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Application of PV/Wind-Based Green Energy to Power Cellular Base Station

Okotie Lucky Edafe; & Obaweki Oziegbe Nicholas
Electrucal/Electronic Engineering Technology Department, National Institute of Construction Technology and Management (NICTM), Uromi, Edo State.

Abstract
Conventional energy sources based on oil, coal, and natural gas have posed a threat to the environment and to human health. Green energy stands as an alternative because of its' environmental-friendly nature. This paper presents a reliable and sustainable alternative means of energy supply based on renewables to meet demand for the power requirement of an operational cellular base station particularly for stations sited in remote environment. Renewable energy sources such as solar panel arrays and wind turbine generators are considered in this work and are designed and developed based on the use of routinely available, indigenous resources/materials resulting in sustainable newer/green energy architecture. Newer/green energy sources (solar energy, wind energy, and modern bioenergy) are currently contributing immensely to global energy demand. This work proposes the application of green energy architecture based on PV/wind sources to address electric energy challenge in the telecommunication sector such as inadequate power to meet demand, fluctuations in power supply, frequent power outages and sudden system collapse leading to enormous amount of economic loss and wastages. The implementation of this energy architecture and with the right policies in place could yield substantial economic savings as the cost for fuel to drive the conventional diesel generator in the telecommunication sector shall be reduced drastically and the environment freed of greenhouse gases which would otherwise deplete the ozone layer causing great discomfort to human existence on earth. This paper therefore suggests and recommend the application of green energy based on PV/Wind energy generator as a non-conventional energy source to power cellular base stations as it is believed that, if this energy architecture is adopted and harnessed it is going to be a major energy source and driver in the telecommunication sector.

Keywords: Base Station, Green Energy, Solar Energy, Wind Energy, Communication Industry, Rotor Efficiency, Energy Storage

Introduction

Energy is a fundamental factor in the communication industry. In Africa and the word at large, the energy sector assumes a critical importance, in view of the ever-increasing energy needs requiring huge investments to meet up with. Statistics have shown that the telecommunication sector consumes about 45% of the entire world energy [John and Tony, 2015]. The usage of non-green energy resources in industry gives room to environmental degradation by contaminating the atmosphere. Practical instances of environmental/air contamination are carbon monoxide, nitrous oxide and Sulphur oxide emissions from boilers and heating systems, Chlorofluro carbons emanating from refrigerants. In chemical industries such as plastic and fertilizer, toxic gases are emitted to the atmosphere. A variety of air pollutants have proved to have harmful effects on human health and the climate. These air pollutants are basically the products of combustion from fossil fuel use. Air pollutants from these sources do not only pollute their immediate environment but also cause problems at far distances. Air pollutants can travel long distances, chemically react in the atmosphere to produce secondary pollutants such as acid rain, black soothes or ozone depletion [Rahman et al 2014]. As a result of the depletion of the ozone layer, this has led to adverse climatic changes, and environmental degradation. Focus in the future generations wireless network has shifted towards enhancing energy efficiency of the networks. Energy can be classified into several types based on the following criteria viz: primary and secondary energy, renewable and non-renewable energy, commercial and non-commercial energy, conventional and non-conventional energy. Primary energy sources are those that are either found or stored in nature. Most commonly used primary energy sources include oil, coal, biomass (wood), natural gas, nuclear energy (from radioactive element), thermal energy accumulated in earth's core, and potential energy owing to earth's gravity. While commercial energy is the energy sources that are accessible in the marketplace for a definite value. Examples are natural gas, coal, crude oil, lignite etc [Mohammed 2021]. Renewable Energy is any form of energy source(s) that is replenished by natural processes at a rate that equals or exceeds its rate of use the sources could be geophysical or biological. It could also be obtained from the continuing or repetitive flows of energy occurring in the natural setting and include resources such as solar energy, hydropower, biomass, tide and waves, ocean thermal energy and wind energy. However, it is possible to utilize biomass at a greater rate than it can grow or to draw heat from a geothermal field at a faster rate than heat flows can replenish. On the other hand, the rate of utilization of direct solar energy has no bearing on the rate at which it reaches the Earth. Renewable energy sources are often considered alternative sources because, in general, most industrialized countries do not rely on them as their main energy source. Instead, they tend to rely on non-renewable sources such as fossil fuels or nuclear power. Because of the energy crisis in the North America within the 1970s, the issue of dwindling supplies of fossil fuels and hazards associated with nuclear power, usage of renewable energy sources such as solar energy, hydroelectric, wind, biomass, and geothermal has risen [Salame, 2022]. Renewable energy comes

from the sun (considered an "unlimited" supply) or other sources that can theoretically be renewed at least as quickly as they are consumed. If used at a sustainable rate, these sources will be available for consumption for thousands of years or longer. Unfortunately, some potentially renewable energy sources, such as biomass and geothermal, are actually being depleted in some areas because the usage rate exceeds the renewal rate. Green energy is any energy type that is generated from natural resources, such as sunlight, wind or water. It often comes from renewable energy sources although there are some differences between renewable and green energy, which we will explore. In order to be deemed green energy, a resource cannot produce pollution, such as is found with fossil fuels. This means that not all sources used by the renewable energy industry are green. Green energy has the capacity to replace fossil fuels in the future; however, it may require diversified production from different means to achieve this. Geothermal, for example, is particularly effective in places where this resource is easy to tap into, while wind energy will be better in deserts areas also solar power may be better suited to other geographic locations that have high and long hours of sunshine [US department of Energy 2019].

However, by bringing together multiple green energy sources to meet our needs, and with the advancements that are being made with regards to production and development of these resources, there is every reason to believe that fossil fuels could be obsolete after sometime. This idea may take some time to be actualized, but the fact remains that it is necessary to reduce climate change, improve the environment and move to a more sustainable and environmentally friendly technology in the future [Murthy and Kavitha, 2012].

TYPES OF GREEN ENERGY SOURCES

This work will consider two major types of green energy sources viz: wind and sun (solar) energy.

- **Wind Energy**

  Particularly suitable for offshore and higher altitude sites, wind energy uses the power of the flow of air around the world to push turbines that then generate electricity.

- Materials and method for wind turbine

  The wind power system comprises one or more wind turbine units operating electrically in parallel. Each turbine is made of the following basic components: (i) Tower structure (ii) Rotor with two or three blades attached to the hub (iii) Shaft with mechanical gear (iv)Electrical generator (v) Yaw mechanism, such as the tail vane (vi) Sensors and control



figure 1: Wind energy farm

The wind turbine receives the wind's kinetic energy in a rotor consisting of two to four blades mechanically coupled to an electrical generator. The turbine is mounted on a tall tower to enhance the energy capture. Many wind turbines are installed at one site to build a wind farm of the desired power generation capacity. Obviously, sites with steady high wind produce more energy over the year. Two different configurations are available for turbine design, the horizontal-axis configuration and the vertical-axis configuration. The horizontal-axis machine has been the standard in some European countries majorly in Denmark from the beginning of the wind power industry. Therefore, it is often called the Danish wind turbine. The vertical-axis machine has the shape of an egg beater and is popularly called the Darrieus rotor, named after its inventor. It has been used in the past because of its specific structural advantage. However, most modern wind turbines use a horizontal axis design. Except for the rotor, most other components are the same in both designs, with some differences in their placements [Renewable Energy Sources 2012].

- Wind velocity and power relations

The kinetic energy in air of mass m moving with speed V is given by the following in joules:

$$E = \frac{1}{2}mV^2 \quad (1)$$

The power in moving air is the flow rate of kinetic energy per second in watts:

$$Power = \frac{1}{2}(mass\ flow\ per\ second)v^2 \quad (2)$$

If Y= mechanical power in the moving air (watts), ρ = air density (kg/m3),
A= area swept by the rotor blades (m2), and V= velocity of the air (m/sec), then the volumetric flow rate is AV, the mass flow rate of the air in kilograms per second is ρAV, and the mechanical power coming in the upstream wind is given by the following in watts.

$$Y = \frac{1}{2}(\rho AV)V^2 = \frac{1}{2}\rho AV^3 \quad (3)$$

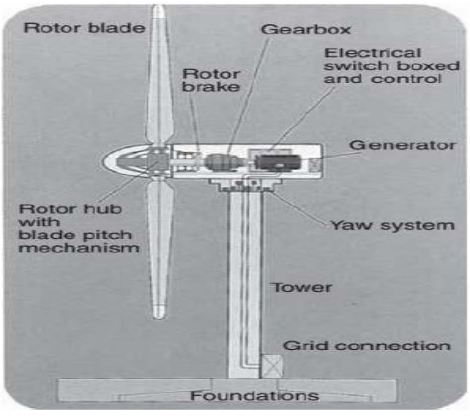
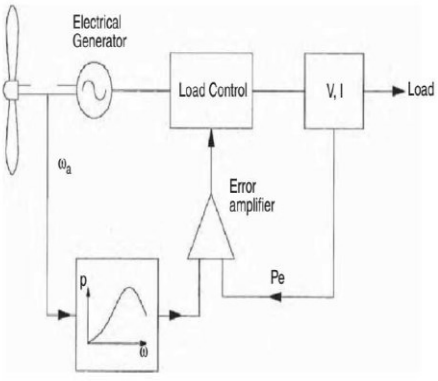


figure 2 (a): Horizontal-axis wind turbine



(b): Electrical Connection of a wind turbine

The potential of the wind sites in terms of the specific wind power is expressed in watts per square meter of area swept by the rotating blades. It is also referred to as the power density of the site, and is given by the following expression in watts per square meter of the rotor-swept area:

$$Ys = \frac{1}{2}\rho v^2 \qquad (4)$$

Where Ys = the specified power of the site
This is the power in the upstream wind. It varies linearly with the density of the air sweeping the blades and with the cube of the wind speed. The blades cannot extract all of the upstream wind power, as some power is left in the downstream air that continues to move with reduced speed [Lorinez and Bule, 2014].

- Power extracted from the wind

The actual power extracted by the rotor blades is the difference between the upstream and downstream wind powers. Using Equation 2, this is given by the following equation in units of watts:

$$Yr = \frac{1}{2}(mass\ flow\ per\ second)\{V^2 - V_o^2\} \qquad (5)$$

Where;
Yr= mechanical power extracted by the rotor, i.e., the turbine output power,
V= upstream wind velocity at the entrance of the rotor blades, and
Vo= downstream wind velocity at the exit of the rotor blades.
Macroscopically, the air velocity is discontinuous when moving from V to Vo at the "plane" of the rotor blades, with an "average" of (V + Vo). Multiplying the air density by the average velocity, therefore, gives the mass flow rate of air through the rotating blades, which is as follows:

$$M_v = \rho A \frac{V + V_o}{2} \qquad (6)$$

The mechanical power extracted by the rotor, which drives the electrical generator, is therefore:

$$P_o = \frac{1}{2}\left[\rho A \frac{(V+V_o)}{2}\right](V^2 - V_o^2) \qquad (7)$$

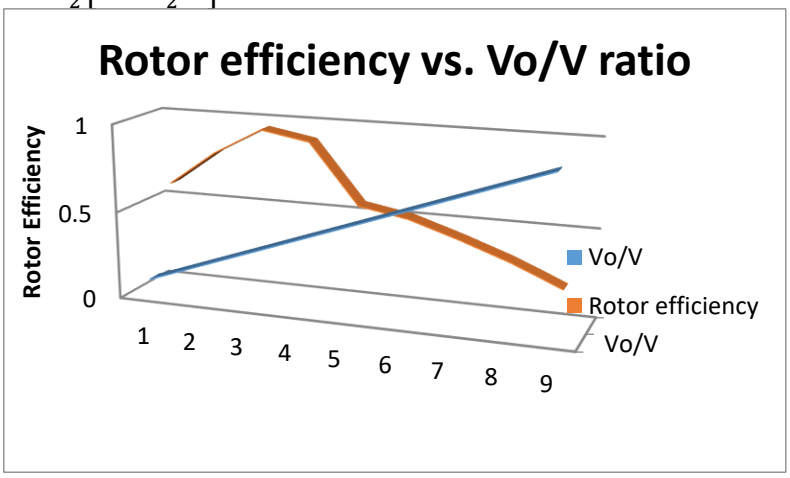


figure 3: Rotor efficiency vs. Vo/V ratio has a single maximum.

The preceding expression is algebraically rearranged in the following form:

$$p_o = \frac{1}{2}\rho A V^3 \frac{\left(1+\frac{V_o}{V}\right)\left[1-\left(\frac{V_o}{V}\right)^2\right]}{2} \quad (8)$$

The power extracted by the blades is customarily expressed as a fraction of the upstream wind power in watts as follows:

$$P_o = \frac{1}{2}\rho A V^3 C_p \quad (9)$$

Where;

$$C_p = \frac{\left(1+\frac{V_o}{V}\right)\left[1-\left(\frac{V_o}{V}\right)^2\right]}{2} \quad (10)$$

Where Cp = power coefficient of the rotor or the rotor efficiency.

Comparing Equation 3 and Equation 9, we can say that Cp is the fraction of the upstream wind power that is extracted by the rotor blades and fed to the electrical generator. The remaining power is dissipated in the downstream wind.

- Wind speed distribution

Having a cubic relation with power, wind speed is the most critical data needed to appraise the power potential of a given location. The wind is never steady at any location. It is influenced by the weather system, the local land terrain, and its altitude above the ground surface. Wind speed varies by the minute, hour, day, season, and even by the year. Therefore, the annual mean speed needs to be averaged over 10 years or more. Such a long-term average gives a greater confidence in assessing the energy-capture potential of a place. However, long-term measurements are expensive and most projects cannot wait that long. In such situations, the short-term data, for example, for one-year period, is compared with long-term data from a nearby site to predict the long-term annual wind speed at the site under consideration. This is known as the measure, correlate, and predict (mcp) technique. Because wind is driven by the sun and the seasons, the wind pattern generally repeats within an annum. The wind site is usually described by the speed data averaged over calendar months. Sometimes, the monthly data is aggregated over the year for brevity in reporting the overall "windiness" of various proposed locations. Wind speed variations over the period can be described by a probability distribution function. The wind shear at a ground-level surface causes the wind speed to increase with height in accordance with the following expression:

$$V_2 = V_1\left(\frac{h_2}{h_1}\right)^{\alpha} \quad (11)$$

Where V1 = wind speed measured at the reference height h1,

V2= wind speed estimated at height h2, and α= ground surface friction coefficient.

SOLAR ENERGY

Solar energy is the ultimate energy source driving the earth. Though only one billionth of the energy that leaves the sun actually reaches the earth's surface, this is more than enough to meet the world's energy requirements. The sun radiates about 3.8 x 1026 W of power in all the directions. Out of this about 1.7 x 1017 W is received by earth. The average solar radiation outside the earth's atmosphere is 1.35 kW/m2 varying from 1.43 kW/m2 (in January) to 1.33 kW/m2 (in July) [Renewable energy sources, 2012]. Solar thermal energy (STE) is a form of energy and a technology for harnessing solar energy to generate thermal energy or electrical energy for use in industry, and in the residential and commercial sectors. The first installation of solar thermal energy equipment occurred in the Sahara Desert approximately in 1910 when a steam engine was run on steam produced by sunlight. Because liquid fuel engines were developed and found more convenient, the Sahara project was abandoned, only to be revisited several decades late. The Solar energy is most important kind of non-conventional source of energy which has been used even during primitive days. It is received on Earth in cyclic, intermittent and dilute form with very low power density 0 to 1 kW/m2 [Rahman et al, 2013]. Solar energy received on the ground level is affected by atmospheric clarity and degree of latitude. For design purpose, the variation of available solar power, the optimum tilt angle of solar flat plate collectors, the location and orientation of the heliostats should be properly designed. The process of directly converting solar energy to heat or electricity is considered a renewable as well as a green energy source. Solar energy represents an essentially unlimited supply of energy as the sun will long outlast human civilization on earth. The difficulty is about how to harness the energy. Solar energy has been used for a very long time to heat homes and water, and modern technology (photovoltaic cells) has provided a way to produce electricity from sunlight. There are two basic forms of radiant solar energy use: passive and active.

Passive solar energy systems: Passive solar energy systems are static, and do not require the input of energy in the form of moving parts or pumping fluids to utilize the sun's energy. Buildings can be designed to capture and collect the sun's energy directly. Materials are selected for their special characteristics: glass allows the sun to enter the building to provide light and heat; water and stone materials have high heat capacities. They can absorb large amounts of solar energy during the day, which can then be used during the night. A southern exposure greenhouse with glass windows and a concrete floor is an example of a passive solar heating system [IRENA, 2012].

Active solar energy systems: Active solar energy systems require the input of some energy to drive mechanical devices (e.g., solar panels), which collect the energy and pump fluids used to store and distribute the energy. Solar panels are generally mounted on a south or west-facing roof. A solar panel usually consists of a glass-faced, sealed, insulated box with a black mat interior finish. Inside are coils full of a heat collecting liquid medium (usually water and augmented by antifreeze). The sun heats the water in the coils, which is pumped to coils in a heat transfer tank containing water. The water in the tank is heated and then either stored or pumped through the

building to heat rooms or supply hot water to taps in the building. Photovoltaic cells generate electricity from sunlight. Hundreds of cells are linked together to provide the required flow of current. The electricity can be used directly or stored in storage batteries. Because photovoltaic cells have no moving parts, they are clean, quiet, and durable. Early photovoltaic cells were extremely expensive, making the cost of solar electric panels prohibitive. The recent development of inexpensive semiconductor materials has helped greatly lower the cost to the point where solar electric panels can compete much better cost wise with traditionally-produced electricity.

- Units of solar power and solar energy:
  In SI units, energy is expressed in Joule. Other units are langley and Calorie where 1 langley = 1 Cal/cm2/day. 1 Cal = 4.186 J
  For solar energy calculations, the energy is measured as an hourly or monthly or yearly average and is expressed in terms of kJ/m2/day or kJ/m2/hour. Solar power is expressed in terms of W/m2 or kW/m2 [U.S department of Energy, 2019].
- Vital subsystems in a solar energy plant:
  Though solar energy itself is free, large costs can be associated with the equipment. Some of the key subsystem includes:
  - Solar collector or concentrator: It receives solar rays and collects the energy. It may be of following types:

  a) Flat plate type without focusing
  b) Parabolic trough type with line focusing c) Parabolic dish with central focusing
  d) Fresnel lens with centre focusing e) Heliostats with centre receiver focusing

  - Energy transport medium: Substances such as water/ steam, liquid metal or gas are used to transport the thermal energy from the collector to the heat exchanger or thermal storage. In solar PV systems energy transport occurs in electrical form.
  - Energy storage: Solar energy is not available continuously. So, we need an energy storage medium for maintaining power supply during nights or cloudy periods. There are three major types of energy storage:

  a) Thermal energy storage; b) Battery storage; c) Pumped storage hydro-electric plant.
  - Energy conversion plant: Thermal energy collected by solar collectors is used for producing steam, hot water, etc. Solar energy converted to thermal energy is fed to steam thermal or gas-thermal power plant.
  - Power conditioning, control and protection system: Load requirements of electrical energy vary with time. The energy supply has certain specifications like voltage, current, frequency, power etc. The power conditioning unit performs several functions such as control, regulation, conditioning, protection, automation, etc.

PHOTOVOLTAIC SYSTEMS

A photovoltaic system is made up of the PV module, as well as the balance of system (BOS) components, which include an inverter, storage devices, charge controller, system structure, and the energy network. The system must be reliable, cost effective, attractive and match with the electric grid in the future. At the component level, BOS components for grid-connected

applications are not yet sufficiently developed to match the lifetime of PV modules. Additionally, BOS component and installation costs need to be reduced. Moreover, devices for storing large amounts of electricity (over 1 MWh or 3,600 MJ) will be adapted to large PV systems in the new energy network [Lorinez and Bule, 2014]. As new module technologies emerge in the future, some of the ideas relating to BOS may need to be revised. Furthermore, the quality of the system needs to be assured and adequately maintained according to defined standards, guidelines and procedures. To ensure system quality, assessing performance is important, including on-line analysis (e.g., early fault detection) and off-line analysis of PV systems. The knowledge gathered can help to validate software for predicting the energy yield of future module and system technology designs.

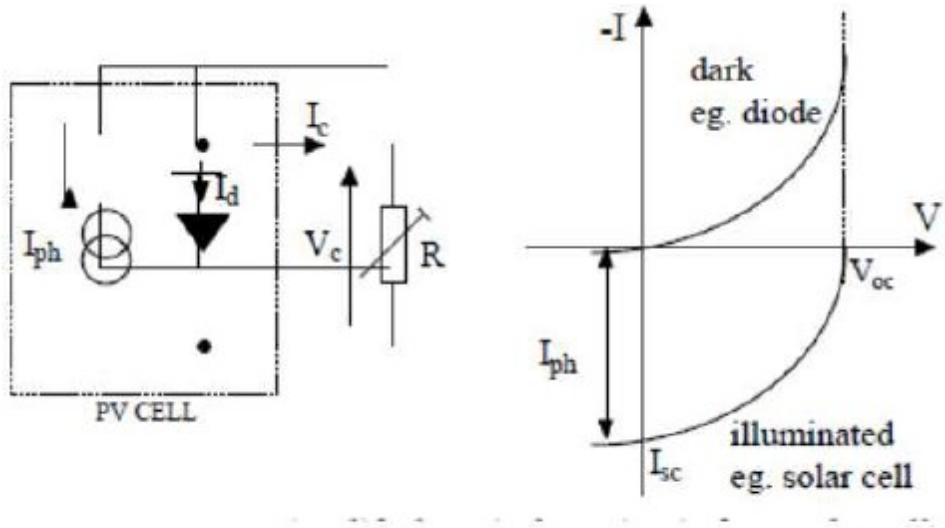


Figure 4: Equivalent circuits of solar cell

A number of semiconductor materials are suitable for the manufacture of solar cells. The most common types using silicon semiconductor material (Si) are: (a) Monocrystalline Si cells (b) Polycrystalline Si cells (c)Amorphous Si cells

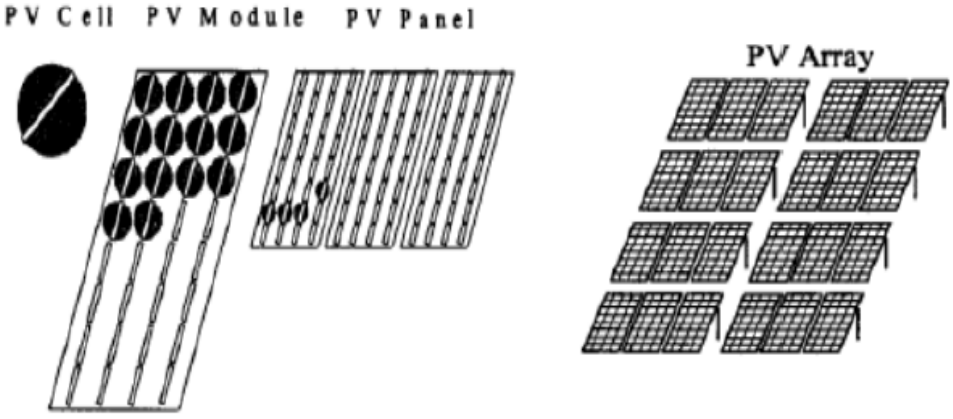


Figure 5: PV cell mode and PV array

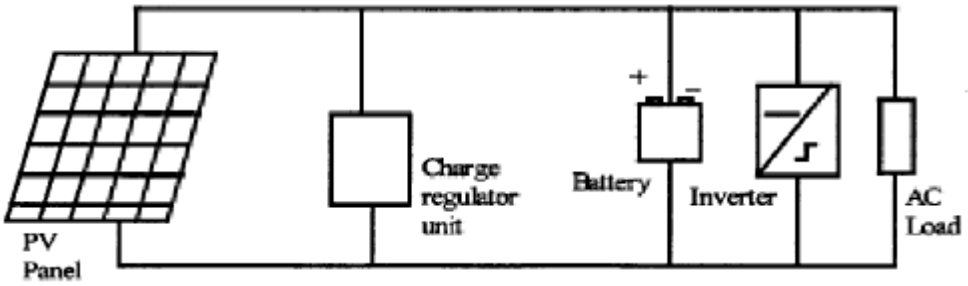


Figure 6: Stand Alone solar system [William, 2011].

Solar thermal collectors are classified as low-temperature collector, medium- temperature collector, or high-temperature collector. Low-temperature collectors are flat plates generally used to heat swimming pools. Medium-temperature collectors are also usually flat plates but are used for heating water or air for residential and commercial use. High-temperature collectors concentrate sunlight using mirrors or lenses and are generally used for fulfilling heat requirements up to 300 deg C/20 bar pressure in industries, and for electric power production. However, there is a term that is used for both the applications. Concentrated Solar Thermal (CST) for fulfilling heat requirements in industries and Concentrated Solar Power (CSP) when the heat collected is used for power generation. CST and CSP are not replaceable in terms of application. Storage system stores heat for a few hours. The heat is released during cloudy hours and at night. Thermal-electric conversion system receives thermal energy and drives steam turbine generator or gas turbine generator. The electrical energy is supplied to the electrical load or to the AC grid.

Application of the green energy to wireless base station

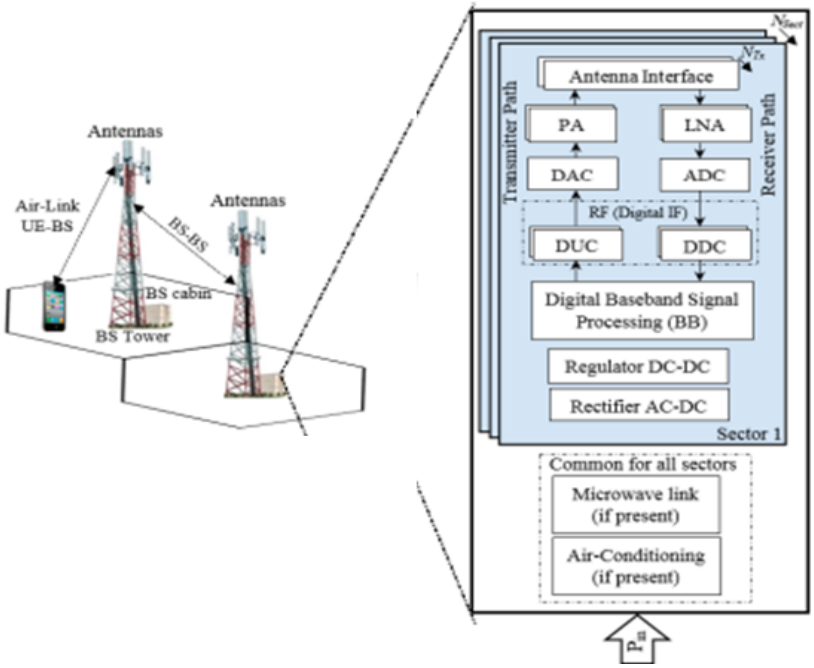


Figure 7: A cellular base station

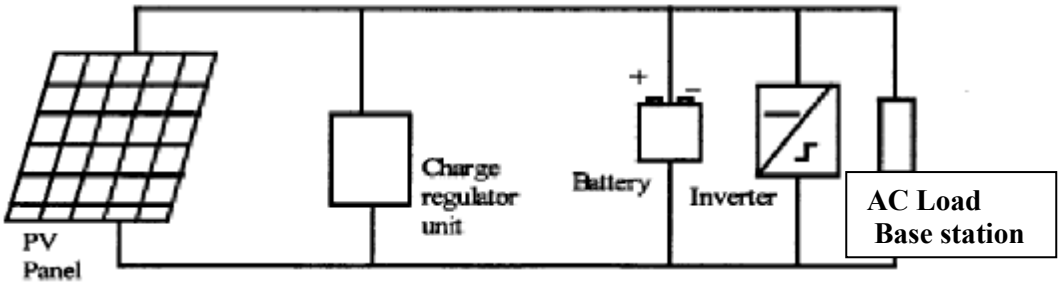


Figure 8: A cellular base station powered by a standalone solar system

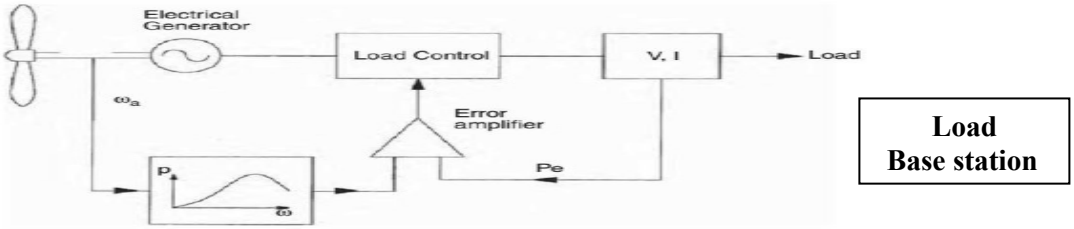


Figure 9: A cellular base station powered by a wind energy system

CONCLUSION

Applications of solar thermal energy systems range from simple solar cooker of 1 kW rating to complex solar central receiver thermal power plant of 200 MW rating. To increasingly penetrate the energy network, PV systems must use technology that is compatible with the electric grid and energy supply and demand. System designs and operation technologies must also be developed in response to demand patterns by developing technology to forecast the power generation volume and to optimize the storage function. Moreover, inverters must improve the quality of grid electricity by controlling reactive power or filtering harmonics with communication in a new energy network that uses a mixture of inexpensive and effective communications systems and technologies, as well as smart meters.

Photovoltaic applications include PV power systems classified into two major types: those not connected to the traditional power grid (i.e., off-grid applications) and those that are connected (i.e., grid-connected applications). Off-grid PV systems have a significant opportunity for economic application in the un-electrified areas of developing countries. In a PV mini-grid system, energy allocation is possible and for a cellular base station located in an isolated area, the power may flow in the mini-grid without considerable losses.

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