ETSI TR 102 532 V1.1.1 (2009-06)

Technical Report

Environmental Engineering (EE);
The use of alternative energy solutions in telecommunications installations

Reference
DTR/EE-00004

Keywords
power supply

ETSI

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Sous-Préfecture de Grasse (06) N° 7803/88

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Environmental Engineering (EE).

Introduction

In last year's thematic, as greenhouse effect and carbon footprint have been more common and well known also to normal citizen; a lot of attention has been also pointed to the telecommunication community impact. The growing public attention to environmental issues leads industry to work on reducing environmental impacts of their business, also in a framework of Corporate Social Responsibility (CSR) and sustainable development.

High prices for oil and electrical energy, which are generally expected to persist, contribute to stimulate interest in new energy sources.

In telecommunication the alternative energy sources, because of the high cost for Wh, are generally used in remote areas where the public mains is unavailable.

The introduction of new components and technologies on the market has recently increased the energy efficiency of alternative sources and in some cases, the Governments economically support the use of this alternative energy sources.

The consequence of those two facts is a better convenience in the use of this type of energy, especially considering the continuous price increase for traditional fossil sources and electrical energy, beyond the attention that is necessary for reducing ecological impacts.

The need for alternative energy may come also to enable telecommunication services (areas with no power grid), to expand coverage and to deploy high data rate services (active equipment in the access network)

It becomes obvious that the use of alternative energy has to be considered with particular effort for only supplying energy efficient ICT equipment.

One important bibliographical reference is the international document produced by ITU-T (CCITT), in 1985 [i.1]

1 Scope

Due to new power and energy context such as greenhouse effect and other environmental issues, fuel depletion and electricity cost increase, new regulation and standards, telecom operators have to make efforts to use alternatives. The present document covers alternative energy sources completed by current and new energy storage that can be used in ICT. Such alternative energy sources are:

- Fuel Cells.
- Photovoltaic Generators.
- Wind Turbine Generators.
- Micro hydro generators.
- Stirling machine.
- Alternative cooling sources, e.g. geo-cooling, fresh air cooling (or free cooling), absorption machines.

The scope of the present document is to propose an overview about practical solutions for power and cooling systems using the alternative energy sources. Interoperability of heterogeneous alternative energy sources is the key issue. The way to ensure hybrid systems reliability and efficiency is also in the scope of the present document.

Bearing in mind the availability and the maintainability of the power plants for TLC, the present document considers:

- the principle of energy converters operating from alternative energy sources;
- the minimum set of information on energy converters;
- the main sizing parameters;
- the architecture of the power systems using the energy converters either only one type or as a combination of two or more such devices;
- existing and new energy storage;
- cooling solutions from alternative sources (geo-cooling).

New (not traditional) solutions for cooling will be proposed and expanded in a separate document.

2 References

References are either specific (identified by date of publication and/or edition number or version number) or non-specific.

- For a specific reference, subsequent revisions do not apply.
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2.1 Normative references

The following referenced documents are indispensable for the application of the present document. For dated references, only the edition cited applies. For non-specific references, the latest edition of the referenced document (including any amendments) applies.

Not applicable.

2.2 Informative references

The following referenced documents are not essential to the use of the present document but they assist the user with regard to a particular subject area**.** For non-specific references, the latest version of the referenced document (including any amendments) applies.

[i.1] ITU-T (CCITT): "Handbook on Primary Sources of Energy for the Power Supply of Remote Telecommunication Systems", 1985.

[i.2] CENELEC EN 62282-2: "Fuel cell technologies. Part 2: Fuel cell modules".

[i.3] CENELEC EN 62282-3-2: "Fuel cell technologies - Part 3-2: Stationary fuel cell power systems - Performance test methods".

[i.4] Council Directive 87/404/EEC of 25 June 1987 on the harmonization of the laws of the Member States relating to simple pressure vessels.

[i.5] Council Directive 90/488/EEC of 17 September 1990 amending Directive 87/404/EEC on the harmonization of the laws of the Member States relating to simple pressure vessels.

[i.6] Council Directive 90/396/EEC of 29 June 1990 on the approximation of the laws of the Member States relating to appliances burning gaseous fuels.

[i.7] Council directive 1999/92/EC of 25 January 1999 on minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres.

[i.8] Council directive 94/9/EC of 23 March 1994 on the approximation of the laws of the Member States concerning equipment and protective systems intended for use in potentially explosive atmospheres.

[i.9] Council directive 97/23/EC of 29 May 1997 on the approximation of the laws of the Member States concerning pressure equipment.

[i.10] CENELEC EN 62124: "Photovoltaic (PV) stand-alone systems. Design verification".

[i.11] CENELEC EN 60904-1: "Photovoltaic Devices Part 1: Measurement of Photovoltaic Current - Voltage Characteristics".

[i.12] CENELEC EN 60904-2: "Photovoltaic devices - part 2: requirements for reference solar devices".

[i.13] CENELEC EN 62093: "Balance-of-system components for photovoltaic systems - Design qualification natural environments".

[i.14] Council directive 2006/66/EC of the European parliament and of the council of 6 September 2006 on batteries and accumulators and waste batteries and accumulators and repealing Directive 91/157/EEC.

[i.15] CENELEC EN 50272-2: "Safety requirements for secondary batteries and battery installations -- Part 2: Stationary batteries".

[i.16] ETSI ETS 300 132-1: "Equipment Engineering (EE); Power supply interface at the input to telecommunications equipment; Part 1: Operated by alternating current (ac) derived from direct current (dc) sources".

[i.17] ETSI EN 300 132-2: "Environmental Engineering (EE); Power supply interface at the input to telecommunications equipment; Part 2: Operated by direct current (dc)".

[i.18] CENELEC EN 61427: "Secondary cells and batteries for solar photovoltaic energy systems".

[i.19] IEC 61400-1: "Wind turbines - Part 1: Design requirements".

3 Definitions, symbols and abbreviations

3.1 Definitions

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

Air Mass (AM): measure of distance that the direct solar beam travels through the earth atmosphere

NOTE: AM = 1,5 in standards corresponds to a sun elevation of approximately 45°.

air pollution: air with contaminants in it that prevent the air from dispersing as it normally would, and interfere with biological processes

alternative energy: energy derived from non-fossil resource and from renewable source

NOTE: A popular term for "non-conventional" or "clean" energy as renewable.

asynchronous generator: type of electric generator that produces alternating current (AC) electricity to match an existing power source

battery: energy storage device made up of one or more cells filled with electrolyte

NOTE: An electrolyte is a non-metallic conductor between positive and negative plates that carries electric charges through ionic displacement.

capacity factor: amount of power a wind turbine produces over a period of time divided by the amount of power it could have produced if it had run at its full rated capacity over that time period

Carbon Dioxide (CO2): colourless, odourless non-combustible gas present in the atmosphere

NOTE: It is formed by the combustion of carbon and carbon compounds (such as fossil fuels and biomass), by respiration, which is a slow combustion in animals and plants, and by the gradual oxidation of organic matter in the soil. It is a greenhouse gas that contributes to global climate change, it remains in the atmosphere during about one century.

Carbon Monoxide (CO): colourless, odourless but poisonous combustible gas

NOTE: Carbon monoxide is produced in the incomplete combustion of carbon and carbon compounds, for example, fossil fuels like coal and petroleum.

central power plant: large power plant that generates power for distribution to one or multiple loads

chemical energy: energy liberated in a chemical reaction, as in the combustion of fuels

constant-speed wind turbines: wind turbines that operate at a constant RPM (Revolutions Per Minute speed). They are designed for optimal energy capture at a specific rotor diameter and at a particular wind speed

conventional fuel: fossil fuels: coal, oil, and natural gas

electric power converter: device for transforming electricity to a desired quality and quantity (voltage or current or power or frequency)

energy converter: equipment transforming alternative energy sources (solar, wind, hydro, etc.) into electrical energy

deregulation: process of changing policies and laws of regulation in order to increase competition among suppliers of commodities and services

downwind wind turbine: horizontal axis wind turbine in which the rotor is downwind of the tower

emission: substance or pollutant emitted as a result of a process

energy storage: process of storing or converting energy from one form to another for later use

NOTE: For example, an electrochemical storage device is a battery, an electromechanical storage device is a flywheel.

environment: all the natural and living things around us: The earth, air, weather, plants, human and animals all make up our environment

fossil fuels: fuels formed in the ground from the decayed remains of dead plants and animals

NOTE: It takes millions of years to form fossil fuels. Oil, natural gas, and coal are fossil fuels.

fuel: any material that can be consumed to be converted into energy

gearbox: protective casing for a system of gears

generator: device for converting any energy resource into electrical energy

geothermal: heat that comes from within the Earth

geothermal heating/cooling: method of heating and cooling a building using underground thermal conditions

geothermal power: electricity generated from naturally occurring geological heat sources

green credit: new way to purchase renewable electric generation that divides the generation into two separate products: the commodity energy and the renewable attributes

NOTE: The green credit represents the renewable attributes of a single megawatt of renewable energy. Also known as green tags, renewable energy credits, or renewable energy certificates.

green power: popular term for energy produced from non-pollutant or renewable energy resources

greenfield: site on which a power plant has not previously existed

grid: common term referring to an electricity transmission and distribution system

gust: sudden brief increase in the speed of the wind

horizontal-axis wind turbines: turbines on which the axis of the rotor's rotation is parallel to the wind stream and the ground

hybrid system: power systems combining two or more energy conversion devices, or two or more fuels for the same device, that when integrated, overcome limitations inherent in either

NOTE: In the present document we define that at least one source is from alternative "renewable" energy source.

inverter: equipment that can convert direct current into alternative current

mean power output (of a wind turbine): average power output of a wind energy conversion system at any given mean wind speed

mean wind speed: average wind speed over a specified time period and height above the ground

mechanical energy: energy possessed by an object due to its motion (kinetic energy) or its potential energy

median wind speed: wind speed with 50 % probability of occurring

nacelle: cover for the gearbox, drive train, and generator of a wind turbine

natural gas: hydrocarbon gas obtained from underground sources, often in association with petroleum and coal deposits

NOTE: It generally contains a high percentage of methane, varying amounts of ethane, and inert gases. Natural gas is used as a heating fuel and for electricity generation.

peak wind speed: maximum instantaneous wind speed that occurs within a specific period of time

photovoltaic: application of solar cells for energy by converting sunlight directly into electricity

power quality: stability of frequency and voltage and lack of electrical noise on the power grid

prevailing wind direction: direction from which the wind predominantly blows as a result of the seasons, high and low pressure zones, the tilt of the earth on its axis, and the rotation of the earth

recycling: process of converting into new products materials that are no longer useful as they were originally designed

renewable energy: energy derived from resources that are regenerative or that cannot be depleted

NOTE: Types of renewable energy resources include wind, solar, biomass, geothermal and moving water.

rotor: blades and other rotating components of a system (e.g. rotor of a wind energy conversion turbine in the alternative energy sources field)

solar energy: electromagnetic energy transmitted from the sun (solar radiation)

solid fuels: any fuel that is in solid form, such as wood, peat, lignite, coal, and manufactured fuels such as pulverized coal, coke, charcoal briquettes, and pellets

step-up gearbox: gearbox that increases turbine electricity production in stages by increasing the number of generator revolutions produced by the rotor revolutions

sustainable energy: energy that takes into account present needs while not compromising the availability of energy or a healthy environment in the future

trade wind: consistent system of prevailing winds occupying most of the tropics

NOTE: They constitute the major component of the general circulation of the atmosphere. Trade winds blow northeasterly in the Northern Hemisphere and southeasterly in the Southern Hemisphere. The trades, as they are sometimes called, are the most persistent wind system on earth.

turbine: term used for a wind energy conversion device that produces electricity

NOTE: see also "Wind Turbine".

turbulence: swirling motion of the atmosphere that interrupts the flow of wind

variable-speed wind turbines: turbines in which the rotor speed increases and decreases with changing wind speeds

NOTE: Sophisticated power control systems are required on variable speed turbines to insure that their power maintains a constant frequency compatible with the grid.

vertical axis wind turbines: turbines on which the axis of the rotor's rotation is perpendicular to the ground

Watt-peak (Wp): unit used to express the maximum power produced (or provided) by a photovoltaic module for solar radiation of 1 000 W/m^2 for a standard spectrum and temperature

wind energy: power generated by converting the mechanical energy of the wind into electrical energy through the use of a wind generator

wind farm: piece of land on which wind turbines are sited for the purpose of electricity generation

wind (turbine) generator: system that converts kinetic energy in the wind into electrical energy

NOTE: See IEC 61400-1 [i.19].

wind power plant: group of wind turbines interconnected to a common utility system

wind resource assessment: process of characterizing the wind resource and its energy potential for a specific site or geographical area

wind speed: rate of flow of wind when it blows undisturbed by obstacles

NOTE: Expressed in m/s.

wind speed frequency curve: curve that indicates the number of hours per year that specific wind speeds occur

wind speed profile: profile of wind speed changes at different heights above the surface of the ground or water

wind turbine: wind energy conversion device that produces electricity

wind turbine rated capacity: power that a wind turbine can produce at its rated wind speed

wind velocity: wind speed and direction in an undisturbed flow

3.2 Symbols

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

Wh	watt-hours
Wp	watt peak

3.3 Abbreviations

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

AC	Alternating Current
AFC	Alkaline Fuel Cell
AM	Air Mass
BB	BroadBand
BMS	Battery Management System
CPV	Concentrating PhotoVoltaic
DC	Direct Current
DMFC	Direct Methanol Fuel Cell
EV	Electrical Vehicle
FC	Fuel Cell
GaAs	Gallium Arsenide
HYP	HYdro-Power
LA	Lead Acid
LVBD	Low Voltage Battery Disconnector
MCFC	Molten Carbonate Fuel Cell
MPPT	Maximum Power Point Tracker
MTBF	Mean Time Between Failure
MTTR	Mean Time To Repair
PAFC	Phosphoric Acid Fuel Cell
PCM	Phase Change Material
PEM	Proton Exchange Membrane
PEMFC	Proton Exchange Membrane Fuel Cell
PTFE	PolyTetraFluoroEthylene
PV	Photovoltaic
PVG	Photovoltaic Generator
RPM	Round Per Minute
SC	Super Capacitor
SMES	Super Magnetic Energy Systems
SoC	State of Charge
SOFC	Solid Oxide Fuel Cell
TLC	Telecommunication
VRLA	Valve Regulated Lead Acid
WTG	Wind Turbine Generator

4 Generator technologies

This part of the present document describes the alternative energy generation technologies that can be considered as a power source for telecommunication applications.

4.1 Fuel cells

A fuel cell is an electrochemical reactor used to convert the chemical energy (reduction and oxidation) contained in an external fuel into electrical energy (Direct Current output power) characterized by a continuous supply of reactants and flowing out of reaction products. The fuel cell can operate without interruptions as long as the necessary flows are maintained.

The fuel cell reactor is composed of sets of positive and negative electrodes, an electrolyte between them (e.g. salt diluted in water or polymer) and a separator (e.g. PEM) to avoid leakage or cross-over of fuel (e.g. H^2 or methanol) directly towards the oxidizing agent (e.g. air) without producing useful electrons in external circuit.

Elementary fuel cell voltage are very low (0,1 V to 1 V in open circuit) and several cells are mounted in serial arrangement (stack) to obtain practical voltage for powering telecom equipment. The current is dependant of the plate surface.

There are various types of fuel cells available as showed in the following table.

Table 1: Types of Fuel Cells

FC type	PEMFC	AFC	DMFC	PAFC	MCFC	SOFC
Name	Proton Exchange Membrane Fuel Cell	Alkaline Fuel Cell	Direct Methanol Fuel Cell	Phosphoric Acid Fuel Cell	Molten Carbonate Fuel Cell	Solid Oxide Fuel Cell
Electrolyte	Polymer membrane protons conductive	KOH solution	Polymer membrane protons conductive	Phosphoric acid	Molten Li_2CO_3 and K_2CO_3 in LiAlO2 matrix	ZrO_2 and Y_2O_3
Ions in electrolyte	H^+	OH^-	H^+	H^+	CO_3^{2-}	O^{2-}
Temperature In operation	40 ℃ to 80 ℃	60 ℃ to 80 ℃	60 ℃ to 100 ℃	180 ℃ to 220 ℃	600 ℃ to 660 ℃	700 ℃ to 1 000 ℃
Fuel	H_2 (pure or from reformer)	H_2	Methanol	H_2 (pure or from reformer)	bio-gas and natural gas	bio-gas and natural gas)
Oxidant	Air	O_2 (pure)	Air	Air	Air	Air
System efficiency	30 % to 50 %	60 %	20 % to 30 %	40 %	45 %	55 % to 60 %
Applications	Transport, Portable equipment, Cogeneration, Back-up	Spatial	Portable equipment	Cogeneration	Cogeneration, Centralized electricity production	Cogeneration, Centralized electricity production Transport
Developing progress	Small series	Used	Small series	Mature technology	Small series	Small series

The most used in TLC applications are the PEM fuel cells based on a polymer electrolyte in the form of a thin, permeable sheet. Efficiency of the commercial systems is greater than 35 %, and operating temperature is about 40 °C to 80 °C. Cells stack outputs generally range from 50 watt to 250 kW. The higher the operating temperature the less degraded on the hydrogen has to be. PEM fuel cells can provide the solid-state backup power solutions.

The electrical characteristics of fuel cells and their performance tests are described in EN 62282-2 [i.2] and EN 62282-3-2 [i.3].

4.1.1 Sources of Hydrogen

PEM fuel cells use hydrogen as a fuel. Hydrogen for fuel cells can be produced in large central locations and delivered in gaseous, liquid or solid (metal hydride) state in tanks, by pipeline, or can be produced at the fuel cell site using an onsite reformer.

Hydrogen high pressure cylinders tanks are typically used in situations where the fuel cell needs to run for a short period of time (approximately 8 hours).

4.1.2 On site H_2 production

Reforming

There are many types of reforming, each with its own strengths and weaknesses. Steam reforming is often selected for projects because of its ability to provide high efficiency use of valuable fuel inputs. Fuel processors have been developed for a variety of common fuels including methanol (a liquid used as windshield washer and many other common products but highly toxic). Extended run fuel cell systems allow supporting back-up requirements of days versus hours by using compact and convenient liquid fuels.

Electrolyser

In some cases it is possible to produce hydrogen directly on site using a photovoltaic system to electrolyze water (reduction of costs may be achieved in combination with wind and/or grid).

In that case, hydrogen has to be stored in hydrogen storage (see clause 4.1.3) for next use. The H^2 is still converting in electricity through a fuel cell or a motor+alternator.

This is a solution for interseasonal storage. Even with an efficiency of only 25 % of the H^2 electrolyser + storage + generator. It can be demonstrated an important gain when producing H^2 with the wasted excess of energy of PV when battery are charged. The major problem is cost and reliability of this very complex solution.

4.1.3 Hydrogen storage

Hydrogen can be stored in many ways: gas, liquid, in solid hydride.

High pressure storage

Commonly H^2 is compressed in steel or composite tanks and held at pressures up to 70 MPa.

Most backup power fuel cell systems will use compressed hydrogen as a fuel source located near the fuel cell system. The most typical hydrogen cylinder is often referred to as a "T-cylinder B50", it is approximately 152 cm high and 25 cm wide and holds about 8,5 cubic meters of gas. Multiple tanks are connected together as needed. Each tank weighs approximately 70 kg. An array of four to six tanks contains enough hydrogen to operate a typical 5 kW fuel cell for nine hours at full load. Cylinders are typically pressurized to approximately 200 bar, but the pressure is regulated down to low pressure at the hydrogen tank enclosure to ensure maximum safety and code compliance.

Each T-cylinder stores enough hydrogen to deliver approximately 10 kWh of regulated AC or DC electricity from a fuel cell system. Hydrogen is typically stored outdoors, but can also be located indoors in certain building types if the right safety and ventilation procedures are followed. Suppliers can offer outdoor enclosures or can also recommend approved hydrogen storage options for specific applications.

Liquid storage

H^2 is liquefied at -252 °C. Liquefying is energy intensive, but liquid hydrogen has three times the amount of energy as an equal weight of gasoline.

Hydride solid storage

Hydrogen can also be stored in metal hydrides - granular metal that absorbs hydrogen. These tanks are comparatively heavy.

Similar, but lighter, are carbon nanotubes, and other carbon absorption techniques still in the experimental stage. Hydrogen can also be stored in chemical hydrides by way of chemical bonds. Chemical hydrides typically allow hydrogen to be stored in conventional tanks that only release hydrogen when a certain catalyst is present, making them very safe for transportation.