length      |
| m        | Milli       |
| R        | Resistance  |
| W        | Watt        |
| $\Omega$ | Ohm         |
| $\sigma$ | Resistivity |

### 3.3 Abbreviations

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

|     |                         |
|-----|-------------------------|
| 5G  | Fifth Generation        |
| AAU | Active Antenna Unit     |
| AC  | Alternating Current     |
| Ah  | Ampere hours            |
| AI  | Artificial Intelligence |

|       |                           |
|-------|---------------------------|
| BBU   | Base Band Unit            |
| BCS   | Battery Control System    |
| BMS   | Battery Management System |
| BS    | Base Station              |
| C-RAN | Centralized or Cloud RAN  |
| DC    | Direct Current            |

NOTE: Also when used as a suffix to units of measurement.

|         |                                             |
|---------|---------------------------------------------|
| DG      | Diesel Generator                            |
| DOD     | Deep Of Discharge                           |
| DP      | Distribution Point                          |
| D-RAN   | Distributed RAN                             |
| DSLAM   | Digital Subscriber Line Access Multiplier   |
| EV      | Electrical Vehicle                          |
| FWA     | Fixed Wireless Access                       |
| GND     | GrouND                                      |
| GPON    | Gigabit Passive Optical Network             |
| Hetnets | Heterogeneous network                       |
| ICT     | Information Communication Telecommunication |
| IoT     | Internet of Things                          |
| LFP     | Lithium Iron Phosphate                      |
| MEC     | Multi-access Edge Computing                 |
| MIMO    | Multi-Input Multi-Output                    |
| mmWaves | millimetric Waves                           |
| MPPT    | Maximum Power Point Tracking                |
| NE      | Network Element                             |
| OS      | Optical Splitter                            |
| PAV     | Power Availability Value                    |
| PN      | Power Node                                  |
| PON     | Passive Optical Network                     |
| PS      | Power Splitter                              |
| PSU     | Power Supply Unit                           |
| PTU     | Power Transmitter Unit                      |
| PV      | PhotoVoltaic                                |
| PVC     | PolyVinyl Chloride                          |
| RAN     | Radio Access Network                        |
| REN     | Renewable ENergy                            |
| RF      | Radio Frequency                             |
| RRH     | Remote Radio Head                           |
| RRU     | Remote Radio Unit                           |
| SEE     | Site Energy Efficiency                      |
| SELV    | Safety Extra Low Voltage                    |
| SOC     | Status Of Charge                            |
| SOH     | Status Of Health                            |
| TDD     | Time Division Duplex                        |
| TTM     | Time To Market                              |
| U       | Unit                                        |
| URLLC   | Ultra Reliable Low Latency Communication    |
| UTRAN   | Universal Terrestrial Radio Access Network  |
| UV      | UltraViolet                                 |

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## 4 5G networks

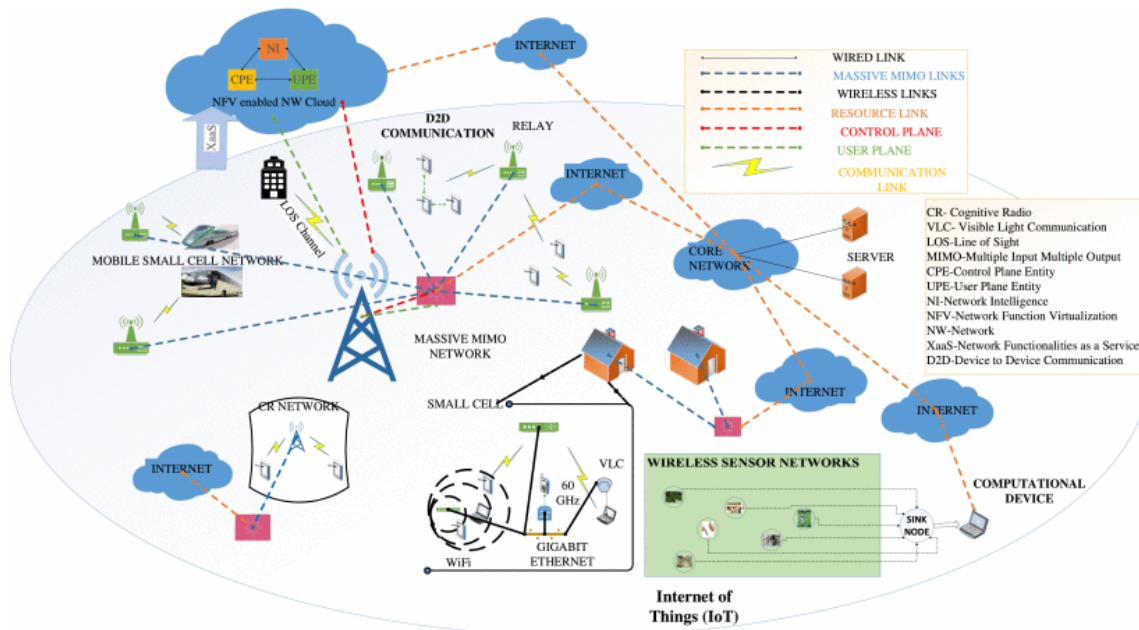
### 4.1 5G Network general description

Figure 1 is presenting a general end-to-end schematics of 5G network to be powered.

It includes stationary and mobile equipment:

- Macro cell equipment 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 its major upgrade both on the power capabilities and the backup duration.
- Small cell, to cover small geographical area in indoor/outdoor applications, typically to satisfy data traffic hot-spots, black-spots and to deliver services at very high frequencies (e.g. mmWaves) that could not be supported just through macro BS installations. Small cells can be subdivided into:
  - Micro cell - normally installed outdoors. Designed to support large number of users in high data traffic areas, to solve coverage issues and to support very high frequency deployment. Capable to cover medium/large cells size and suitable for application like smart cities, smart metro, etc.
  - Pico cell - normally installed indoors. Suitable for enterprises, shopping centres, stadiums applications, for extended network coverage and data throughput.
  - Femto cell - basically small mobile base stations designed to provide extended coverage for residential and SoHo applications. Poor signal strength from 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.
- 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.



Source: "A Survey of 5G Network: Architecture and Emerging Technologies" [i.20].

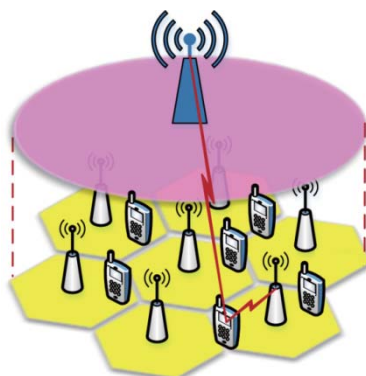
**Figure 1: General principle of a 5G cellular network architecture with interconnectivity among the different emerging technologies like Massive MIMO network, Cognitive Radio**

## 4.2 Cells coverage and impacts on powering strategy

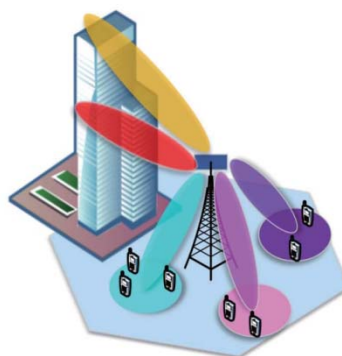
In the 4G era, a base station covers a radius of hundreds of metres, while a 5G base station operating at mmWave may cover only 20 m to 40 m, needing a much higher number of equipment to be spread-out in the field to guarantee appropriate coverage. More dense deployment will also be needed to cover high traffic areas (e.g. stadiums) and indoor locations. That 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 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 Figures 2(a) to 2(c).



**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 (macro cell, micro cell and pico or femto cell), with correlation to aggregated RF power, is available in Table 1, together with 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          | INDOORS                      | OUTDOORS | TYP              | MAX   | BATTERY          | Local mains | Remote power | PoE | minimum BACKUP time | Wireline / Wireless    | Connection flavour                      | MIN                 | MAX           |
|                                                                                                 | Private premises | Public sites and enterprises |          | (W)              | (W)   | Duration (years) |             |              |     |                     |                        |                                         | (W)                 | (W)           |
| <b>WIRELESS</b>                                                                                 |                  |                              |          |                  |       |                  |             |              |     |                     |                        |                                         |                     |               |
| 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           |
| <b>WIRELINE</b>                                                                                 |                  |                              |          |                  |       |                  |             |              |     |                     |                        |                                         |                     |               |
| VDLSL2 DSLAMs                                                                                   |                  |                              | Cabinets | 150              | 250   |                  | X           | X            |     | advised minutes     | Wireline               | Optical                                 |                     |               |
| G.FAST                                                                                          |                  |                              | Cabinets | 25               | 40    |                  |             | X            |     |                     | Wireline               | Optical                                 |                     |               |
| <b>IoT</b>                                                                                      |                  |                              |          |                  |       |                  |             |              |     |                     |                        |                                         |                     |               |
| 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 user such as street Lighting equipment or electric car charging stations, etc.

Power Interfaces for each case are described in clause 5.

A possible solution using streetlamp post for small cell deployment can be found in ETSI TS 110 174-2-2 [i.5].

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

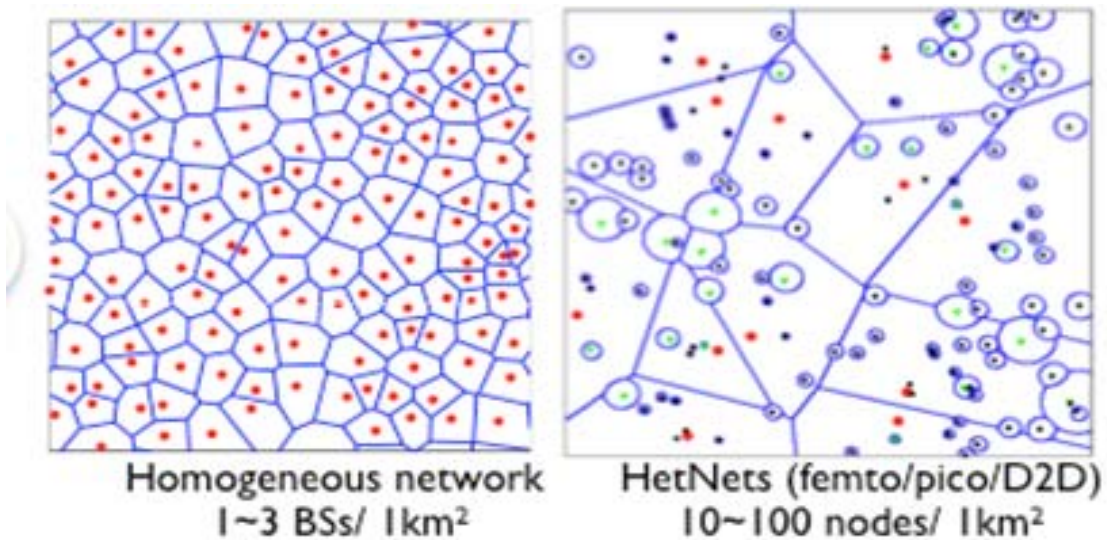
Figures 2(a) to 2(c) give a base on possible 5G cellular network configurations, based on these figures it is possible to identify 5G required power:

- 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 maximum aggregated power limit considering the AC grid connection available to this cluster site.

The network can have homogeneous patterns based on 1 to 3 macro cell BS per km<sup>2</sup>, while it can be more heterogeneous (HetNets) with 10 to 100 cells per km<sup>2</sup> ranging from macro to femto cells, a possible evolution is reported in Figure 3:

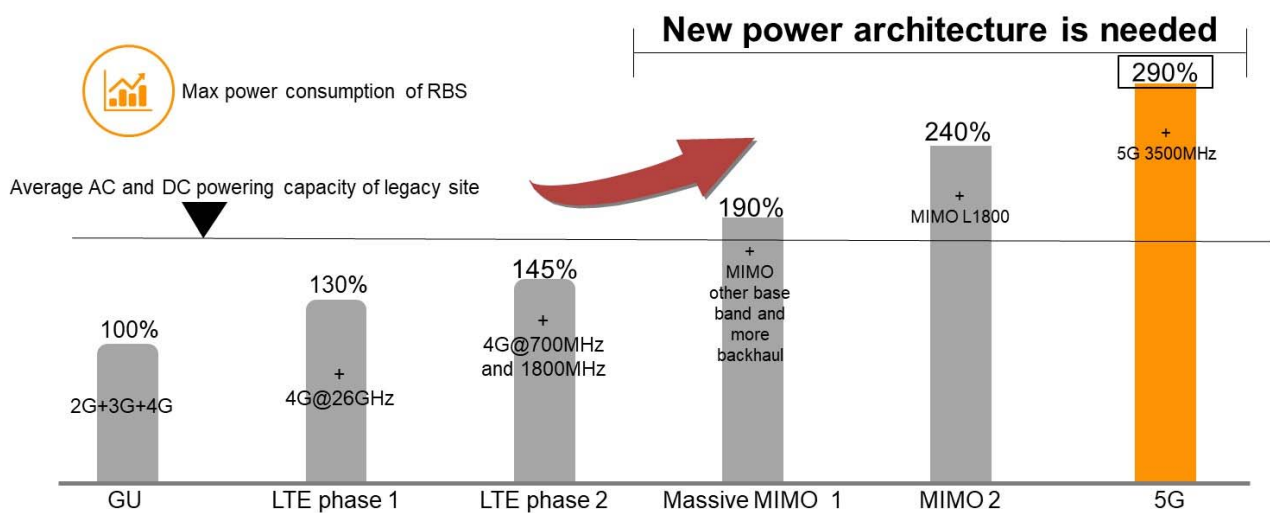
- To establish the local power system and the number of power access either from AC grid or by DC remote powering it is necessary to define power requirement and energy consumption of each site and capacity of NE equipment. The cooling thermal limit and availability of local power can be a determinant parameter.
- To define remote power, the location and configuration are very important as they will need to reuse existing pairs or existing ducts to install power cable (or hybrid powering/optical cable). In case this would turn out to be impracticable, it can be considered building new buried or aerial lines although this is going to be more expensive.

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



**Figure 3: Evolution of 5G cellular network configurations to HetNets**

Figure 4 reports an estimation of possible power request for a full radio site containing different bands for different developments of 5G technologies.



**Figure 4: Estimate radio base station power site rating**

## 5 Powering solutions

### 5.0 General

The present clause defines requirements on 5G powering considering different site topologies.

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

- ETSI EN 300 132-2 [2] interface A for 40,5 V DC to 72 V DC powering. The equipment of the Remote Radio Unit (RRU/AAU) is designed to work with the most common powering architectures found in telecommunications sites with operating voltages in the range -40,5 V DC to 72 V DC. Feeding DC voltages within such range enables the use of common and lower cost equipment. The use of voltages below 60 V DC 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.

NOTE: ETSI EN 300 132-2 [2] defines as nominal voltage 48 V DC and voltage of 60 V DC.

- ETSI EN 300 132-1 [1] interface A1 for AC powering.
- Recommendation ITU-T L.1200 [i.13] or ETSI EN 300 132-3 [3] interface P for up to 400 V DC powering.
- Recommendation ITU-T L.1001 [i.12] for low DC voltage 5 V or 12 V e.g. used for little 5G femto or pico cells.
- IEEE 802-3 [i.18] allows the same cable to provide both data connection and electric power to the devices. Sometimes referred to as Power over Ethernet (PoE), Recommendation ITU-T L.1220 [i.14] specifies remote power feeding over 2 and 4 balanced pairs of cables of Category 5 and above (as specified in EN 50173-1 [i.8]). In addition, IEEE 802.3cg [i.9] specifies remote power feeding of a variety of 1 pair balanced cables. Both implementations use voltages of below 60 V DC. The power feeding of IEEE 802.3bt [i.19] provides up to 71 W at the remote equipment using 4 balance pairs at maximum distance of 100 m while IEEE 802.3cg [i.9] delivers 14 W at 300 m and 2 W at 1 000 m.

The following clauses consider the power requirement for:

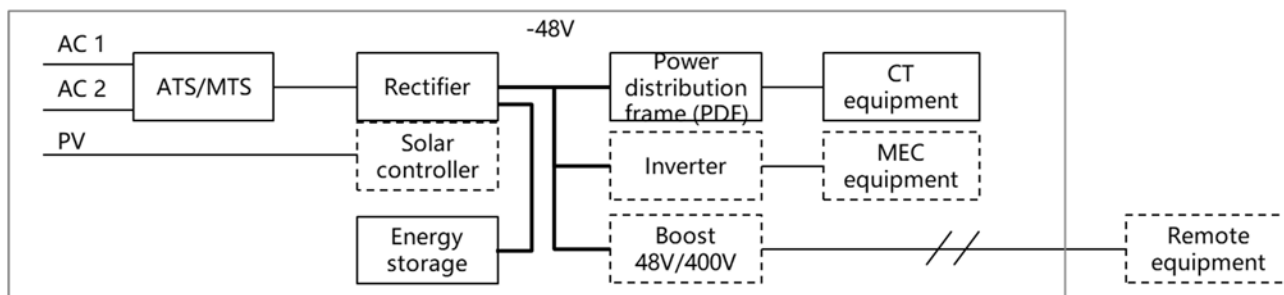
- Aggregation and Core equipment room.
- C-RAN and D-RAN site.

### 5.1 Convergence and Core Room Power Supply

#### 5.1.1 Scenario 1: -48 V DC Power Supply Solution

Figure 5 reports a power feeding distribution in the case to use a -48 V DC power supply solution. The system shall support -57 V DC power supply, as it is defined in ETSI EN 300 132-2 [2] that the upper limit value of a -48 V DC system should be -57 V DC.





NOTE 1: AC2 can be a Diesel generator or any other type of emergency generator.

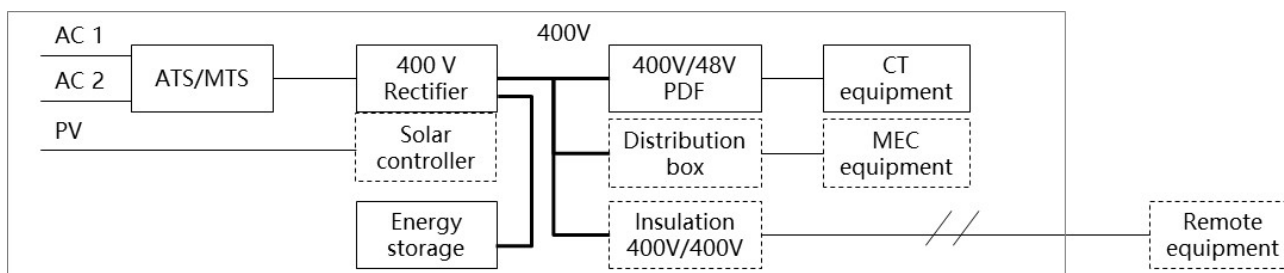
NOTE 2: Energy storage in some cases can be a fuel cell.

NOTE 3: In some cases WIND generator can be used to replace solar (PV) or in conjunction with them.

**Figure 5: Network diagram of -48 V DC power supply solution**

### 5.1.2 Scenario 2: up to 400 V DC Power Supply Solution

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



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 WIND generator can be used to replace solar (PV) or in conjunction with them.

**Figure 6: Networking diagram of the up to 400 V DC power supply solution**

### 5.1.3 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 ICT integration needs.
  - Multi-input: multi-type of AC energy inputs and solar (optional WIND) energy input.
  - Multi-output: 230 Vac, 400 V DC and other voltages output by adapting different power modules.
- 2) Lithium batteries:
  - Lithium replacing lead-acid battery is expected to reduce more than 60 % 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:
    - a) battery material: at current stage of technology lithium iron phosphate is required for safety concern;

- b) safety management: abnormality of external charging voltage and current does not affect battery safety work;
  - c) flame-retardant: materials used in battery pack shall meet IEC 60695-11-20 [5];
  - d) fire control: when the cell has a fire problem, flame inside the battery pack shall not leak outside, and the temperature of battery pack outer surface shall not exceed 120 °C.
  - Lithium discharge capability in parallel: when the modules are connected in parallel, the maximum discharge capacity can reach  $P \times N$  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 V DC, 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 requirements: 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 V DC for remote load.
- Insulation monitor for 400 V DC: monitor system insulation impedance, including + to GND and - to GND. Triggering alarm or cutting output when impedance is lower than defined threshold.
- AC utility monitor: detect AC voltage on the system. Triggering alarm or cutting output when impedance is lower than defined threshold.

## 5.2 Impact of 5G in C-RAN&D-RAN Sites

### 5.2.1 Changes due to 5G implementation

The power consumption of 5G increases significantly compared with that of the 4G. In the 5G era, for example, the estimated maximum power consumption 64T64R AAU could be 1 000 W to 1 400 W, and the estimated maximum power consumption of the BBU could be about 1 200 W to 1 500 W including also actual 3G and 4G cards.

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.

### 5.2.2 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 needs grid modernization. The time to modernize the grid is 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, huge voltage drop on 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, low energy density, heavy weight and big volume of lead-acid battery further aggravate the difficulty to deploy 5G especially on some rooftop sites with limited weight capacity and space availability.
- Cooling Challenges:
  - The heat consumption increases in the same pace as the power consumption. Thus the heat dissipation capability of some sites needs to expand, which takes long period and 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.
- O&M Challenges:
  - Higher Electricity Cost:
    - The current electricity cost accounts for 1 % to 8 % of the carrier's revenue. Since the increase in power consumption and electricity unit price bring much higher electricity cost in 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 when 5G URLLC services will have to be supported as such services will require five or more "nines" availability. More bands and higher frequency in 5G sites increase the number of equipment, complexity and manpower for O&M, leading to higher site maintenance cost.
  - 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.

## 5.2.3 Problems to Be Addressed by 5G Power Systems

### 5.2.3.1 Low Cost Deployment

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

### 5.2.3.2 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 cost for site renegotiation. For new sites, the footprint should be minimized while the installation should be as simple and fast as possible.

### 5.2.3.3 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 sub-systems shall be considered based on both the whole site and the whole network to save OPEX.

### 5.2.3.4 Smooth Evolution

The sub-systems of the power solution can evolve to 5G smoothly at the same or even less initial investment as 4G construction.

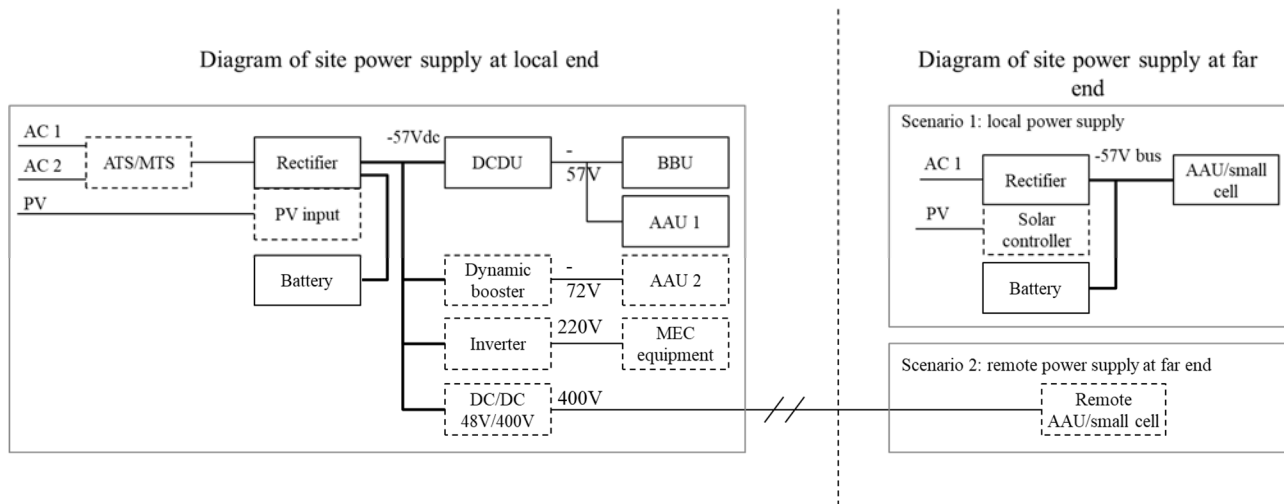
### 5.2.3.5 Simple O&M

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

## 5.2.4 C-RAN & D-RAN Powering Scenario

### 5.2.4.1 Networking diagram of powering scenario

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



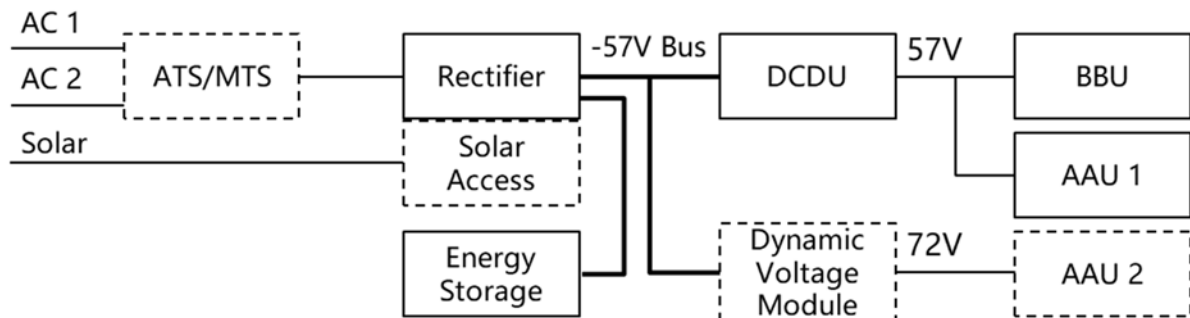
- NOTE 1: AC2 can be a Diesel generator or any other type of emergency generator.  
 NOTE 2: Energy storage in some cases can be a fuel cell which supports constant 57 V DC output.  
 NOTE 3: In some cases WIND generator can be used to replace solar (PV) or in conjunction with them.  
 NOTE 4: It is 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 V DC voltage, energy storage is working at -57 V DC.

**Figure 7: Networking diagram of C-RAN powering scenario**

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 MEC equipment, and the power supply system needs to be also smoothly evolved.

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



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

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

## 5.2.5 5G Power Solution for C-RAN&D-RAN site

Considering the changes in the power supply requirements of the C-RAN&D-RAN site in the 5G network and the requirements for long-term evolution:

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

- Multi-input: multi-input of AC, up to 400 V DC input, and solar/wind access:
  - The solar access module shall 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 shall support the MPPT (maximum power point tracking) 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 V DC, AC, 400 V DC, etc. (by configuring different modules).

According to ETSI EN 300 132-2 [2], annex B (reported in Table 2), the -60 V DC is allowed for telecommunication base station used with a normal service voltage up to -72 V DC.

The maximum power consumption of 5G AAU is significantly higher than that of 4G. Under the -48 V DC system, the maximum allowable power supply voltage of the system is -57 V DC, 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 V DC interface. The use of voltages below 60 V DC incurs less demanding safety requirements and eases installation and maintenance see Recommendation ITU-T K.64 [i.6] for more information.

**Table 2: Voltage definition for -60 V DC voltage**

|                                                        |                                                     |
|--------------------------------------------------------|-----------------------------------------------------|
| <b>Nominal value of the supply voltage</b>             | -60,0 V DC                                          |
| <b>Normal service voltage range at interface "A"</b>   | -50,0 V DC to -72,0 V DC                            |
| <b>Abnormal service voltage range at interface "A"</b> | 0 V DC to -50 V DC; and<br>-72,0 V DC to -75,0 V DC |

2) Efficient:

- a) Rectifier Efficient Module:
- D-RAN scenario: It is recommended that the level 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 highly efficient 98 % rectifier module to achieve more benefit considering high power consumption of C-RAN.
- b) Efficient Cooling: It is recommended to adopt heat exchanger cooling system for equipment cabin to save more energy than air conditioner and provide better environment protection (IP55) than direct ventilation. Battery cabin shall adopt suitable cooling system accordingly for better energy saving and protection.
- c) Efficient Site: The outdoor deployment solution is preferred as site construction. In cabinet scenario: The SEE of the entire site, defined in Recommendation ITU-T L.1350 [i.17], 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 V DC, in line with ETSI EN 300 132-2 [2], maximally to match the AAU requirement when its power consumption increases, reducing the cable loss while satisfying the safety requirement of -48 V DC system ETSI EN 300 132-2 [2].

- 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 shall support the Maximum Power Point Tracking (MPPT) function with a maximum efficiency of over 98 % and an MPPT control accuracy of over 99,8 %.
  - f) Other active modules: Other modules like DC/AC, DC/DC need to 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 generator:
    - Site in off-grid scenario: Choose solar power supply in priority, Diesel Generator (DG) & solar hybrid power second, D.G. & lithium battery hybrid power as the last option to avoid 24-hour D.G. running.
    - Site in poor grid scenario: Grid & 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  $\geq 7$  kW/U (power distribution included).
    - b) Basic Power Capacity  $\geq 24$  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 15 U @ 24 kW/12 U @ 36 kW. The basic cooling capacity for the telecommunication equipment is not less than 1 500 W, and can be expanded to 3 000 W maximum.
    - c) Battery capacity:  $\geq 600$  Ah.
  - Outdoor Power system for pole/wall/tower mounting solution:
    - a) Fan-free natural cooling design of power system avoids routine maintenance.
    - b) Power system density:  $\geq 333$  W/L.
    - c) When the power system modules system are used in parallel, the output power of the parallel system shall be no less than 90 % of the total power in case of two power modules and 80 % of the total power in case of more than 2 power modules.
- 5) Intelligent: see clause 5.2.6.
- 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: System automatically shall check the cable route and remote load correctness in a safe voltage mode, then output voltage increases up to 400 V DC to remote load.
    - b) Insulation monitor for 400 V DC: System automatically shall monitor system insulation impedance, including + to GND and - to GND. The system shall trigger alarm 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 alarm or cut output when impedance is lower than the defined threshold.

## 5.2.6 Intelligent Features for C-RAN&D-RAN site

### 5.2.6.1 Intelligent Peak Shaving

Since the past 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 to cooperate with the energy storage system to shave the peak power when 5G accesses for minimizing the grid modernization and accelerating the 5G deployment.

Figure 9 and Figure 10 show peak shaving functionality concept and an example of sizing.

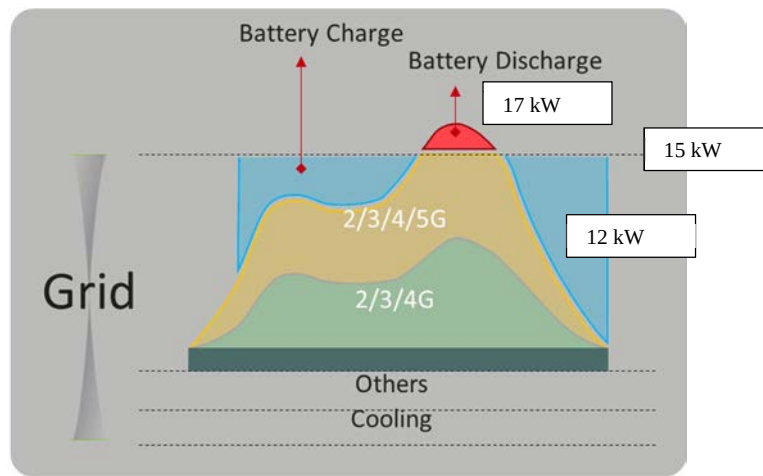


Figure 9: Peak shaving of a radio site functionality

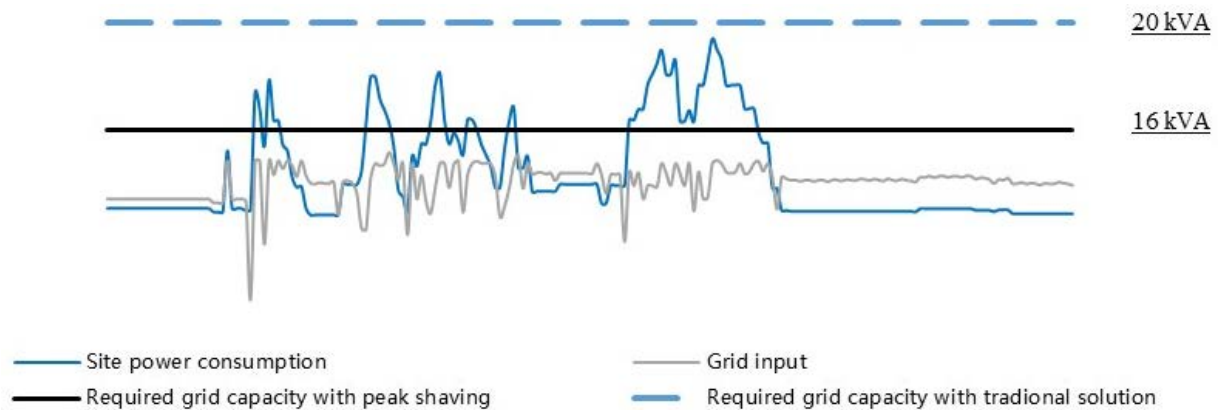


Figure 10: Example of peak shaving of a radio site sizing

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

The battery capacity should be designed as reported below:

$$C = (P_{\max} - P_{\text{limit}} \times k1 \times k2) \times T \times 1,25 / 48 \text{ V} \times \text{DOD} \quad (1)$$

Table 3 reports a calculation example.

**Table 3: Example of backup capacity dimension**

| <b>C: Capacity<br/>(Battery capacity for new peak)</b> | <b><math>C = (P_{\max} - P_{\text{limit}} \times k1 \times k2 \times T \times 1,25 / (48 \text{ V} \times \text{DOD}))</math></b> |
|--------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|
| $P_{\max}$                                             | Site peak maximum power                                                                                                           |
| $P_{\text{limit}}$                                     | 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                                                                     |
| 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:

- Existing grid power: 15 kW (enough for 2/3/4G peak power)
- Peak power of 2/3/4G: 12 kW (including battery charging power)
- Peak power of 5G access: 5 kW
- Peak time/day: 2 h
- $P_{\max} = 12 + 5 = 17 \text{ kW}$
- $P_{\text{limit}} = 15 \text{ kW}$
- $T = 2 \text{ h}$
- $C = (17\,000 \text{ W} - 15\,000 \text{ W} \times 0,94 \times 0,8) \times 2 \times 1,25 / (48 \times 0,85) = 350 \text{ Ah}$

#### **Working principle of battery for peak shaving:**

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

Meanwhile, in order to ensure the reliable power supply and easy site maintenance, a software management platform should be deployed to 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  $P_{\text{limit}}$  value.

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

NOTE 2: There is no strict relationship between the breaker 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.  $I_{\text{charge/discharge}} \leq I_{\text{MCB}} \leq I_{\text{wire}}$ . The specific selection refers to the breaker specification/manual from different breaker suppliers. Where  $I_{\text{charge/discharge}}$  is the charge or discharge battery current,  $I_{\text{MCB}}$  is the breaker trip current,  $I_{\text{wire}}$  is the cable maximum current.

#### **5.2.6.2 Advance Sleep/Hibernation Mode function**

Rectifier Sleep Mode is also one 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 ( $\geq 97\%$ ) and properly sized.



## 5.3 Intelligent Management

### 5.3.0 General

In order to meet the ultimate business requirements of 5G network, the standard of power reliability, site energy efficiency, O&M efficiency and site safety of the whole network should be much higher. 5G power system 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 4 key management ability.

#### 5.3.1 Power availability Management

Power Availability Value (PAV) refers to the site DC power supply reliability. It is a percentage of site on-line working time (total time except site shutdown time caused by various DC power supply outage) divided by total designed duration time. The calculation format is:

$$PAV = \frac{\text{Site designed working duration time} - \text{Site outage time}}{\text{Site designed working duration time}} \quad (2)$$

The management of PAV could be helpful for the precise investment to improve the 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 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 the up-coming potential risks. For example, it should analyse the real power back-up capability of the energy storage system to provide maintenance suggestions in advance during early grid outage together with the consideration with load changing, so as to avoid site interruption and improve power supply reliability.

#### 5.3.2 SEE Management

Site Energy Efficiency (SEE) is an indicator of site E2E energy usage efficiency. When a particular sum of energy is provided to one site, only one part of the energy is used by telecommunication devices while the rest is consumed by site supporting devices such as lighting, cooling, PSU and power distribution.

Recommendation ITU-T L.1350 [i.17] defines Site Energy Efficiency (SEE). SEE is the ratio between the total energy consumption of telecommunication equipment and the total energy consumption on site:

$$SEE = \frac{E_{CT}}{E_{TS}} \times 100 \% \quad (3)$$

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

- 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 sub-system energy consumption. Then it should provide SEE result on the basis of detail calculation. 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 suggestion 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 considerate 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 versus watt to reach high efficiency ratio of bit per watt.

### 5.3.3 Remote Maintenance

- The maintenance of ICT network 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.
  - Achieve remote and automatic maintenance. 5G power solutions should be able of 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 a large sum of operation costs.
- Precise site maintenance reduces unnecessary site visits:
  - On the basis of site situation close monitoring, the system provides remote trouble-shooting and cause analysis of the already happened malfunction and potential risks. The target is to avoid unnecessary site visits and make only one visit to solve all the problems.

### 5.3.4 Intelligent Security

Site quantity 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 anti-theft ability to maximize site security and reduce the loss caused by theft:

- Comprehensive digitization is the basis of intelligent security.
- It is proved that the traditional physical anti-theft design cannot solve the theft issue. On one hand the 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 those frequent happened theft issue is the profit chain.
- 5G power should build a whole series of digital protection system surrounding the power and site. For example, digital lock of battery that makes it useless if left on the site location; site access management automatically records abnormal site visits to avoid theft problem.
- Innovative anti-theft features such as smart video, smart lock, smart alarm, and cloud & AI 5G power ensures site productivity security and asset security comprehensively by adopting innovative anti-theft features such as smart video, smart lock, smart alarm, and cloud & AI.

### 5.3.5 Intelligent Energy Storage System

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

- Limited space and weight capacity of numerous existing sites including rooftop site and greenfield site, which future leads to high rental, expensive construction cost, long time for site acquisition and even no space for evolution.
- Insufficient power supply distance for 5G equipment on tower 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 short time.
- Natural short service life, expensive maintenance cost.

- Long charging time.

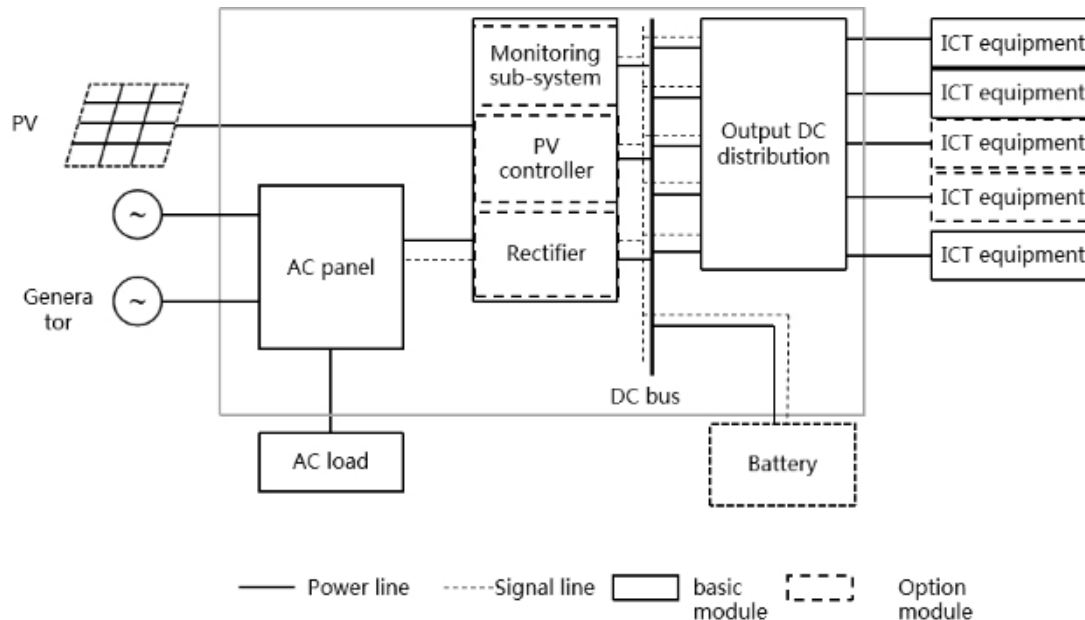
Lithium battery in line with Recommendation ITU-T L.1221 [i.15], which can solve all the above problems, is essential for 5G evolution. A lithium battery shall contain the following capabilities to match 5G evolution:

- 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 shall communicate with power system and management system for remote management. The remote O&M including visible battery parameters like voltage, current, temperature, SOC, 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 lithium battery shall be Lithium Iron Phosphate (LFP) and pass the safety tests such as nail test, burning test, water-immersion test and thermal shock test based on the principle of no fire and no explosion.

## 5.4 Renewable energy solution for 5G base stations

Different energy sources such as the Grid, renewable energy, Generator are connected to the input AC terminal connection 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 firstly and it will choose Grid, or battery storage system or Generator based on the operation cost in different conditions considering cost of Grid and others. The example to show basic structure of the system is as shown in Figure 11.



**Figure 11: Multiple energy source input system for 5G base station including renewable energy**

When the capacity of Grid is not enough due to increasing power of 5G base station, then renewable energy such as 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.

## 5.5 Hybrid architecture scenario, with integration of power and optical networks

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 cost, 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 dedicated supply. 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 back-up system: supercapacitor, when the need is only to cover micro interruptions, and lithium battery to cover longer black out.

While local powering solutions are well suited for current mobile and fixed access networks, cost and efficiency are becoming a main issue when a huge 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 sub-optimal location 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 central office or in external power concentrator.
- Remote feeding using up to 400 V DC 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 back up represents a more efficient solution with associated cost reduction.

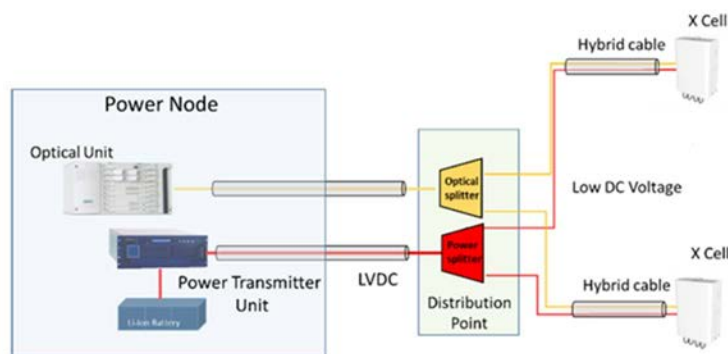
Among the different back-hauling or front-hauling possibilities for future 5G networks, the one based on Passive Optical Network (PON) networks is a promising one. It is based on a tree architecture realized using passive optical splitters. The powering structure could efficiently replicate such communications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

As shown in Figure 12, a power layer overlays the optical one. The general principle is to reuse at maximum existing infrastructures as already done for the deployment of optical access network. This means that also power component and cables shall be realized in order to fit these infrastructures (e.g. a power cable should be installable inside a microduct for fibre delivery) and hybrid copper-fibre cables have to be taken in consideration.

Basic concepts are:

- Introduction of a power splitter where an optical splitter is present.
- Usage of "up to 400 V DC" technology in the primary distribution segment.
- Usage of Safety Extra Low Voltage (SELV) DC voltage to feed the equipment.

Figure 12 contains the hybrid architecture and Figure 13 contains a schematics architecture.

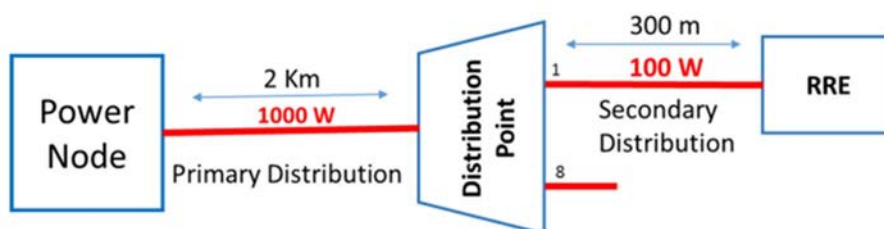


**Figure 12: Power-optical hybrid access architecture**

Due to the density of small cells, an architecture based on direct connections from Power Nodes to the Remote Radio Unit could not be efficient. A solution is the introduction of an intermediate distribution point splitting the power network in two different segments.

The first one, at higher DC voltage, named 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 RRUs. This will avoid co-location of Power Node and Optical Unit, enabling cost-effective powering.

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



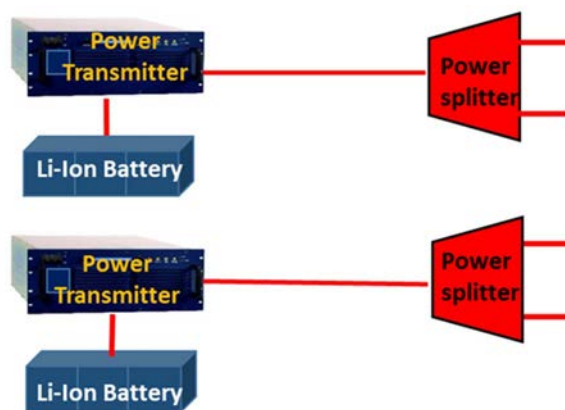
**Figure 13: Architecture schematics**

#### a) Network architecture: Primary Distribution

Two different architectures are analysed, as detailed in Figure 14 and Figure 15.

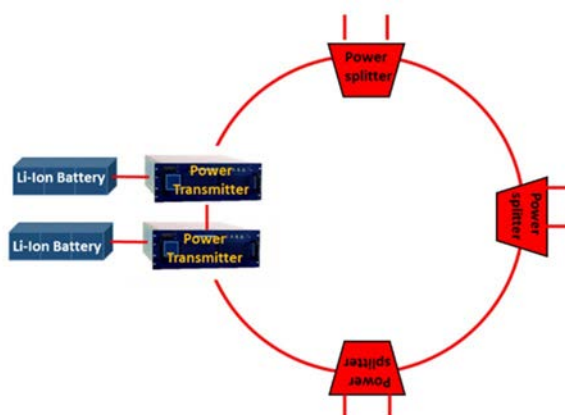
A simple tree solution where an AC/"up to 400 V DC" converter, named Power Transmitter Unit (PTU), implemented in a Power Node (PN) feeds a Distribution Point (DP) where a Power Splitter (PS) is located, together with an optical one (OS). PN will be in a Central Office or located depending on the network demand.

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



**Figure 14: 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 one. This architecture allows to feed 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 aligned their parameters.



**Figure 15: Power Ring architecture**

#### b) Network architecture: Secondary Distribution

This segment connects DP to the final equipment Remote Radio Unit (RRU). In order to compensate the drop on cables a voltage up to 60 V DC could be used, staying in the Safety Extra-Low Voltage (SELV) range to simplifying 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 V DC" to SELV levels. Independent converter per RRU can be implemented to avoid influence between outputs in case of fault, increasing service availability as reported in Figure 16.

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

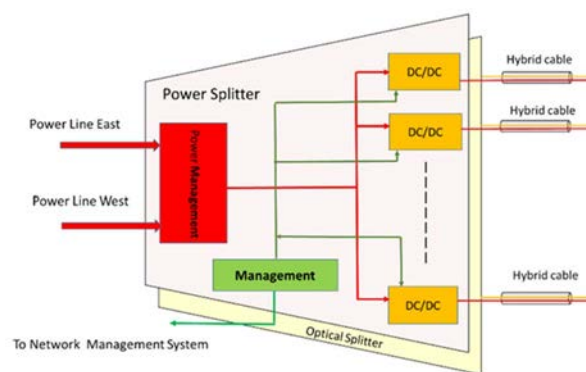


Figure 16: DP structure

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 see ETSI ES 202 336-12 [i.2].

d) **Backup element**

The back-up solutions are specified in standard series for innovative energy storage selection and tests method overview in ETSI TS 103 553-1 [i.11] or Recommendation ITU-T L.1220 [i.14], case of batteries in Recommendation ITU-T L.1221 [i.15] and case of super capacitors in Recommendation ITU-T L.1222 [i.16].

e) **Cables considerations**

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

**EXAMPLE:** In the primary distribution segment it would be opportune to opt for power cables that can be installed in existing telecommunications 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 ETSI EN 301 605 [i.3], some conductors could be required for earthing purposes.

It can be assumed that the leading transmission architecture will be GPON, needing only one fibre, nevertheless one extra fibre would be useful as a backup, for architectures using two 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 shall be made of fire retardant material and resist the atmospheric agents (rain, UV rays, ice, etc.). If the installation is mechanically stressful, the composite or hybrid cable shall integrate a tensile high strength core, to be safely pulled or to resist external mechanical agents.

The sizes of the electrical conductors are obviously depending on the applications, that is 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 V DC" voltages, the relevant safety standards apply and further details can be found in ETSI EN 300 132-3 [3] and Recommendation ITU-T L.1200 [i.13].

## 6 Energy Efficiency

### 6.1 Power equipment energy efficiency

For the purpose of more efficient, greener and energy saving, the efficiency of rectifier 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 over-configured rectifier. Thus considering less than 10 % load rate is meaningless

### 6.2 NE static and dynamic power requirement management and impact on powering

#### **Low power mode management:**

The NE shall have a power level dependant to Telecom service load, in order to be able to put the power supply 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 back-up considering the hold-up time of NE as defined at their interface A ETSI EN 300 132-2 [2], or A1 ETSI EN 300 132-1 [1], or A3 ETSI EN 300 132-3 [3].

#### **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.

#### **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.

## 7 Dependability, reliability and maintenance

The availability and reliability of the powering shall be defined in coherence with the service and end-to-end network-.

ETSI TS 122 261 [i.4], Table 7.2.2-1 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 to define the powering solution and sizing are:

- The AC grid availability, quality and time to restore from a grid failure.
- The compatibility of a new powering with existing NE on the same site.
- The power load evolution within the site and the NE configuration evolution (number and type of equipment, setting of the equipment, etc.).
- Coverage and Traffic.

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

- Power supply and distribution redundancy, when considering a remote powering, it 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 remote site.
- Choice of power generators (grid, renewable energy, hybrid systems, etc.).

**Safety:**

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

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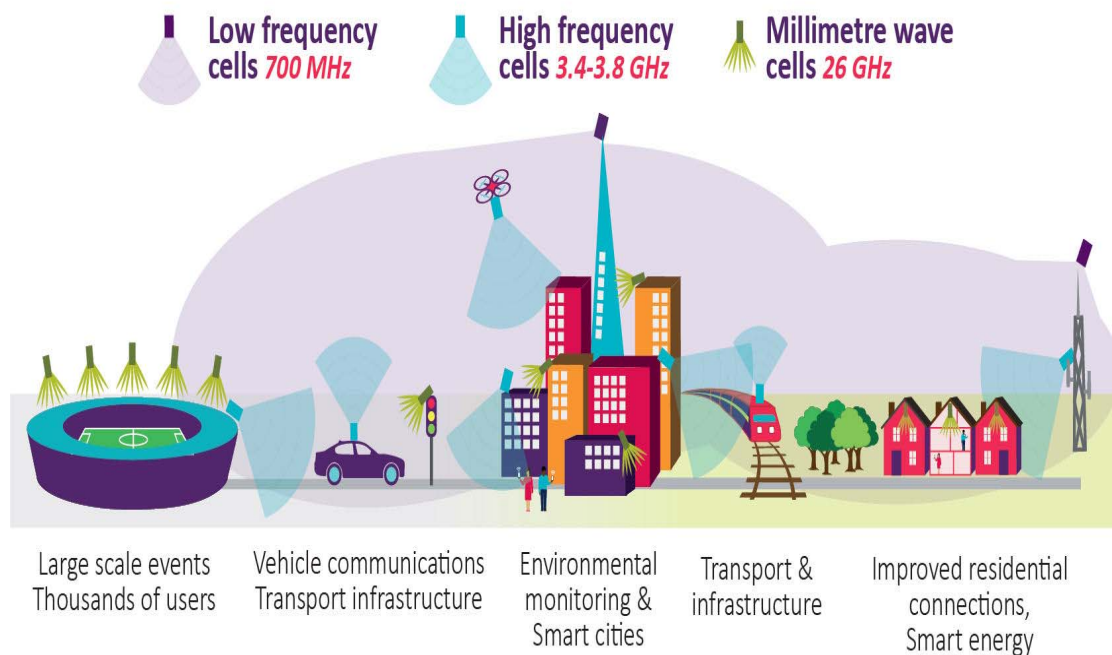
## 8 Environmental impact

Environmental impact assessment of 5G powering solution shall be conducted in line with the methodologies described in ETSI ES 203 199 [4].

## Annex A (informative): Which power and where for 5G cells

This annex is providing information to understand which power requirement is required and where:

- Higher frequency would be used first in the range 700 MHz to 30 GHz (maybe later up to 300 GHz), offering higher bandwidth than 4G, up to 20 Gbps. At high frequency and bandwidth it is interesting to work with smaller cells than macro-cells used in previous 2G to 4G. As for 2G to 4G, low band up to 2 GHz are for 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 electronic is still a critical point, see Figure A.1.



Source: "5G Frequency bands: Spectrum Allocations for Next-Gen LTE" [i.21].

**Figure A.1: 5G frequency subdivision**

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

- 0,1 km to 0,3 km range Small Cells rather than 1 km range Macro Cells. That means a density of cell per km<sup>2</sup> multiplied per 10 to 100.
- The small cell will be installed far from existing grid or other power indirect connection such as bus stop or streetlight.

NOTE: The indirect connection of small cells is less convenient as they are switched off during the day, so a battery would be required in the 5G cell.

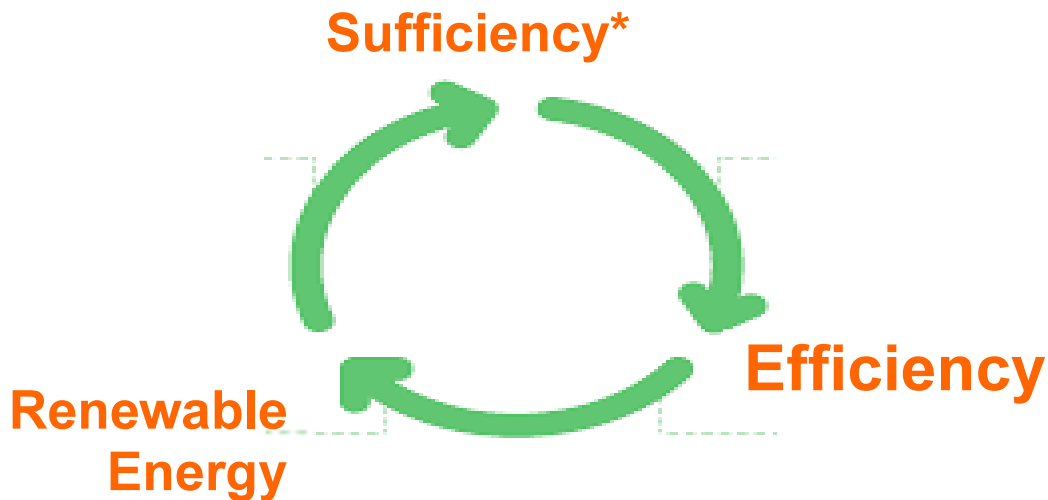
**The small cell average power consumption** range is in the range of tens of watts to hundreds of watts.

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

If only short interruption are to be considered, it could be interesting to use high power supercapacitor or Lithium battery in ETSI TS 103 553-1 [i.11] or Recommendations ITU-T L.1220 [i.14], L.1221 [i.15] and L.1222 [i.16].

## Annex B (informative): Method of optimization of equipment, power and energy

In order to reduce the number of cells and their powering issues and avoid explosion of power consumption and cost, the following optimization method reported in Figure B.1 is proposed.



**Figure B.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 service and minimize functional requirement.
- Energy and material Efficiency is a way to optimize equipment in terms of impact on environment, thermal management and electric 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 generator and energy storage.

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

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

In some cases (bad grids, difficult remote powering, etc.), standalone energy will be chosen as first entrance step. It is often wished to avoid use of fuel generators and all their issues (higher operational cost, fuel risks, noise, pollution, etc.) depending on the generator type. So REN is chosen and it absolutely needs to optimize iteratively 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. is it really necessary to have the maximum bandwidth 24 hour per day and every day?).
- Then it is checked if it opens new efficiency gain.
- Then REN is resized.
- Then other turns are done until the solution status is considered acceptable.

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

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## Annex C (informative): Example of powering requirement definition on site and remote powering area

This annex considers the powering solution not the energy consumption of different configurations of networks, 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:

- Macro cell site 2 kW to 8 kW for NE equipment, power station and cooling.
- Micro cell site up to 500 W.
- Pico cell up to 100 W.
- Femto cell up to 20 W.

Different network configurations and the possible powering solutions are reported below.

### Case study of 1 km<sup>2</sup> homogeneous cell network

There will be very few small and very small cells e.g.:

- The global power is at 80 % for 1 to 3 macro cell sites and so for example less than about 15 kW/km<sup>2</sup>, the micro cell accounting for 3 kW.

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

### Case study of 1 km<sup>2</sup> cell Hetnet

The power could be used for 1 macro cell complemented by 10 to 100 small cells. For example, 1 macro cell of 5 kW + 5 micro cells of 0,5 kW + 20 pico cells of 50 W + 50 femto cells of 10 W.

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

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

In addition, it is highly probable that there will be much less than 76 lines as many sites would be gathered on the same main branches with ramifications to distribute small power to pico and femto cells connected to the same branch (or bus) in the area of 1 km<sup>2</sup>.

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

## Annex D (informative):

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

This annex considers the required output voltage variation under correlation models between different loads and different cable lengths, which is taken as reference when evaluating whether the existing cable deployment is acceptable for 5G AAU when working under general voltage range and temperature condition 35 °C.

Premise:

- 1) Consider the conductivity of copper cable being  $57 \text{ m} / \Omega \times \text{mm}^2$ ,  $R = 2 \times L/S \times \sigma$ , with Resistivity  $0,0175 \Omega / \text{m} \times \text{mm}^2$  under temperature coefficient  $0,00393 \Omega / ^\circ\text{C}$ .
- 2) The input voltage at the load end from 36 V to 57 V is considered as general working range of the 5G AAU.

Figure D.1 reports the result considering a 6 mm<sup>2</sup> cooper cable.

Figure D.2 reports the result considering a 8,2 mm<sup>2</sup> cooper cable.

Figure D.3 reports the result considering a 10 mm<sup>2</sup> cooper 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 | 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 | 72 | 72 | 72 | 72  | 72  | 72  | 72  | 72  | 72  | 72  |
| 1300    | 48 | 48 | 48 | 48 | 57 | 57 | 57 | 57 | 57 | 57 | 57 | 57 | 57 | 57 | 72 | 72 | 72  | 72  | 72  | 72  | 72  | 72  | 72  |
| 1200    | 48 | 48 | 48 | 48 | 57 | 57 | 57 | 57 | 57 | 57 | 57 | 57 | 57 | 57 | 57 | 72 | 72  | 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  | 57  | 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  |

Cable Length (m)

**Figure D.1: Required output voltage variation under correlation between load and cable length (6 mm<sup>2</sup> cooper 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 D.2: Required output voltage variation under correlation between load and cable length (8,2 mm<sup>2</sup> coper 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  | 72  | 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  |

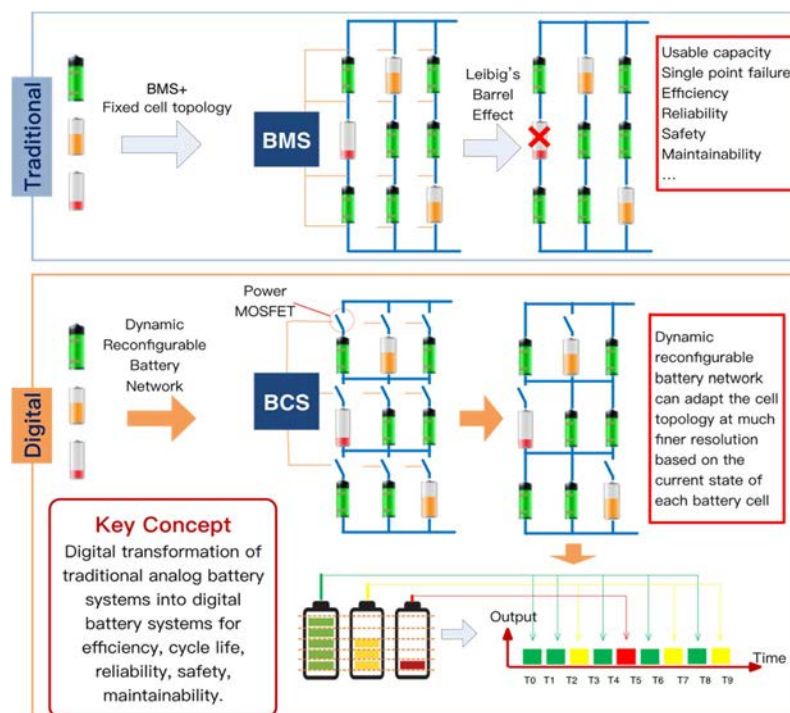
Cable Length (m)

**Figure D.3: Required output voltage variation under correlation between load and cable length (10 mm<sup>2</sup> coper cable)**

## Annex E (informative): Digital Reconfigurable Battery solution for 5G base stations

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 network.

A digital reconfigurable battery system is illustrated in Figure E.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 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 states across the entire battery pack.



**Figure E.1: Architecture of digital reconfigurable battery system**

Figure E.2 illustrates the system diagram of a typical digital battery system, where a switching circuit enables reconfiguration on cell level topology within 10 ms. As a result, power management and control in this system can be conducted dynamically on cell level, array level, pack level, and battery network level by means of 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 condition, meaning that the lifespan of the system will become much longer than that of traditional battery pack with 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 EV battery.



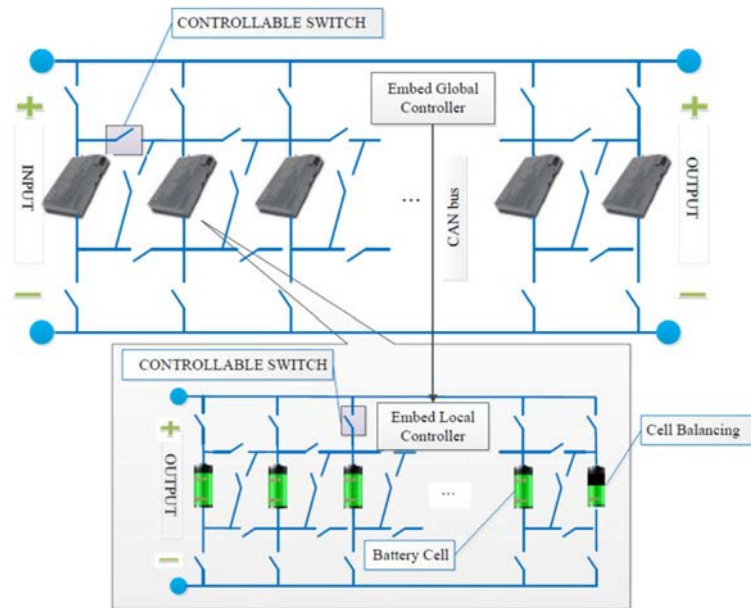


Figure E.2: System diagram of digital reconfigurable battery systems

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## Annex F (informative): Bibliography

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## History

| Document history |                |                                                                          |
|------------------|----------------|--------------------------------------------------------------------------|
| V1.1.1           | February 2021  | Publication                                                              |
| V1.1.7           | July 2025      | Membership Approval Procedure      MV 20250907: 2025-07-09 to 2025-09-08 |
| V1.2.1           | September 2025 | Publication                                                              |
|                  |                |                                                                          |
|                  |                |                                                                          |