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Environmental Engineering (EE); Interfacing of renewable energy or distributed power sources to 400 VDC distribution systems powering Information and Communication Technology (ICT) equipment

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Foreword

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

The up to 400 VDC power solutions feeding the power interface to ICT equipment as defined by ITU-T (Recommendation ITU-T L.1200 series [1], [2], [3], [i.1], [i.3]) and ETSI [8], are well adapted to straight forward use of renewable energy or distributed power sources through new simple DC nano or micro grids. This series defines the coupling of local or remote renewable energy into an up to 400 VDC power system without reducing DC performances defined in Recommendation ITU-T L.1202 [2] mainly for efficiency and reliability. The main advantages are saving of fossil fuel (as a source of primary energy consumption), reduction of GHG emission and increase of resilience. Additional site interconnection by DC grid can even bring more optimization. One other big benefit is that compared to AC, on 400 VDC there is no synchronization required between the various inputs, which keeps the architecture simple.

Modal verbs terminology

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Introduction

The up to 400 VDC power feeding solution for ICT sites (datacenters, telecom centers) and other building using the up to 400 VDC power interface Recommendation ITU-T L.1200 [1], are well adapted to straightforward use of renewable energy or distributed power sources through new DC nano or micro grid, most of them being more complex in AC than in DC. The DC would allow great simplification by avoiding frequency and phase synchronization of AC generators or inverters.

The present document aims at defining interface and architecture for injecting renewable energy into an up to 400 VDC power system in charge of providing power to ICT and facilities equipment with an interface compliant to Recommendation ITU-T L.1200 [1], and with a DC power architecture as defined in Recommendation ITU-T L.1204 [i.3], without reducing DC performances defined in Recommendation ITU-T L.1202 [2] mainly for efficiency and reliability.

The addition of local renewable energy will reduce energy consumption from the public utility, and possibly fossil primary energy consumption and the corresponding high GHG emission.

It can also provide more resilience in case of public electric grid interruption.

In addition, energy exchange is simple with distributed green power sources e.g. photovoltaic, wind power, fuel cell (FC) or engine generator using green fuel through a DC nano or micro grids at the level of a multi-building site or between different sites. These sites can be any type of ICT sites such as network access or nodes, data-centers, customer premises including IoT devices, etc.). Such an inter-buildings or sites power interconnection is called "site grid" by opposition to public electric utility.

These DC energy exchanges through site grid can bring higher level of optimization such as:

- exploit green-energy sources more efficiently by optimal location of renewable energy generator (e.g. for wind system in windy places and for PV system, in places out of shadow);
- complement local back-up power system e.g. battery;
- share local renewable energy excess of one site with other sites;
- ensure remote powering of distributed ICT site in the neighbourhood (e.g. by dedicated remote DC power cables or hybrid optical and DC power cables).

Injection of the renewable energy into the legacy AC public utility should consider the use of electricity for ICT services, and avoids undetermined use in the neighbourhood that can be inefficient. Key performance indicators could be used for reducing inconsidered use by accounting for efficient use of renewable energy on one ICT site or interconnected sites through a nano grid.

Many documents provided in bibliography are elaborating on the benefit and the need of coupling REN energy to local installation or to nano grid [i.7], [i.14] to ICT installation and the advantages of doing it in DC [i.8], [i.9], [i.10], [i.11], [i.12]. LCA approach is more detailed in [i.13].

The present document was developed jointly by ETSI TC EE and ITU-T Study Group 5 and published respectively by ITU and ETSI as Recommendation ITU-T L.1205 [i.1] and ETSI ES 203 474 (the present document), which are technically equivalent.

1 Scope

The present document defines interconnection of site power installation feeding up to 400 VDC interface, to site renewable energy or to distributed DC power. The covered aspects are:

- general power architectures for:
  - connection of a site renewable energy source (PV, wind generator, fuel cells, etc.) to a site power plant and especially the DC power system, (the site sources being on the buildings or around);
  - exchange of power to and from a DC nano or micro grid for use and production out of the site (this includes dedicated remote powering network built for ICT access equipment but also more general purpose DC electric grids);
  - conditions required to keep specified performance for the up to 400V power system:
    - electrical stability;
    - reliability and maintainability;
    - proper battery charge and management;
    - lightning protection coordination;
    - EMC and transient limits;
  - specification of proper power sizing, Requirement for control-monitoring and power metering;
  - assessment of performances (AC grid energy saving, reliability, flexibility, environmental impact, etc.).

The present document does not cover:

- renewable energy dimensioning;
- power injection into the legacy AC utilities which is already covered by many standards (e.g. from IEC);
- some of the smart power management possibilities through exchanges with DC nano or micro grid.

2 References

2.1 Normative references

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

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

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

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

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

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

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

[5] ETSI ES 202 336 (all parts): "Environmental Engineering (EE); Monitoring and Control Interface for Infrastructure Equipment (Power, Cooling and Building Environment Systems used in Telecommunication Networks)".

[6] IEC 60364 series: "Low-voltage electrical installations".

NOTE: Available at https://webstore.iec.ch/searchform&q=IEC%2060364.

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

[8] ETSI ES 203 408 (V1.1.1) (2016-12): "Environmental Engineering (EE); Colour and marking of DC cable and connecting devices".

2.2 Informative references

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

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

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

[i.1] Recommendation ITU-T L.1205 (October 2016): "Interfacing of renewable energy or distributed power sources to up to 400 VDC power feeding systems".

[i.2] ETSI EN 302 099 (V2.1.1): "Environmental Engineering (EE); Powering of equipment in access network".

[i.3] Recommendation ITU-T L.1204 (2016): "Extended architecture of power feeding systems of up to 400 VDC".

[i.4] Recommendation ITU-T L.1302 (2015): "Assessment of energy efficiency on infrastructure in data centres and telecom centres".

[i.5] Recommendation ITU-T L.1350 (2016): "Energy efficiency metric of base station site".

[i.6] Recommendation ITU-T L.1410: "Methodology for environmental life cycle assessments of information and communication technology goods, networks and services".

[i.7] K.K. Nguyen et al. (Projet GreenStar) (2011): "Renewable Energy Provisioning for ICT Services in a Future Internet" Future Internet Assembly, LNCS 6656 (open access at SpringerLink.com), pp. 421-431.

[i.8] IEEE/Intelec 2013 (Hamburg): "DC power wide spread in Telecom/Datacenter and in home/office with renewable energy and energy autonomy", Didier Marquet and al. Orange Labs; Toshimitsu Tanaka et al. NTT.

[i.9] Vicor White paper: "High-voltage DC distribution is key to increased system efficiency and renewable-energy opportunities", Stephen Oliver.

NOTE: Available at http://www.vicorpower.com/documents/whitepapers/wp-High-voltage-DC-Distribution.pdf.

[i.10] STARLINE: "Phasing Out Alternating Current Directory: An Engineering Review of DC Power for Data Centers", David E. Geary.

[i.11] 400 VDC Power Solutions from Emerson Network Power: "Innovative Power Architecture for Data Center and Telecommunications Sites".

NOTE: Available at https://www.vertivco.com/globalassets/products/critical-power/dc-power-systems/400v-dc-power-solutions-brochure.pdf.

[i.12] IEEE/Intelec 2014 (paper quoted on Emerge Alliance): "Three Case Studies of Commercial Deployment of 400V DC Data and Telecom Centers in the EMEA Region", Sara Maly Lisy, Mirna Smrekar Emerson Network Power.

NOTE: Available at http://www.emergealliance.org/portals/0/documents/events/intelec/TS01-2.pdf.

[i.13] IREED 2011 (Lille 23-24 March 2011, 7 p): "Wiring design based on Global Energy Requirement criteria: a first step towards an eco-designed DC distribution scheme", C. Jaouen, B. Multon, F. Barruel.

[i.14] Micro grids: "A bright future".

NOTE: Available at http://www1.huawei.com/enapp/198/hw-110948.htm.

3 Definitions and abbreviations

3.1 Definitions

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

back-up power system: power system providing energy to equipment of an ICT site in case of downstream electric unavailability

distributed power source: local electrical power source where energy is produced close to the user and distributed by a nano or micro grid by opposition to a centralized power plant with a long distance electricity transport grid

NOTE: This local power source can be an individual user power system or a small collective energy power plant for a group of customers. It can include energy sources or storage or cogeneration of heat and electricity using any primary energy renewable or not.

distributed power system: system of distributed power source and possibly other function such as energy conversion, interconnection, safety system, energy storage and corresponding management

ICT equipment (Recommendation ITU-T L.1200 [1]): information and communication equipment (e.g. switch, transmitter, router, server, and peripheral devices) used in telecommunication centres, data-centres and customer premises

Interface P (Recommendation ITU-T L.1200 [1]): interface, physical point, at which power supply is connected in order to operate the ICT equipment

nano grid, micro grid: local area grid connecting some building together at relatively short distance

NOTE: It can be in AC or DC. In general nano grid is lower than 100 kW, micro grid can be of higher power. "Nano or micro grid" will be used in the present document.

renewable energy: energy which can be obtained from natural resources that can be constantly replenished

NOTE: Source: Australian Renewable energy Agency.

renewable energy source: source producing electrical energy from renewable energy

site grid: DC nano or micro grid between ICT sites by opposition to public electric utility

3.2 Abbreviations

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

AC	Alternating Current
BMS	Battery Management System
CHP	Combined Heat and Power
CT	Current Transducer
CU	Control Unit
DC	Direct Current
EE	Energy Efficiency
EMC	Electro-Magnetic Compatibility EMC
FC	Fuel Cell
GHG	Green House Gas
HV	High Voltage
HVAC	High Voltage AC
ICT	Information and Communication Technology
IoT	Internet of Things
KPI	Key Performance Indicator
LCA	Life Cycle Analysis
LVAC	Low Voltage AC
LVDC	Low Voltage DC
MW	Megawatt
PDF	Power Distribution Frame
PDU	power Distribution Unit
Ppeak	Peak power
Pu	Used power
PV	Photovoltaic
PWM	Pulse Width Modulation
REN	Renewable Energy
RF	Rectifier Function
TCO	Total Cost Ownership
VDC	Volt DC

4 Architecture of up to 400 VDC power with REN coupling

4.1 Overview

In existing buildings, AC grid (HVAC or LVAC) and LVAC distributions are powering ICT equipment, cooling systems, back-up power systems, control/monitoring, lighting, office computers, Ethernet switches routers and many other equipment in the building such as ventilation, heater, lifts, etc. A part of the equipment is DC powered by the DC power feeding systems, and this part is mainly using 400 VDC rather than -48 VDC because of the higher power density of equipment in order to reduce cable cross-section area and distribution losses.

ICT sectors work on the reduction of the non- renewable primary energy use by reducing direct electricity consumption and producing more Renewable Energy (REN).

The REN generators are generally in LVDC and so power arrangement up to 400 VDC power systems is much more convenient for injecting REN.

NOTE: REN generators that are in AC are generally producing variable frequency and voltage requiring precise synchronization for connection to AC grid.

DC REN generators allow easier consumption of locally generated energy or generated by a group of close sites through DC nano or micro grid compared to solution with local AC generator synchronized with AC grid.

Due to the wide use of AC in ICT buildings, the REN coupling solutions should consider a progressive swap from AC injection to DC. Figure 1 gives the general principle of energy flow of the renewable energy or distributed DC power to the existing power system of the building integrating an up to 400 VDC system.

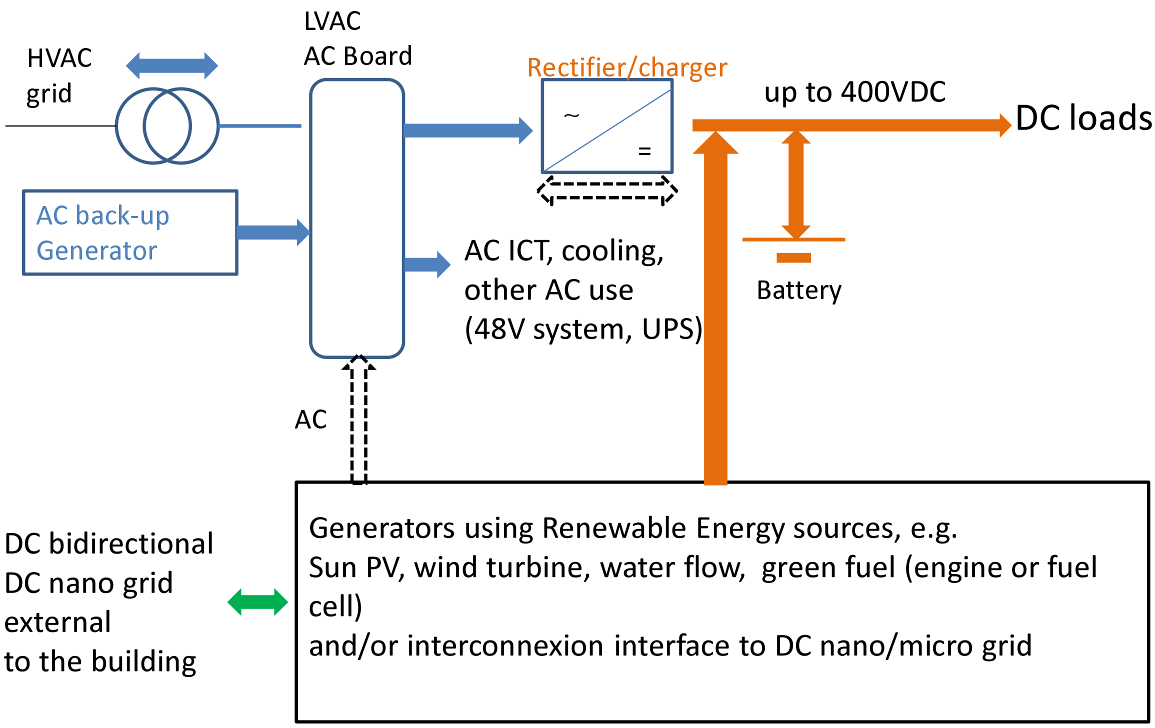

Figure 1: General energy flow principle for coupling renewable or distributed DC site grid to an up to 400 VDC power system in a building of a site

The flow direction is indicated by the arrow and reverse direction from REN to grid depends on excess of power not used by the sites for powering ICT equipment, cooling and air conditioning equipment and building use could be sent to the AC or DC grids. This is to avoid loss of productivity and to contribute to the local or regional nation electric mix and CO_2 reduction effort and to obtain a better TCO for the user.

Combined Heat and Power generation (CHP) and storage can be also alternatives, but they are not covered in the present document focused on injection of electricity in DC and partly in AC.

4.2 Local and distant Renewable Energy coupling architecture to sites with up to 400 VDC

There are different architectures for interconnections of local REN or distributed power systems or DC nano and micro grid up to 400 VDC power systems in buildings or sites. It includes local renewable power sources:

- connected to AC and/or DC distribution:
  - for local consumption;
  - for local injection of excess of production into external grid;
- connected to an external DC nano or micro grid:
  - for injection of excess of DC production towards other buildings or sites;
  - for remote interconnection to the AC grid e.g. for mutualized injection of DC energy excess on one single point;
  - for islanding the group of sites when running on own distributed power production capacity (e.g. pure or hybrid renewable energy source with energy storage).

NOTE: The connection to DC nano or micro grid for different services is not fully covered in the present document as R&D is still on-going in many directions such as swapping part of the AC grid power systems to more energy coming from local renewable energy or from external DC nano or micro grid, extending resilience of the site to face grid power interruption, taking advantage of smart grid services at the level of the interconnection to AC grid e.g. renewable energy injection or storage to support the grid, on demand peak shedding, etc.

Figure 2 gives the general principles of electrical coupling interconnection of the local REN or from DC from nano/micro grid to the existing power systems of the building integrating up to 400 VDC systems. The power injection can be done:

- in DC only;
- in AC only;
- in AC and DC.

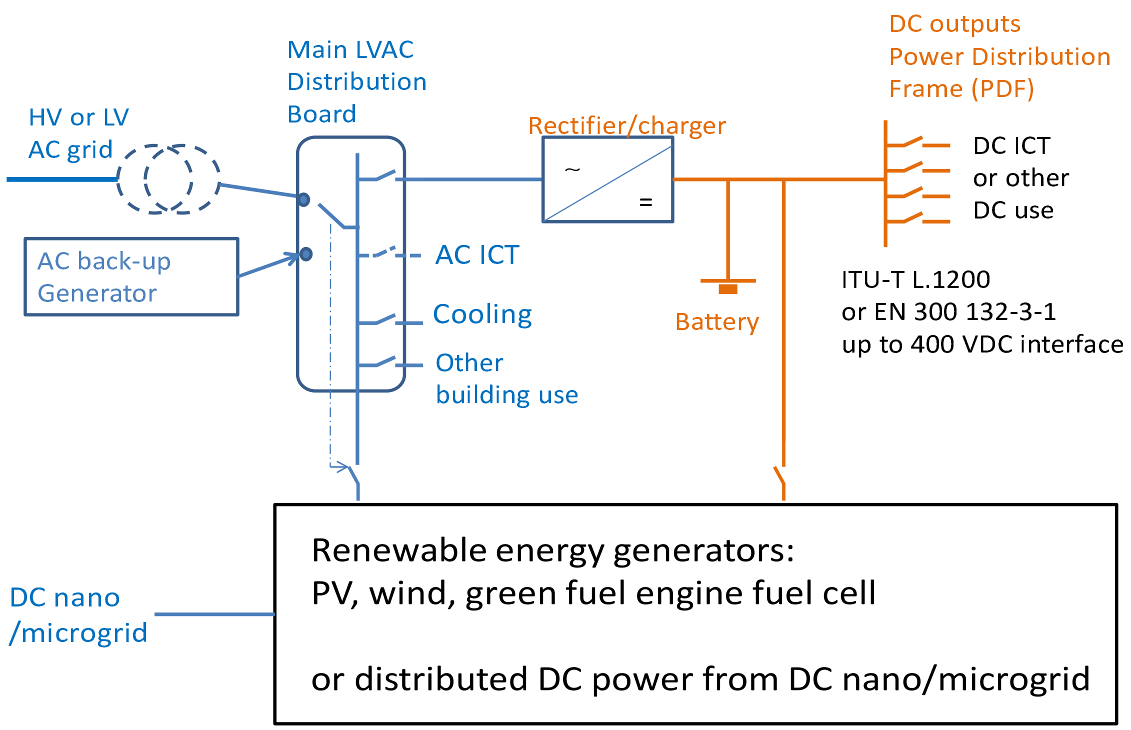

Figure 2: Coupling local REN or DC nano/micro grid to the AC and DC power systems of a site

The different configurations recommended in annex A should be preferred, but others are possible and will require further studies.

In a redundant system, interconnection and coupling can be done on several power chains, and with different shares between AC and DC injection.

The coupling architectures should be implemented with the less power conversion stages as possible between:

- the local renewable energy sources;
- the site DC power system for local use of up to 400 VDC compliant with Recommendation ITU-T L.1200 [1];
- the remote power supply to user equipment on remote DC powering lines compliant with ETSI EN 302 099 [i.2];
- other DC sites and REN sources interconnected to an inter-sites DC micro and nano grid.

More details will be given in the next clauses to check the considered architectures on the critical conditions:

- the safety shall be ensured whatever will be the increase of maximum combined source impedance and short-circuit current on the DC bus;
- the interface shall comply in any case in voltage range and other characteristics of the up to 400 VDC powering interface (Recommendation ITU-T L.1200 [1]);
- the proper operation, reliability and safety of the battery connected to the DC Bus shall be ensured by avoiding any contradiction with the up to 400 VDC system existing charge control in current, voltage, timing characteristics.

5 Conditions required to keep specified performance for the up to 400 V power system

5.1 General introduction

The following clauses list the conditions of interconnection of renewable energy generators for up to 400 VDC power systems in a building, considered from AC input to DC output.

These conditions cover the following aspects:

- electrical stability;
- reliability, maintainability, safety;
- proper battery charge and management;
- lightning and protection coordination and distribution for EMC, transient limitation.

5.2 Electrical Stability

5.2.1 General consideration on REN power injection

Different rate of REN self-consumption on site is observed, from few percent of yearly consumption to about 100 %. Details are given in annex D.

In general, with intermittent source the higher the self-consumption ratio, the higher the peak power ratio Ppeak/Pu.

EXAMPLE 1: On a vertical building with relatively small roof, a PV power generator will be very small compared to the used power e.g. 50 kW for a 400 kVA AC grid contract and 100 kW DC use. The risk of instability is low as all parameter will stay below the limit of the AC source.

EXAMPLE 2: On a small country datacenter with a PV field, this can be the opposite, 1 MW of PV and 100 kW consumption. In that case, the peak power can reach 10 times the used power. Power injection limitation are necessary between the PV system and the AC or the up to 400 VDC system. It is also highly recommended to study the possibility to inject directly energy to the AC grid acting as an huge consumer, or to add a local energy storage; which will be able to filter the power peaks for providing a permanent means of power.

Considering orders of magnitude, the following classification can be applied:

a) Local power generation lower than local power consumption:

- Local power generation is at all times lower than power consumed at the site, in general, no power will flow to the grid. Local power generation might be used as backup-up power for poor grid sites or to reduce power consumption from grid. Storage capacity for electricity might be available at the site to cover short term overproduction.

b) Local power generation equivalent to local power consumption:

- The local power generation might exceed local power consumption for extended periods of time. The site shall be either able to feed the excessive energy back into the grid or otherwise sufficient storage capacity shall be installed to utilize all locally generated energy.

In that case, the REN system may not produce all the energy required by the site.

c) Local power generation higher than local energy consumption:

- An ICT site might be combined with a large power generator (solar farm, large wind generator, etc.) producing more power than needed most of the time. A grid connection is required to utilize the full amount of produced energy. The REN generator can also be connected remotely through this grid. The grid can be utility grid or DC nano/micro grid.

Prior to the installation of local energy generation, an LCA should be carried out to analyse the total life time effect of local energy generation and the most efficient amount of REN production.

5.2.2 DC injection of locally generated REN power

For local electrical distribution design reason the DC power interface of REN energy to the up to 400 VDC system shall be limited by the protection devices to the maximum power rating of the fully equipped DC power system defined at the level of the DC power bus able to accept the maximum rectifier or battery current.

The power flow shall be managed to give preference to the REN usage.

The REN DC power injection limit should be reduced for different reasons:

- limiting the risk of over-charge current in the battery to avoid thermal run-away. This should cover multiple faults in the charge control at the level of the rectifier, battery management system or REN output stage control;
- dynamical limiting REN power to the momentary DC system load to avoid risk of voltage overshoot.

When the local DC site provides remote powering in DC 400V to several neighbourhood ICT sites, additional precautions should be taken to avoid dynamic instability through remote line and distant systems. Appropriate decoupling should be defined e.g. by limiting power rising slope of distant system, line inrush current, etc.). This can be obtained through proper automation, local energy storage, etc. Remote powering interface in 400 VDC of ETSI EN 302 099 [i.2] should be used to limit these risks.

5.2.3 AC injection of REN power

The injected AC power from REN system in the AC distribution of the site shall be done in coordination with the AC power distribution and back-up source of the site.

The protection of the line to the REN output, AC inverter system shall keep a correct fault discrimination in case of short circuit, in order not to affect the AC power feeding from the grid or from the back-up generator. In particular, when the installation is running on the AC back-up generator, generally the short-circuit current is much lower than on the AC grid or transformer.

5.3 Reliability, Maintainability, Safety

The reliability of up to 400 VDC systems can be affected by REN AC or DC coupling by:

- equipment failures;
- possible current or voltage surges;
- interventions errors for electrical maintenance or electrical work (extension, modification).

Manual decoupling device (e.g. disconnection switch) of REN system shall be possible before any operation on the REN system. This is useful to avoid propagation of failure, e.g. short circuit creating high current stresses and voltage transient.

Automatic disconnection of the REN system should be provided in case of failure in the REN system, to avoid propagation of fault to the up to 400 VDC system considering that the REN power is not used as main source of the considered on-grid site.

NOTE: Further studies are required to determine the rules of disconnection and reconnection.

The rules could be very different compared to a standalone off-grid site without AC grid input where, there is in general no automatic disconnection of the generator but only regulation and battery charge management with the appropriate redundancy.

When REN power is injected in the electrical system either in AC or DC, manual disconnection with proper safety rules defined by IEC and national standards and regulations shall be applied.

This is critical for safe out of voltage operation on the up-to 400 VDC system.

Particularly in this case of DC with multi sources inputs (rectifiers, batteries, REN input), the presence of voltage should be very clearly signalled.

Any ICT equipment used in the up to 400 VDC REN coupling system shall comply with IEC 62368-1 [7].

5.4 Proper battery charge and management

5.4.1 DC injection of REN power

The DC power of the REN generators when connected directly to the battery shall be injected according to the battery charge/discharge requirements. This shall be done in line with the management achieved by the existing Control Unit (CU) of the DC power system i.e. rectifiers or by the controller of some advanced battery (e.g. Lithium equipped with BMS).

In general the important conditions to comply with are:

- avoiding any over-voltage or over current compared to the limit imposed by the rectifiers under their controller or by the battery controller if any (e.g. in Lithium-ion battery systems);
- avoiding any change of the charging characteristics of the battery.

The maximum values and the charging modes are set according to the installed battery type, its capacity and the battery manufacturer datasheet.

In normal operation, there are charging modes and steps with parameters of voltage, current, time, charge quantity, temperature and many thresholds to pass from one step to another. Deviation from these values can have immediate effects and long term impacts on:

- operation (e.g. disconnection of the battery in case of over-voltage or current, loss of autonomy in case of confusion inside the existing control on the charge management);
- safety (risk of fire if overcharge);
- life-time (by changing charge conditions e.g. more cycling for a battery not designed for this type of operation).

In practice, several solutions of REN coupling on the DC bus are possible:

1) voltage follower REN solution: in that case the REN generator voltage is following the up to 400 VDC system voltage;
2) DC/DC converter coupling solution: in that case a converter e.g. DC/DC separates the REN generator from the up to 400 VDC system voltage which adapts to the up to 400 VDC system;
3) upstream solution: the up to 400 VDC system has a dedicated input for REN energy system in addition to AC input.

Detailed information on these solutions is provided in clause 6, annexes B and D. Other solutions may be possible.

In general, the common DC power feeding systems are designed with the assumption of connecting a single power source type at a time e.g. a set of rectifiers of the same type with same control. This raises new issues when connecting renewable energies to such a DC power feeding system. More details can be found in annex C.

5.4.2 AC injection of REN power

AC needs an AC/DC conversion system in order to be connected to the battery able to follow the battery management requirements as in clause 5.4.1.

5.4.3 EMC, transient voltage and current surge limitation

It is of high importance to check the compliance of the lightning protection, EMC and voltage transient limits of the REN system output, as the PV system or wind generator or DC micro grid can cover wider area and may be of much higher peak power than the ICT site where is installed the DC power system, and could bring more electrical disturbances.

The full system shall follow ETSI EN 301 605 [4]. It may be necessary to add protection inside the REN energy system or filters in the power distribution interface between the REN system output and the DC and AC site power systems.

When distributed power sources such as PV are installed outside and connected to the power feeding system, it would be highly probable to get affected by a lightning surge. In order not to cause degradation of reliability of the power feeding system, some countermeasures should be taken. Insulating points and dielectric strength voltage shall be specified in order to prevent ICT equipment from destruction and malfunction.

Next clause 5.4.4 gives complements on cabling and risk limitation on and from the REN generator itself.

5.4.4 Protection of distribution cables and protection coordination

The system configuration (connection points of distributed power sources and locations of circuit breakers) shall be very clearly studied, documented and use clear marking of the different circuits to discriminate the installation from ICT high reliability system and local or distributed REN energy circuits. The up to 400 VDC wires, cables and distribution equipment colour and marking shall comply with ETSI ES 203 408 [8]. The distribution used in the up to 400 VDC REN coupling shall comply with IEC 60364 [6].

Appropriate standards from IEC should be followed for REN system installation which is out of the scope of the present document.

In general for ICT installation, it is recommended to reduce the risk of overcurrent and voltage transient as follows:

- reduce at minimum the area of loop in the cabling to reduce the voltage induction by magnetic coupling;
- minimize the earth connection length using local earthing on the REN generator itself;
- when using underground cable conduit, the conduit shall be made of metallic conductor and earthed;
- use transient protective device as necessary depending on environment and climatic condition and on possible induction from high power line in the neighborhood;
- increase equipotential grounding by inter-connecting the metallic parts when there is a risk of high resistance of the earthing especially on rocky and dry ground.

When distributed power sources are connected to the power feeding system, if a failure of a short circuit occurs, it would be probable to cause a larger short-circuit current. In order not to have this serious event, there would be necessity to do some countermeasure.

When these REN local or distributed sources are under the same user responsibility, previous precaution can be applied.

When this is not the case, additional precaution shall be taken.

It is necessary to specify connection points of distributed power sources and locations of circuit breakers in order to implement the protection of distribution cables and protective coordination work.

On wide area REN installation attention should be focused on cabling to avoid source of serious trouble by high current and voltage induction from other cable and from Lightning. This is better solution than spending lot of time and money with high difficulty and uncertainty to try to correct the consequences.

6 Control-monitoring and metering

A local and remote energy metering and management of coupling installation shall be defined and installed in compliance with ETSI ES 202 336 [5] control monitoring standards.

The requirement for control-monitoring-metering are considered in addition to those of the up to 400 VDC system to get full view of the energy flows including REN in and outside the considered architecture or site and for better management of operation and maintenance.

If REN injection is also performed by coupling REN on AC side, the metering and management of coupling should be compliant to ETSI ES 202 336 [5].

7 Assessment of performances improvement of up to 400 VDC systems with REN power

7.1 Reliability, efficiency performance assessment

Performance reliability and comparative Energy Efficiency assessment methods defined in Recommendation ITU-T L.1202 [2] shall be used.

At minimum, it shall be checked that the coupling of renewable energy or distributed power does not reduce the Energy Efficiency and reliability or availability of the power systems existing in the building which could happen for example as follows:

- change in power load of the existing rectifiers when REN is injected to DC bus;
- change in reliability due to more dynamic load behaviour.

The EE shall be studied and then measured on site on a yearly base to integrate ICT load variation and seasonal effect, and more dynamic load variation due to intermittent REN injection.

7.2 Operational KPI of REN coupling to sites with up to 400 VDC systems

KPI are intended to reflect the operational benefit of injecting renewable energy at the level of site and particularly in DC on a relevant period, typically of one year to have profile and average including seasonal variations.

Follow of KPI on several years will show the evolution including load changes, equipment ageing, installation of more REN, effect of additional functions such as energy storage, setting changes, etc.

When KPI reflecting the renewable energy self-consumption and production are required, they should use standards for renewable energy use such as Recommendation ITU-T L.1302 [i.4] and Recommendation ITU-T L.1350 [i.5].

When KPI reflecting other Environmental Impact Reduction are required, they should use result of assessment based on Recommendation ITU-T L.1410 [i.6] for assessing the change on the life cycle impacts of goods network and services when using more renewable energy, etc.

This would also allow assessment of AC grid energy saving and other performance (KPI) such as reliability/maintainability, complexity, resilience, flexibility, economic and environmental sustainability, etc.

The basic data used for these KPIs should come from the control-monitoring systems defined in clause 6 and from additional meters and sensors on the REN system itself.

Annex A (informative): Different possible coupling architectures of REN energy to AC and DC site powering systems or to nano or micro grid

A.0 General view

This annex gives a set of possible detailed configurations and functions of the REN coupling to site including up to 400 VDC systems.

Advantages and drawbacks are discussed.

A combination of these configurations is possible on some big sites, and other configurations can be studied.

A.1 Interconnection of REN on single AC site input

Figure A.1 shows the legacy interconnection of REN sources to AC grid. The power source can be PV, Wind generator, fuel cell or engine-generator possibly using biofuel.

The REN output power is converted in AC, and either can be sold only or can be used by all loads in the site and only excess sold to the AC supplier.

The drawback of AC injection is that the inverter is stopped in case of grid interruption in accordance to relevant standards for of grid inverter in order to avoid electrocuting people making intervention on the AC grid.

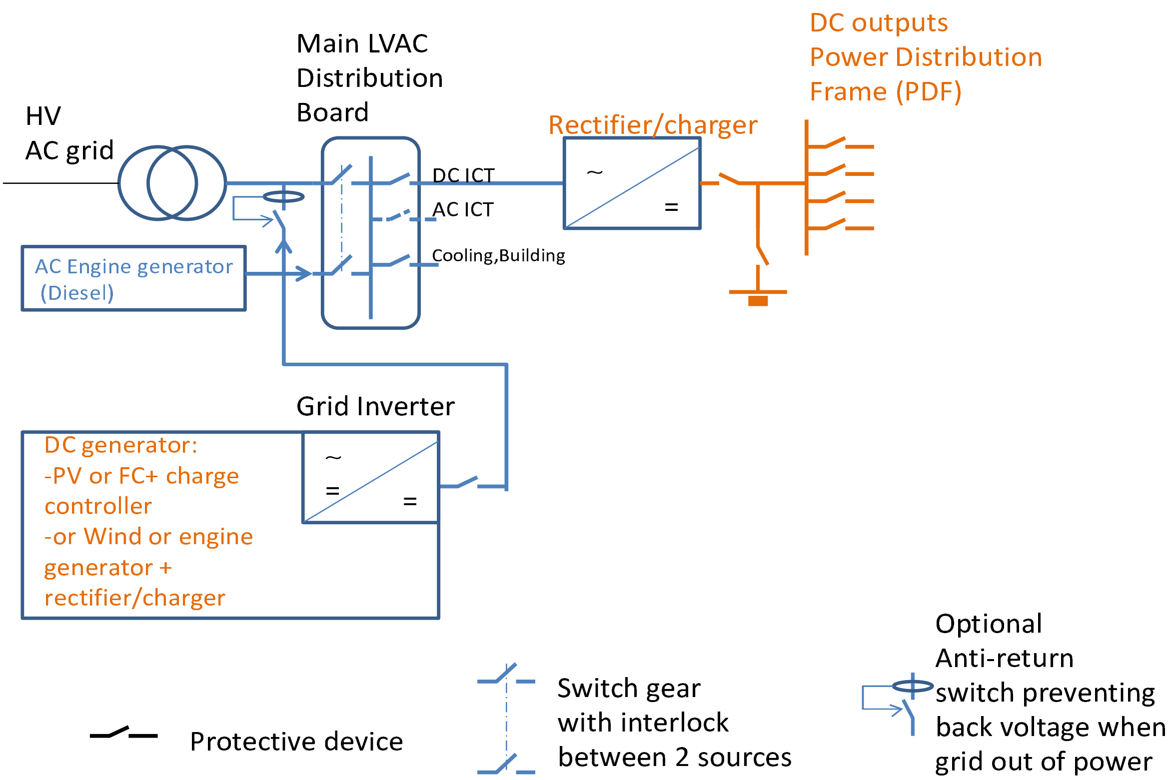

Figure A.1: Interconnection of REN on AC site input

A.2 Interconnection of REN on single and multiple DC distribution

The source output power is converted in DC, so only DC load can use, and excess power is not sold to AC grid. The advantage is higher efficiency of self-consumption of renewable energy, no need of interruption in case of AC grid interruption as there is no power injection in the AC grid.

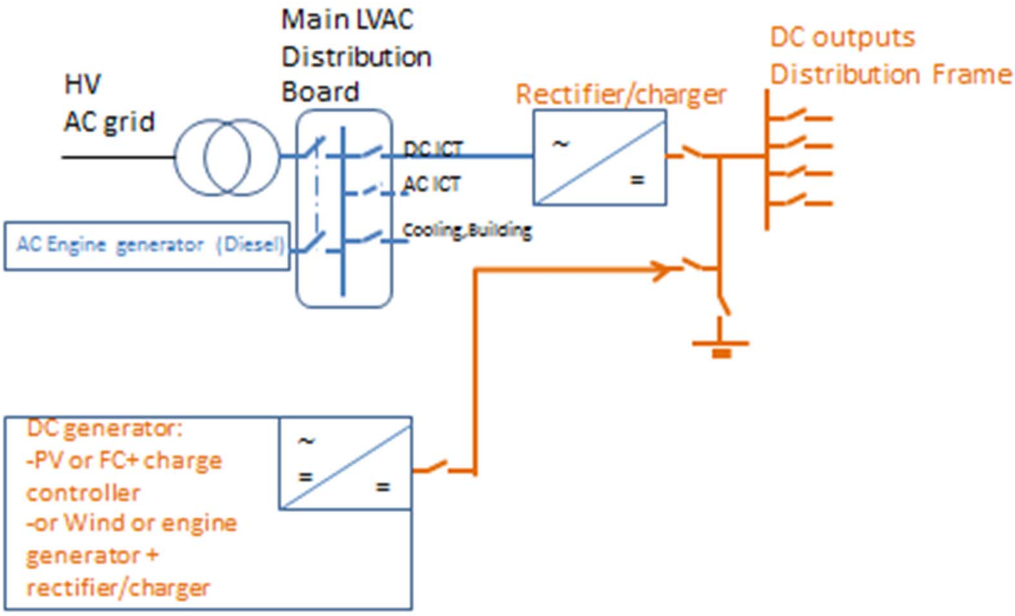

Figure A.2: Interconnection of REN on DC system

Figure A.3 presents interconnection of REN to multiple DC systems possibly in redundant configuration or not.

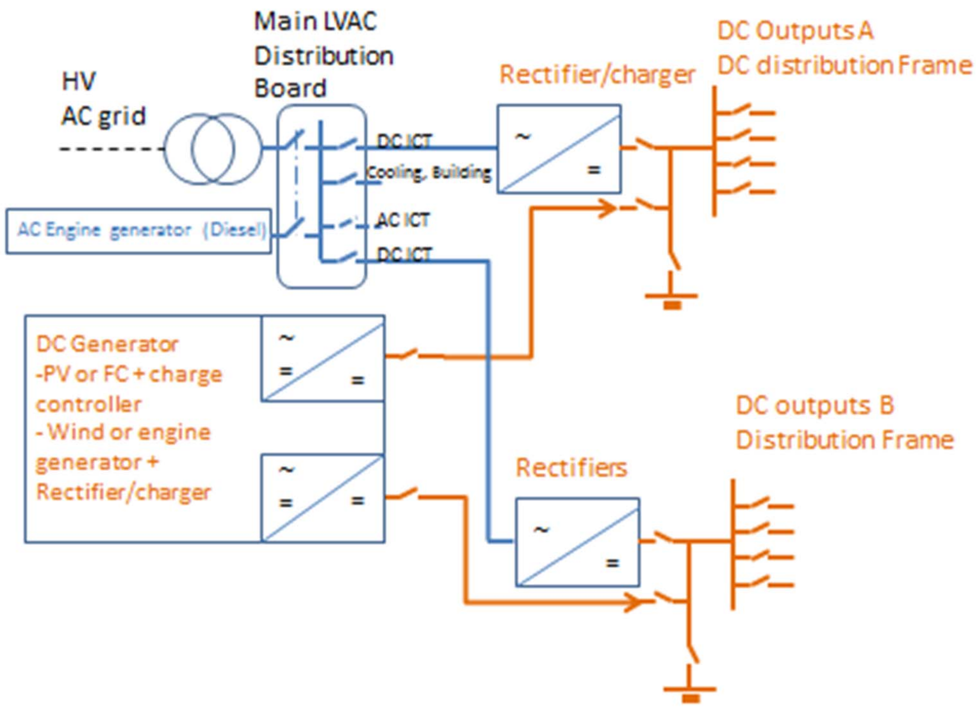

Figure A.3: Interconnection of REN on multiple DC systems

A.3 Interconnection of REN on single or multiple AC distribution frame

Figure A.4 shows REN source output power converted in AC and injected in the AC frame, so all site loads can use it. This configuration is a simple solution for self-consumption and peak shedding to reduce AC grid power contract and its cost, but it needs an AC synchronized inverter stopping when there is intervention on AC grid, and it is less efficient than using directly REN DC as it needs two conversion stages: inverters followed by rectifiers.

It could be possible to run on renewable energy without stopping the inverter, when the AC grid is interrupted. It requires the use of an AC isolation switch that can safely disconnect the AC grid from the inverter and local AC distribution.

Unless specific contract it does not allow selling the excess power.

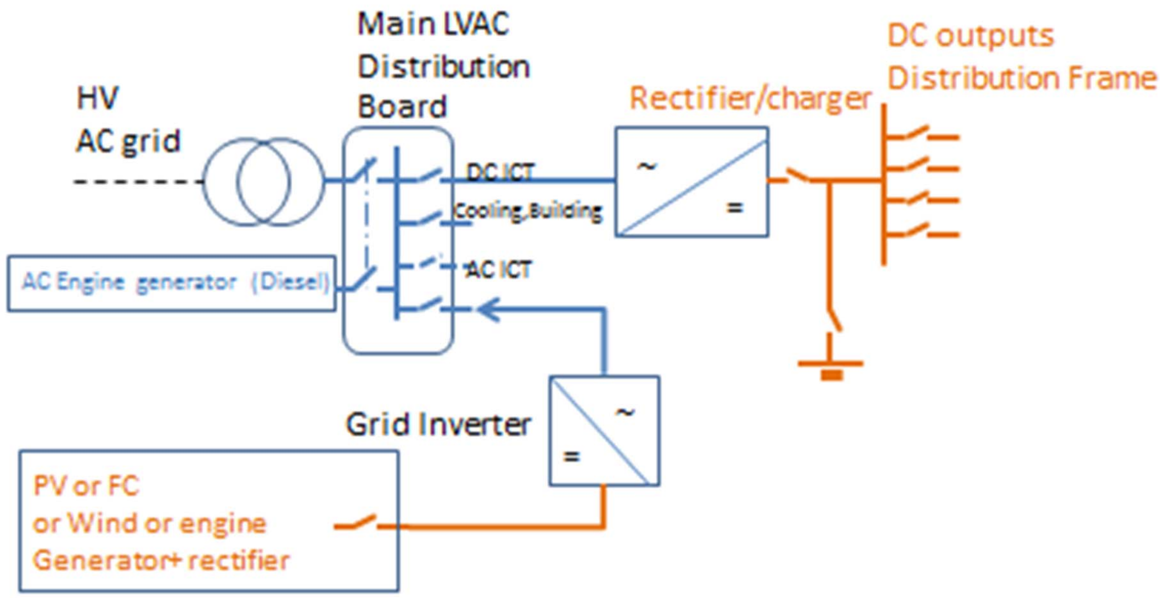

Figure A.4: Interconnection of REN on AC distribution frame and DC system

Figure A.5 shows injection of REN energy in redundant AC distribution in a site.

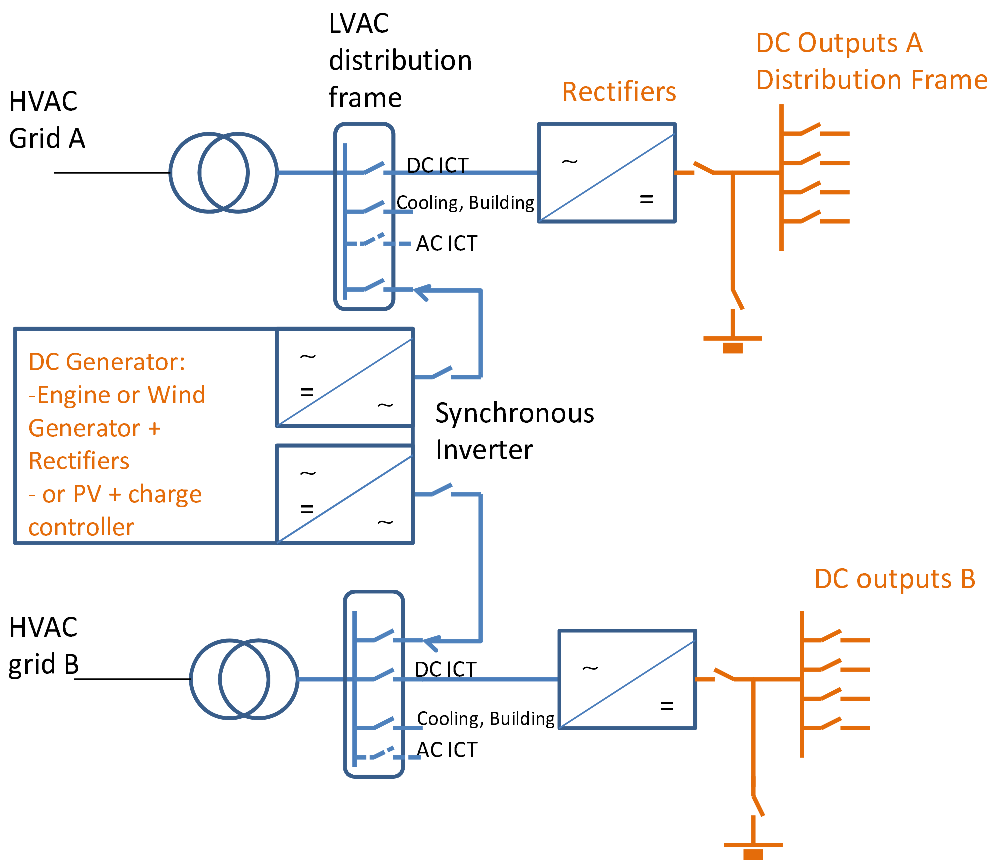

Figure A.5: Interconnection of REN on redundant AC distribution frame

A.4 Hybrid interconnection of REN on AC and DC distribution

Figure A.6 shows a hybrid injection of a REN source on AC and DC sides. The REN source output power is converted in DC and AC, so all site loads can use its power.

This configuration is more complex but allows maximum efficiency and reliability for DC use.

This configuration is a simple solution for self-consumption and peak shedding to reduce AC grid power contract and its cost and it may allow to sell the excess power under certain conditions on the AC switch gear as described in clause A.3.

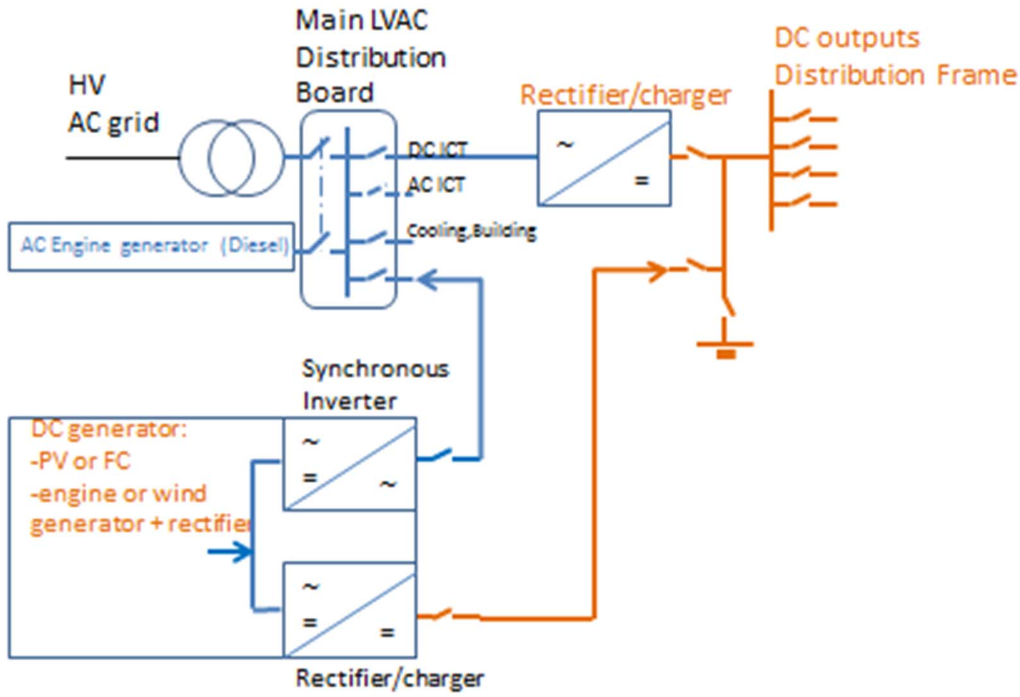

Figure A.6: Hybrid interconnection of REN on AC and DC

Figure A.7 shows a variant of hybrid configuration where the DC is secured by a DC biofuel engine generator, while the PV or wind energy is injected on AC distribution on all site loads and can be sold under certain conditions as described in clause A.3.

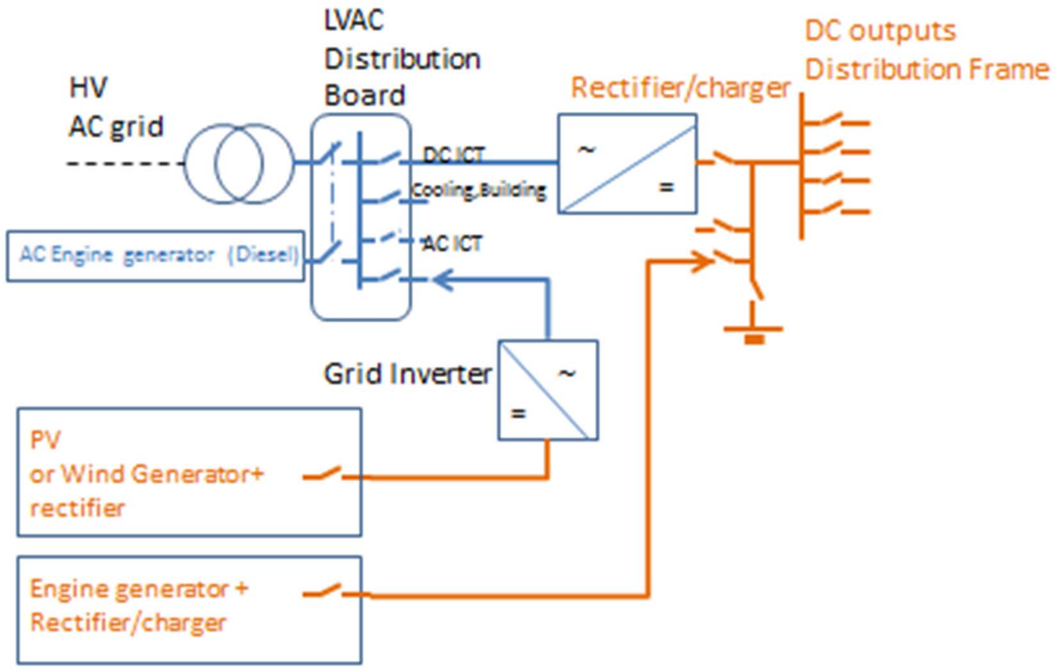

Figure A.7: Hybrid interconnection of REN on AC and DC

A.5 Interconnection of REN to DC nano or micro grid

Figure A.8 shows a possible interconnection of REN systems of a site to DC micro or nano grid, the local REN source being already coupled to AC and DC systems of the site.

The energy exchange can be bidirectional between the site and the micro or nano grid by importing or exporting energy at a given voltage range e.g. at up to 400 VDC as defined for remote powering in ETSI EN 302 099 [i.2].

The REN energy can be imported from REN source of another ICT site or from a REN source located outside the site (e.g. a PV array on a surround building roof or a wind machine on a windy place far from inhabitants). This is done through an interface converter to an internal power bus of the local REN system of sources.

The imported energy is then considered as being from a virtual local REN source and can be managed as the local REN sources energy though coupling converter to the AC or DC systems of the site.

On the other end the local REN source energy production can also be exported to the DC grid, by the interface conversion when it is made in a bidirectional arrangement.

The detailed control of power exchange on the DC micro or nano grid is out of the scope of the present document.

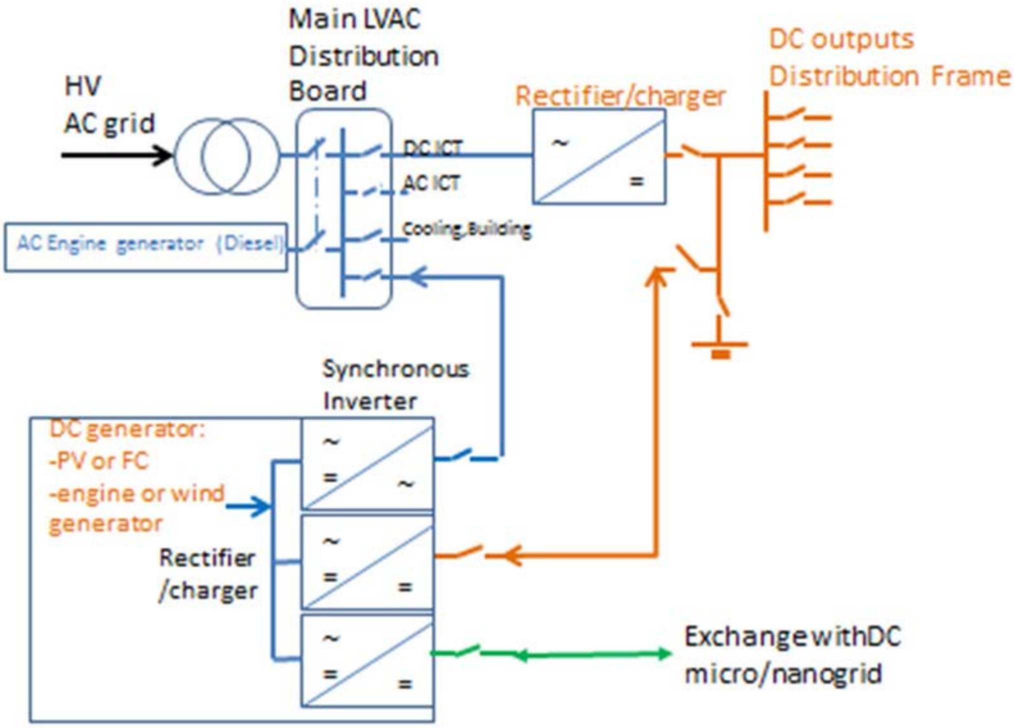

Figure A.8: Interconnection of REN source to a DC micro or nano grid

Annex B (informative): Details on coupling solution of REN generator to an up to 400 VDC system

This annex proposes some detailed solutions for coupling REN generator to an up to 400 VDC system.

1) Voltage follower REN solution:

- REN energy is supplied by an output power stage controlled (see figure A.2) at a voltage a little bit higher than the battery charge voltage provided by the up to 400 VDC rectifier. This solution is equivalent to the so called "PWM solar controller" following the battery voltage, to avoid any discharge and using the maximum REN as possible. The voltage difference should be very low to avoid an alarm of rectifier control fault by the controller.

- For keeping the control of the battery charge current and voltage, this requires a protocol between the DC system control and the REN system to exchange settings and also a measurement of the sum of REN and rectifier current into the battery. This solution may be difficult to adjust and can be unstable with change of load or REN power.

2) Converter coupling solution:

- This solution eliminates the difficulties of control of 1). Some up to 400 VDC power system manufacturers are providing DC/DC converters equivalent to AC/DC rectifier that can work coupled in parallel on the output DC bus. They are controlled by the same system control unit, so that it is easy to keep exactly the same battery management with AC and DC inputs (see figure B.1). This is a very stable and reliable solution based on the same DC system manufacturer. There is no need of complex output power stage on the REN power system.

- This may be difficult to mix manufacturers solutions as there is no interoperability standard between DC/DC converters and AC/DC rectifiers.

3) Double input up to 400 VDC system (Optimized solution):

- Rectifiers could be created with 2 inputs, one AC and one DC, avoiding additional rectifiers for REN as in 2). In this solution the priority to REN power should be managed inside each converter.

NOTE: In solution of voltage follower, the additional voltage should be adjustable and not higher than 500 mV compared to the normal operation of the power system without the renewable energy system in order to avoid a too high floating voltage reducing the battery life.

A simple solution is to reduce a little bit the battery floating voltage setting of the DC power system to avoid this overvoltage.

EXAMPLE: When using a PV system, and adding a delta of +300 mV on the PV regulator, the CU floating voltage could be set at -150 mV in order to compensate. On day time, the voltage will be at +150 mV of the ideal floating voltage, on night, it will be at -150 mV. These values are indicative and would need more feedback from field experiments.

Annex C (informative): Control/Monitoring consideration for Renewable Energy system connexion to AC and DC points in DC systems

This annex provides some solutions (case 1 and 2) of renewable energy power flow from site or from a DC micro grid control to a single up to 400 VDC power source. This annex explains also some typical issues identified in this situation.

Case 1:

Figure C.1 shows renewable energies interconnection to the up to 400 VDC power feeding system. Looking at this configuration, when the amount of power feeding energy of renewable energy sources exceeds the power consumption of ICT equipment, there would be a flow of redundant energy to the Storage for Backup, which it is fully charged. This could result in the battery overcharged.

In order to avoid this situation, it would be necessary to detect the output current of the Rectifier Function (RF), using a Current Transducer sensor (CT). This CT should give the capability of controlling the amount of current from the renewable source by the control unit shown in figure C.1 in order for the output current of the RF not to be equal to zero or flow reversely.

It should be noted that excess of energy from the renewable source, which is not used for power feeding, will be kept in the local battery temporarily or sent back to building AC grid and air conditioning system in the case of power failure. When there is a shortage of renewable energy, the local battery would be discharged in order to stabilize the power feeding system.

The dotted line indicates different point of connexion for DC power feeding system:

- when the renewable source is connected to the DC power feeding line in between the RF and the backup battery, the whole ICT equipment can be powered, on the other hand;
- when the renewable source is connected to the PDU, a specific ICT equipment can be powered, with which different quality of power feeding would be possible.

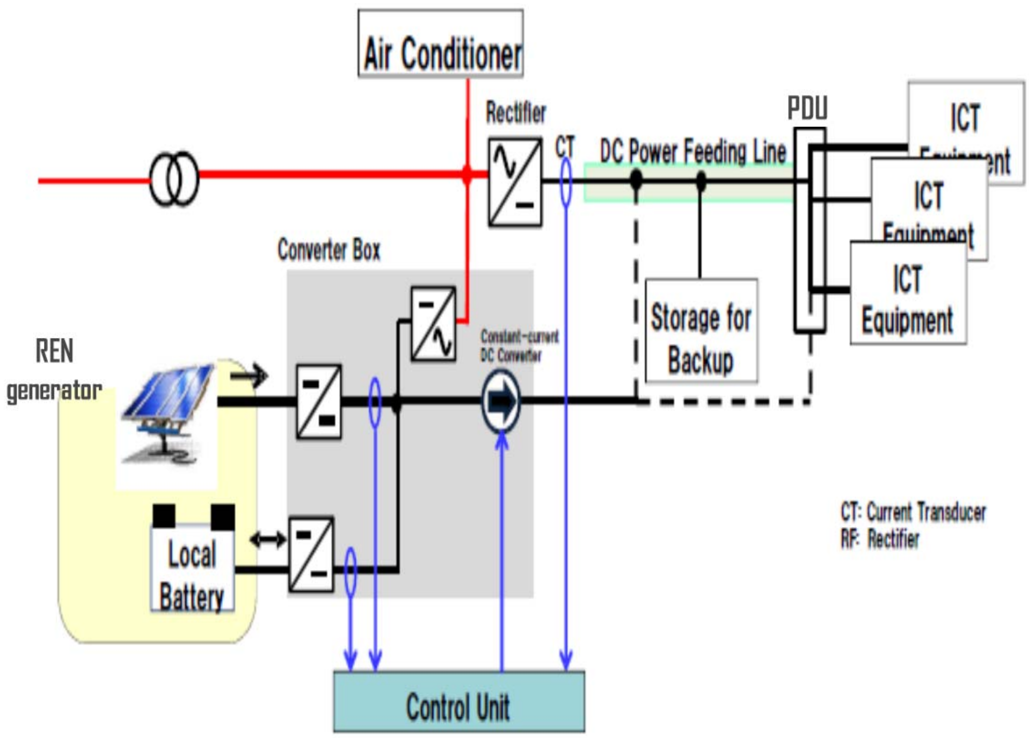

Figure C.1: REN interconnection to the up to 400 VDC power feeding system, Case 1

Case 2:

Figure C.2 shows a similar configuration to the one in figure C.1 except that there is not a DC/DC convertor for charging/discharging the local battery. In this case, the voltage of the local DC bus in the converter box is equal to that of the local battery. This would make the voltage of the local DC bus stable due to the local battery.

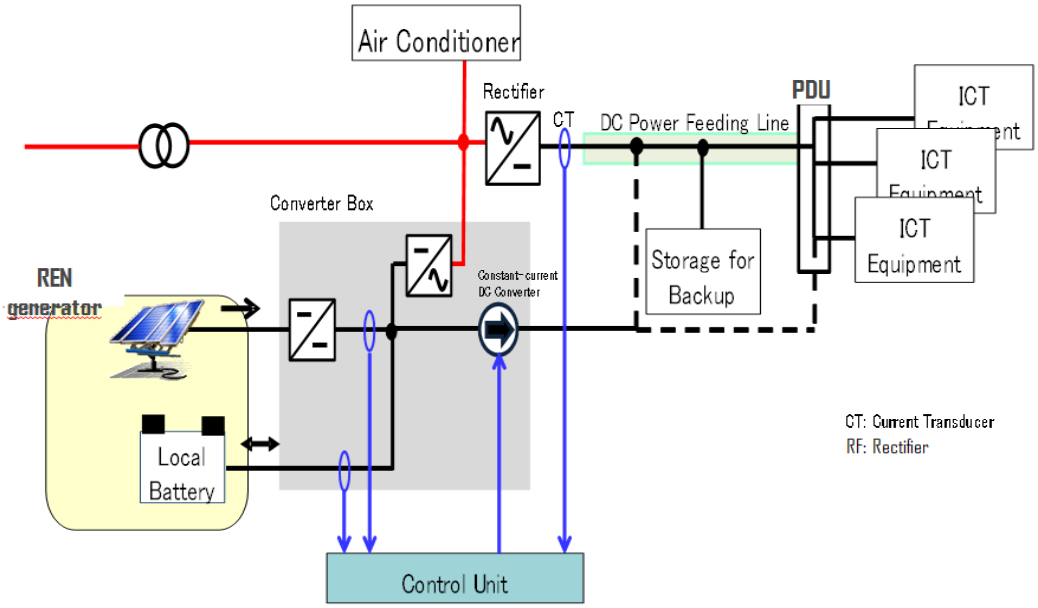

Figure C.2: REN interconnection to the up to 400 VDC power feeding system, Case 2

Annex D (informative): General consideration for sizing and power coupling of REN system to up to 400 VDC systems

D.1 General conditions impacting on the REN sizing and power coupling

The effects and interactions of REN or distributed power on the site power system are linked to the REN system power sizing. The specification of proper power sizing of the REN system connected to the 400 VDC takes into account:

- the power range of the generator;
- the variability of production (e.g. zero power by night on PV);
- the self-consumption condition;
- the availability of excess of production at some periods;
- the authorization of injection in the building AC distribution or in DC micro grid or in public AC grid as it introduces another level of complexity compared to REN coupling on an 400 VDC system;
- the level of possible interactions to the 400 VDC system stability and reliability.

D.2 Monosource system

Power threshold or limit to renewable energy injection e.g. site self-consumption can be defined for mono REN source with or without battery storage.

Table D.1 is giving an example of a rough estimation of energy self-consumption and power energy injection on external grid. Precise calculation should be done considering local data for renewable energy and precise local power consumption profile.

Table D.1: Example of estimation of energy self-consumption and power energy injection on external grid with average French meteo data and a constant power Telecom use

Study case	REN peak power/average used power (Pu)	energy storage (h)	REN yearly energy production: % of Pu*8766	Injected power on grid/Pu	Energy excess injected to grid
1	1	0	5 to 20 %	0	0
2	3	0	20 to 40 %	2	50 to 90 %
3	3	12 to 24	60 to 80 %	2	0
4	10	12 to 24	80 to 100 %	9	2 to 300 %

It appears clearly that case study 1 corresponds to a simple and efficient self-consumption:

- Case 2 is a case of local self-consumption and power injection to grid.
- Case 3 is an improvement of case 2, by adding a reasonable energy storage and leads to a high rate of self-consumption, avoiding a grid connection or losing to much excess of REN production.
- Case 4 is a case where the REN generator covers more the local use but would have to send much more energy on an external grid to be competitive as it is highly oversized related to the local load.

D.3 Multisources management and balance between power sources and backup batteries

During the condition of unbalanced power supply in which much more power than the power consumption of ICT equipment is available from distributed power sources for the power feeding system, there is a high risk to accelerate the degradation of backup batteries that are in floating condition. Therefore, it is necessary to adjust the balance of supplied power among multiple power sources.

When there is no possibility to inject the excess of produced renewable energy from the site into an external electric grid, it can be interesting to use other battery technology than the one optimized for back-up and floating, in order to absorb the maximum renewable power as possible, and give it back when renewable energy is not productive (e.g. by night for PV).

The best choice of battery could be cycling batteries that can stay in partial charge state without degradation. This is one problem of the lead-acid technology, it needs a full recharge regularly to avoid sulphating degradation mode. Lithium and Nickel technologies are not suffering from partial charge ageing. For lithium this is even the contrary, it is ageing faster when fully charged.

History

Document history		
V1.1.0	January 2018	Membership Approval Procedure MV 20180317: 2018-01-16 to 2018-03-19
V1.1.1	March 2018	Publication