ICT Applications in Green and Renewable Energy Sector

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Abstract

In this paper a review of the possible applications of Information and Communications Technologies (ICT) to the renewable energy sector is presented. Renewable energies are provided by natural resources (sunlight, wind, water, and geothermal heat) through the use of engineering technologies able to collect the energy and to convert it in a more usable form. ICT can play a significant role in this context, especially if it is considered as a whole thus reusing much of the theories developed in other sectors.

1. Introduction

Climate change is one of the biggest environmental challenges of the 21th century and has been the subject of increasing political attention worldwide. Various scientific sources link the climate change to the increasing Green House Gases (GHGs) emissions, and more specifically CO_2 ones. Rising CO_2 emissions are pushing up to earth's carbon stack and increasing global temperatures.

Achieving 20% savings of energy consumption by 2020 through energy efficiency is underlined as one of key ways in which CO_2 emission savings can be realized [1]. The ICTs could have a significant role in reducing the emissions and increasing the energy efficiency of the global economy. Technologies, simulation, modeling, analysis, monitoring and visualization tools offered by ICTs could allow to optimise the use of existing physical resources taking into account the many factors that influence the energy demand. Currently, the potential impacts of ICT-based applications have been identified in:

- *Buildings.* The Heating Ventilation Air Conditioning (HVAC) systems are analysed considering the potential energy efficiency gains enabled by ICT control and monitoring capabilities (e.g. temperature monitoring and heating control, switchable vacuum insulated panels, switchable mirror film on windows, integrated cooling of ICT equipment, integrated control of clean room conditions).
- *Lighting systems.* The increased energy efficiency of lighting systems through ICT based lighting technologies (e.g. LED) and control systems is analysed (e.g. occupancy and daylight sensors).
- *Industrial equipment and automation.* Energy efficient technologies based on ICT are applied to electrical drivers (motors, pumps, and fans).
- *Energy grid.* Smart metering and smart grids represent important means to maximise energy savings in buildings, for the widespread deployment of electric vehicles, and for efficient energy supply and distribution and for integrating renewable energy sources.
- *Renewable Energy sources.* The energy, provided by natural sources, can be converted and used effectively through ICT tools.

In this scenario, this paper aims at examining the possible impact of other ICT applications in support of the energy production and management by renewable energy sources. After a brief review of the principal renewable energy sources, we have focused on the following topics: *i)* use of renewable energy sources for the development of rural telecommunications systems; *ii)* Prognostics and Health Management (PHM) technology for Wind Turbines; *iii)* Renewable Energy Sources Mapping; *iv)* Security of Strategic Electric Facilities against terroristic attacks and of sensitive data related to renewable potential sites against cyber-spying.

2. Renewable Energy Sources

The main renewable energy sources can be grouped in: Solar Energy (Photovoltaic, Thermodynamic, Concentrating); Wind Energy; Hydro Energy (related to Tides, Waves and Rain); Geothermal Energy.

2.1 Solar Energy

Solar energy mainly refers to the use of solar radiation for practical ends. However, all renewable energies, other than geothermal and tidal, derive their energy from the sun. Solar technologies are broadly characterized as either passive or active depending on the way they capture, convert and distribute sunlight. Active solar techniques use photovoltaic panels, pumps, and fans to convert sunlight into useful outputs. Passive solar techniques include selecting materials with favorable thermal properties, designing spaces that naturally circulate air, and referencing the position of a building to the Sun. Active solar technologies increase the supply of energy and are considered supply side technologies, while passive solar technologies reduce the need for alternate resources and are generally considered demand side

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technologies. Solar chemical processes use solar energy to drive chemical reactions. These processes can convert solar energy into storable and transportable fuels.

In Section 4.1 we have focused on the very interesting technology based on the use of Concentrating Solar Power (CSP) systems to obtain clean energy and its possible application to thermo-chemical water splitting for the production of hydrogen is an example of an all green conversion process. Finally, we have reported a review about an interesting study on possible realization of Solar Power Satellites (SPS) on the basis of Dr. Peter Edward Glaser's idea already developed in 1968 [2].

2.1.1 Concentrating Solar Power

Concentrating Solar Power (CSP) systems use lenses or mirrors and possibly tracking subsystems to focus the sunlight from a large area onto a small area. There are four typical approaches for the concentration of the sunlight:

1) Linear parabolic trough solar collector: it uses single axis, tracking, parabolic, trough shaped reflectors that concentrate direct solar radiation onto a receiver tube located along the focal line of each parabolic trough reflector.
2) Linear Fresnel trough solar collector: it uses single axis tracking reflectors as the parabolic trough linear Fresnel diagram system does, but it uses less expensive flat reflectors.
3) Array of heliostats with a central tower: it uses a large array of solar tracking heliostat mirrors that reflect incoming solar rays to a central receiver at the top of a tall tower.
4) Parabolic dish: it uses a two axis tracking parabolic dish reflector that focuses the solar energy on a single point.

As a consequence, the small area of sunlight concentration can achieve very high temperatures, greater than 500 K. Arrays of heliostats and parabolic and dishes concentrate light to much higher levels than troughs and are thus capable of achieving temperatures much greater. The achieved thermal energy can then be converted to other forms of energy such as: mechanical energy, electric energy and chemical energy.

2.1.2 Solar Power Satellites

The Solar Power Satellite (SPS) concept involves a satellite carrying photo-voltaic panels in geo-stationary orbit (GEO) to generate electricity, and transmitting this power to the Earth's surface. The most significant advantages related to use of the solar collectors directly in space derive from the unobstructed view of the Sun, unaffected by the day/night cycle, weather, or seasons.

The SPS essentially consists of three parts: a huge solar collector (e.g., solar cells); a microwave antenna on the satellite, aimed at Earth; a large antenna on Earth to collect the power called *rectenna*. The rectenna consists of a series of short dipole antennas, connected with a diode. Microwaves broadcast from the SPS are received by these dipoles with about 85% efficiency. With a conventional microwave antenna the reception is even better, but the cost and complexity is considerably greater. Rectennas would be about 5 km across, and receive enough microwaves to be a concern. Some have suggested locating them offshore, but this presents problems of its own. In order to achieve the best efficiency, the satellite antenna should have a diameter between 1 and 1.5 km, while the ground rectenna around 14 km by 10 km.

An interesting approach to SPS is the exploitation of a Flower Constellation as "space dynamo" where multiple Secondary Paths form inclined circles. In this configuration each Secondary Path can be considered a very long single wire where the circuit could be closed by electron cannons [3].

2.2 Wind Energy

Wind power is the conversion of wind energy into a useful form of energy, such as using wind turbines to make electricity, wind mills for mechanical power, wind pumps for pumping water or drainage, or sails to propel ships. At the end of 2009, worldwide nameplate capacity of wind-powered generators was 159.2 GW. A wind turbine installation consists of the necessary systems needed to capture the wind's energy, point the turbine into the wind, convert mechanical rotation into electrical power, and other systems to start, stop, and control the turbine. The Betz's law represents the theoretical maximum coefficient of power for any wind turbine: no more than 59.3% of the kinetic energy of the wind can be converted into mechanical one turning a rotor. To assess the frequency of wind speeds at a particular location, a probability distribution function is often fit to the observed data. Different locations will have different wind speed distributions. The Weibull model closely follows the actual distribution of hourly wind speeds at many locations.

2.3 Hydro Energy

2.3.1 Tides Energy

The tide moves a huge amount of water twice each day, and its use could provide a great deal of energy. Although the energy supply is reliable and plentiful, converting it into useful electrical power is not easy. Only around 20 sites in the world have been identified as possible tidal power stations. *Tidal power* mainly means *tidal barrage*. A huge dam (called a "barrage") is built across a river estuary. When the tide goes in and out, the water flows through tunnels in the dam. The ebb and flow of the tides can be used to turn a turbine, or it can be exploited to push air through a pipe, which then turns a turbine. Large lock gates, like the ones used on canals, allow ships to pass. The largest tidal power station in the world (and the only one in Europe) is in the Rance estuary in northern France, near St. Malo. It was built in 1966. A major drawback of tidal power stations is that they can only generate when the tide is flowing in or out (i.e. only for 10 hours each day). However, tides are totally predictable, so we can plan to have other power stations generating at those times when the tidal station is out of action.

2.3.2 Waves Energy

Ocean wave energy is captured directly from surface waves or from pressure fluctuations below the surface. Waves are caused by the wind blowing over the surface of the ocean. In many areas of the world, the wind blows with enough consistency and force to provide continuous waves. Wave-power rich areas of the world include the western coasts of Scotland, northern Canada, southern Africa, Australia, and the northwestern coasts of the USA. A variety of technologies has been proposed to be installed to capture the energy from waves in nearshore, offshore, and far offshore locations. Some of the more promising designs are undergoing demonstration testing at commercial scales.

Offshore systems are situated in deep water, typically of more than 40 m. Wave energy technologies mainly differ in their orientation to the waves with which they are interacting and in the manner in which they convert the energy of the waves into other energy forms, usually electricity. The use of the wave energy technologies might cause: positive or negative impacts on marine habitat; toxic releases from leaks or accidental spills of liquids (e.g., for systems with hydraulic fluids); visual and noise impacts; conflict with other sea space users, (e.g., commercial shipping).

2.3.3 Rain Energy

Some Researchers have developed a technique that harvests energy from rain and converts it into electricity. The technology could work in industrial air conditioning systems, where water condenses and drops like rain. It could also be used in combination with solar power to capture as much energy from the environment as possible, or to power wireless sensors designed to monitor environmental conditions.

2.4 Geothermal Energy

Geothermal power is extracted from heat stored in the earth. This geothermal energy originates from the original formation of the planet, from radioactive decay of minerals, and from solar energy absorbed at the surface. Almost everywhere, the shallow ground or upper 3 m of the Earth's surface maintains a nearly constant temperature between 10°C and 20°C. Geothermal heat pumps can tap into this resource to heat and cool buildings. A geothermal heat pump system consists of a heat pump, an air delivery system (ductwork), and a heat exchanger-a system of pipes buried in the shallow ground near the building. In the winter, the heat pump removes heat from the heat exchanger and pumps it into the indoor air delivery system. In the summer, the process is reversed, and the heat pump moves heat from the indoor air into the heat exchanger. The heat removed from the indoor air during the summer can also be used to provide a free source of hot water.

3. Renewable energy sources for rural telecommunications systems

For communities living in emerging countries, wireless communications networks create significant economic development prospects. Studies have shown that access to telephone and Internet services offer an impetus for both economic and social development. However, finding reliable electricity sources to power the base stations - that are the capillaries of wireless networks - has been a substantial obstacle in developing these critical communication systems. It is estimated that 2.6 billion people in the world live in villages with no reliable electricity source - or no electricity at all. The use of alternative energy sources such as solar and wind-based power, combined with more energy-efficient equipment and networks, makes it possible for communities without access to electricity to enjoy the far-reaching benefits of wireless communications networks. However, these considerations are not limited only to emerging markets. Wireless network operators in developed regions would use renewable energy sources in order to streamline their networks, so reducing their carbon footprint and controlling rising energy costs. Until now, diesel generators have been the main source of power for wireless network base stations lacking access to a reliable electricity grid. These so-called ‘gen-sets’ have significant drawbacks. Diesel fuel is very expensive to begin with, and its transportation and storage can increase its cost substantially, especially in remote areas. Wireless network operators in some parts of Africa report that diesel-related costs are more than two-thirds of their total operating expenses. As a non-renewable fossil fuel, diesel fuel causes environmental damage. These problems are not limited to developing regions. Research suggests that electricity costs will rise faster than the savings gained through more efficient equipment and networks. According to this analysis, global power consumption for wireless network base stations will decline by three percent annually over the coming years, while the cost of the electricity powering those stations will increase by nine percent annually. When evaluating the environmental impact of gen-sets, it is worth noting that wireless networks account for a relatively tiny portion of global CO_2 emissions. Data from the International Energy Agency suggests that wireless networks produce about 0.3 to 0.6 percent of global CO_2 emissions, compared with an estimated 17 percent for the transportation industry and about 13 percent for manufacturing. The comparative benefits wireless networks provide are substantial. As they enable long-distance communication and information transfer, wireless networks actually help reduce carbon emissions from transportation and other sources. In fact, it is estimated that the ICT industries could potentially reduce global greenhouse gas emissions by 15% by 2020. The adoption of alternative energy powered base stations can only increase these benefits. The efficient deployment of these renewable resources requires the removal of trade and investment barriers between countries. The goal is the electrical interconnection of regions with abundant renewable resources to those nations with the highest consumption.

4. Identification of ICT Opportunities in Renewable Energy Applications

4.1. Hydrogen Production

An interesting example of an "all-green" conversion process is the CSP's thermal energy applied to thermo-chemical water splitting for the production of hydrogen. Low-temperature electrolyzers could be used to convert solar electricity to hydrogen, but this process is relatively inefficient. The overall conversion efficiency can be increased if solar heat is directly converted to hydrogen via a thermo-chemical process. In this frame, an important project called Solar Hydrogen Generation Research (SHGR) project, led by the University of Nevada Las Vegas Research Foundation, concerns the definition of economically feasible solutions for solar-powered production of hydrogen from water [4], [5].

4.2. Use of PHM Technology for Wind Turbines

Avoiding unnecessary and nugatory maintenance is critical in the case of offshore wind turbine installations, given the difficulty of routine access. Prognostics and Health Management (PHM) technology could be used to remotely verify fault conditions at the earliest stage, without the need for conventional methods of inspection, and minimizing false alarms. For offshore wind turbines in particular, there is a financial advantage in ensuring that any necessary maintenance can be predicted and then arranged to take place at the most convenient time, thus minimising the associated cost and outage time. PHM moves beyond conventional monitoring systems, adding the critical element of timescale to enable truly proactive maintenance methods to be implemented. The current state of the art in PHM of rotor and gearbox systems of similar complexity to those used in wind turbines is to be found in helicopter HUMS (Health and Usage Monitoring Systems), which include sophisticated, onboard vibration monitoring systems. Such systems are expensive to produce, install and maintain and are only justifiable in the context of the extraordinarily high costs of in-service helicopter failures.

In this scenario, the PHM technology could represent an alternative approach to the use of conventional and expensive components. Some works carried out in the development of diagnostic systems for monitoring other forms of rotating machinery [1] have demonstrated that that the torsional vibration characteristics of rotor and driveline systems are extremely sensitive to the presence of mechanical defects. Therefore, an intensive research activity focusing on development of PHM technologies for wind turbines is mandatory. It is important to develop an approach that will yield prognostic data for maintenance planning purposes rather than simplifying the of-the-moment view of vibration levels obtained from current monitoring systems. This will require the development of indicators, derived from the torsional vibration signal, which are adequately sensitive to the onset of failure to provide sufficient forewarning for maintenance to be planned. It is anticipated that the maximum benefit will only be realised if intelligent/model based systems are used to manage and analyse a large number of measurement and operational variables, and in turn this will require sophisticated software tools to be available.

4.3. Renewable Energy Sources Mapping

In this scenario, a geographic mapping of renewable energy sources, as solar, wind, geothermal, hydro, ocean and bioenergy, is mandatory in order to understand and manage the potential exploitation of these resources. Deserts can provide solar energy on an enormous scale, while coasts in the temperate zones offer huge potential for wind energy. On the other hand, great geothermal energy resources are located along the circum-Pacific "Ring of Fire", while mountainous countries with sufficient rainfall offer high potential for hydropower. Subtropical regions instead represent a great potential for bioenergy. The technical potential for the utilization of renewable energy is nearly 20 times greater than current global energy demand. Yet, today renewable energy only provides 17% of the world's primary energy needs and traditional renewable energy use (biomass and large hydro) make up the greater share (9% and 5.7%, respectively). New renewables such as wind and solar provide only 2% of total global primary energy consumption. In particular, in the last years, many wind farms have been built in complex terrains, offshore, forests, and at high levels in the atmosphere. Marketing of large, multi-MW wind turbines is in continued growth. At the same time our basic knowledge on winds in these challenging environments is inadequate.

The method traditionally used for accredited measurements for wind energy purposes is to mount cup anemometers on met masts. As turbines grow in height, mast instrumentation, erection and maintenance have become expensive. At the same time, the discrepancies between the measured wind at the rotor centre and the turbine performance have increased the need for determining the wind over the whole turbine rotor. The successful development of wind power should be based on sound information on winds in each location. To achieve this, it is mandatory to identify and develop new observation methods and strategies. The most promising ones are the new (for wind energy purposes) remote sensing techniques: Sodar, Lidar and satellite. Sodar is based on sound propagation, Lidar on laser Doppler and satellite on microwave scatterometry and Synthetic Aperture Radar (SAR) methods. Satellite remote sensing provides wind maps (snap-shot images) of the surface wind at 10 m above sea level. From a scatterometer, twice daily, wind maps at grid resolution of 25 km are available. The data series from July 1999 to present holds more than 5000 observations at most locations of the globe. Due to the resolution of 25 km, observations are not available close to the coastline (usually there is a void around 40 to 50 km distance offshore). In contrast, SAR wind maps cover the near coastal zone in which most wind farms are located. Far fewer SAR wind maps are available (e.g. a few hundred or less), but by using statistical treatment of a few samples, rough estimates of the wind resource can be obtained. The accuracy, around 1.1 m/s standard error, on a series of wind maps compared to offshore mast observations is useful in pre-feasibility studies and in decisions about the location of offshore masts. In addition, if high-quality met-observations are available within a mapped area, the relative differences in winds between different locations can be estimated with higher accuracy, possibly around 0.6 m/s. The major limitation is that the accuracy is sufficient in pre-feasibility phase but not bankable. This means satellite based wind resource mapping is relevant in the early phase of a wind farm project. At a later stage, when the financing is decided, other sources of wind resource statistics are needed.

4.4 Security of Electric Facilities Against Terrorist Attacks

Securing the electric infrastructure and its critical facilities (as nuclear plants) from terrorist attacks is becoming one of the most significant security challenges for the United States and Europe in the 21st century. In 2003 an electricity blackout affected many countries in the world: the northeastern and mid-western U.S. and Canada at first, then Europe (in particular Denmark and Italy). Typically, blackouts are caused by severe weather damage or facility equipment failures, most of which can be repaired quickly. However, for destruction of electricity facilities caused by terrorism, the situation would be much more serious. The electricity blackout in 2003, though not itself the result of a terrorist attack, highlights the vulnerability of electric power transmission lines to such attacks. The current electric power distribution system is still primarily using technologies developed in the 1950s or even earlier. The system cannot handle increased market demand and the digital users of the 21st century. Moreover, it is easy vulnerable to potential terrorist cyber attacks: a cascading failure of ICT control systems related to power management could cause electricity blackout and unbelievable economic losses elsewhere. Therefore, security is fundamental in order to reduce the risk of possible terrorist attacks and the ongoing cost of cyber-spying that cause significant jobs loss and higher energy prices.

5. Conclusions

The paper surveys the well-known renewable energy sources, briefly and, moreover, introduces the application of ICT background in that field. In more detail, ICTs can be applied in two possible ways: to produce renewable energy and to support the current renewable energy production process. In the former case, technologies and methodologies, typically applied to ICT field, could be reused in the future to produce energy in different and efficient way. In the latter case, the current ICT tools may help to support the current green energy production process aimed at enhancing the efficiency and the safety of the employed plants. Vice versa, the paper also individuates the application of renewable energy sources to serve existing telecommunication systems in rural areas. Future extensions of this work will cover all the mentioned applications, which are objects of ongoing research of the authors' laboratories.

6. References

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