Renewable Energy Research at the Pakistan Navy Engineering College

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Abstract

Rapidly depleting conventional energy sources and a realization of the increasing global warming and its associated climate change forced the world to seriously start looking for alternate and clean energy sources, also called the renewable energy sources, during the mid 1980's. The world has moved very quickly during recent years to respond to the new challenges. A brief overview of the current state of integration of these resources into the world energy mix is presented first, and then the research efforts to develop cost effective indigenous renewable energy technologies, carried out at the Pakistan Navy Engineering College, Karachi, over the years have been described in this paper. The work has so far generated nine patents.

Introduction

The first natural candidate to fuel the ever increasing hunger of the world for power is our Sun. Our Sun radiated over 50,000 times more power to the Earth during 2010 than was its total energy demand [1]. There is a long history of harnessing the solar energy for cooking and other applications on limited scale. Photo voltaic technology to produce electricity from the solar radiation was discovered in 1839 [2], and the first solar cell was constructed in 1877 [3]. The first silicon mono-crystalline solar cell was made in 1941 [4]. Later, more efficient solar cells were developed mainly for space technology applications. The cost of production was nearly US $ 2000 per watt during the mid 1950's. The cost has dropped down to about US 0.75 per watt during 2012, making it much more affordable for commercial applications. This cost is expected to fall down further during the coming years [5]. Use of concentrated solar power (CSP) for electricity generation was proven in 1968 [6]. In this concept solar radiation is concentrated onto a receiver through the use of mirrors. A thermal oil is circulated through the receiver, where it gets heated to several hundred degrees Celsius. The heated oil transfers its energy to water through a series of heat exchangers producing superheated steam. This steam finally turns a steam turbine to produce electricity. This technology was successfully applied at large scale during the mid 1980's, and has gained rapid grounds during the last couple of years. The cost of electricity production using this method is expected to decrease rapidly during the years to come. India has planned to install over 20,000 megawatts of solar power during the next ten years [7].

According to a report titled "What's Next for Alternative Energy?", by a global management consulting firm "The Boston Consulting Group" the CSP technologies are expected to achieve grid parity within the next 5-10 years [8]. BCG's analysis suggests that CSP's localized cost of electricity (LCOE) could fall to $0.11 to $0.16 per kilowatt-hour by 2015. By 2020, CSP could provide power at $0.10 or less per kilowatt-hour. With the addition of thermal storage capacity to provide on-demand power, CSP is expected to profoundly affect the conventional power generation by 2025 if major barriers, such as limitations in transmission infrastructure are overcome. Solar thermal electricity will be able to run with a profitable business model – challenging conventional and other renewable energy sources without any subsidies. Its penetration is expected to reach 12 GW of installed capacity by 2015, 30 GW by 2020 and between 60 and 100 GW by 2025 [9].

A study in the journal 'Energy Policy' proposes that all the energy needs of the world including electricity, transportation, heating/cooling can be met using only wind, water, and solar power by 2030 [10]. The study estimates the world could be entirely powered by electricity and electrolytic hydrogen (mostly for transportation fuel) using approximately 4 million 5MW wind turbines, fifty thousand 300MW concentrated solar thermal plants, forty thousand 300 MW solar PV plants, 1.7 billion 3 kW rooftop PV systems, five thousand 100 MW geothermal power plants, 270 new 1.3 GW hydro plants as well as some additional wave & tidal energy. The US president has put up plans of producing 80% of the US electricity from clean sources by the year 2035 [11]. The number of wind turbines installed during the last 13 years, have grown by 30 per cent annually. If current trends continued, wind capacity could reach 7,500GW by 2025 – making half of all new power projects wind or solar, while the conventional power stations could be phased out completely by 2037 [12].

Nearly one percent of the solar energy intercepted by Earth is transferred to wind due to its uneven heating. Again the history of harnessing wind energy is at least 4000 years old for sailing of ships and boats. First wind mills were made in Egypt around the seventh century A.D. primarily for the grinding of grains and water pumping. The modern electricity production wind turbine was invented in 1891. Since then a lot of improvements have been incorporated in its designing and productivity. Hundreds of billions of dollars were spent in USA and Europe for the development and testing of large wind

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turbines after the 1973 oil crisis. Large scale harnessing of wind power was made possible only during the last two decades. Now the single largest six megawatt commercial wind turbines are being made by the German company Enercon. Currently, over 280,000 megawatt capacity wind turbines have been installed worldwide, with nearly 55,000 megawatts added just the last year [13]. Wind energy industry has maintained a status of the fastest growing energy industry in the world during the last more than fifteen years. China and USA are leading the world in terms of new wind installations.

Other forms of renewable energy include, geothermal, ocean, bio-diesel and biomass. While substantial amount of R&D work is being carried out in these forms of energy, wind and solar remain the most widely developed commercially competitive sources holding the greatest amount of promise.

Developments at PNEC

In view of the above developments, a wind energy research project was initiated at PNEC at the beginning of the last decade. Under the special directives of the President, the government of Pakistan asked the Pakistan Meteorological Department (PMD) in 2001, to carry out a three year project of wind resource assessment in the coastal areas of Pakistan. The implementation of the project was jointly monitored by the author of this article and the Director General of the Pakistan Council of Renewable Energy Technologies (PCRET). Round the clock wind data was collected at one hundred feet high purpose built towers at forty five different locations along the coastal areas of Sindh and Baluchistan. The digital data was collected from data loggers for three years. The data was analyzed in 2004 and forty four thousand megawatt wind power potential was identified in the Gharo wind corridor alone, near Karachi. One quarter of this resource, that is, eleven thousand megawatt is technically extractable. Extrapolation of this assessment indicates at least three times more off shore resource in the Pakistani territory of the Indian Ocean. For comparison, the current total energy demand in Pakistan is around eighteen thousand megawatts. A second phase wind data collection project at another forty five locations in the Northern areas of Pakistan is currently underway. The data compilation is expected to conclude by this year.

Modern wind turbines are complex machines. Making these wind turbines requires good command over a number of research disciplines, like physics, statistics, aerodynamics, mechanical engineering, electrical engineering, manufacturing engineering, civil engineering and modeling and simulation. One must enter this field not only with a strong determination but also with a fair realization of the level of associated design complexities and unpredictability of the wind behavior. Careful planning and lots of field testing are the keys to success. Wind turbines mainly consist of several components – namely blades, generator, gearbox, direction controller, over speed controller, charge controller, support structure, batteries and inverter. Each of these components needs special individual attention. Moreover, complete comprehensive designing is based upon the analysis of wind data of a particular site. Normally, a minimum of three years data is required for large wind turbines, and at least a one year data is needed for small wind turbines.

The wind energy research project of PNEC was aimed at the indigenous designing and fabrication of small wind turbines according to the local wind conditions in Pakistan. A number of horizontal and vertical axis wind turbine concepts have been explored in the power range of 300 to 1000 watts during these years, despite severe financial limitations. Wind turbines are highly localized machines. One wind turbine suitable for a given location may not operate optimally at another location. Most of the imported wind turbines are designed at high wind speed ratings at 10–13 meter per second, and therefore do not operate properly in Pakistan, where we have average wind speeds in the range of 5–7 meters per second. This is to be realized that the power in the wind depends upon the cube of the wind speed, hence power in the 8 meter per second wind is only half as compared to the power in the 10 meter per second wind. Following is a pictorial overview of the wind turbines developed at PNEC at wind speed ratings of 8 meters per second. Special emphasis is laid on developing low cost technologies, so that the end product may become more affordable for the common user in Pakistan.

Fig. 1 shows a 500 watt two bladed horizontal axis wind turbine. The two bladed wind turbines are known to experience jerks when the blades are in the horizontal position and the wind direction changes. Fig. 2 shows a three bladed horizontal axis wind turbine, which operates very smoothly. Fig. 3 shows a 1000 watt vertical axis self starting wind turbine.

Fig. 3 Three bladed 1000 watt vertical axis wind turbine with a combination of Savonious and Darrius type blades

Fig. 4 shows a 300 watt 'Egg Beater' type vertical axis wind turbine, while Fig. 5 shows a very successful model of a high speed, self starting vertical axis wind turbine.

Fig. 6 shows another highly successful model of a 1000 watt horizontal axis wind turbine developed at PNEC. Fig. 7 shows a wind turbine whose blades have been made out of a PVC pipe. The low cost construction of these blades was matured after many tests and improvements. Fig. 8 shows a 50 watt prototype wind turbine mounted on a pedestal fan structure, while Fig. 9 shows two permanent magnet electric generators of 500 and 1500 watt capacities. The indigenously developed technology costs only third compared to the comparable imported generators.

The Wind & Solar Research Laboratory was established at PNEC in 2007 after receiving a grant from HEC for the study of Doubly-Fed Induction Generators for the production of constant voltage and frequency power in stand alone wind turbines. A second grant has been released for the designing and fabrication of a two kilowatt solar thermal power plant at PNEC. A number of products have been developed at the laboratory in the field of solar thermal energy. Here is a pictorial overview of these products. Fig. 10 shows two views of a prototype solar parabolic trough to heat thermal oil to high temperatures.

Fig. 1 Two bladed 500 watt horizontal axis wind turbine

Fig. 2 Three bladed 500 watt horizontal axis wind turbine

Fig. 3 Three bladed 1000 watt vertical axis wind turbine with a combination of Savonious and Darrius type blades

Fig. 4 Egg beater type 300 watt vertical axis wind turbine

Fig. 5 350 watt high RPM vertical axis wind turbine

Fig. 6 Three bladed 1000 watt horizontal axis wind turbine

Fig. 7 Three bladed 300 watt horizontal axis wind turbine with PVC blades

Fig. 8 A 50 watt horizontal axis prototype

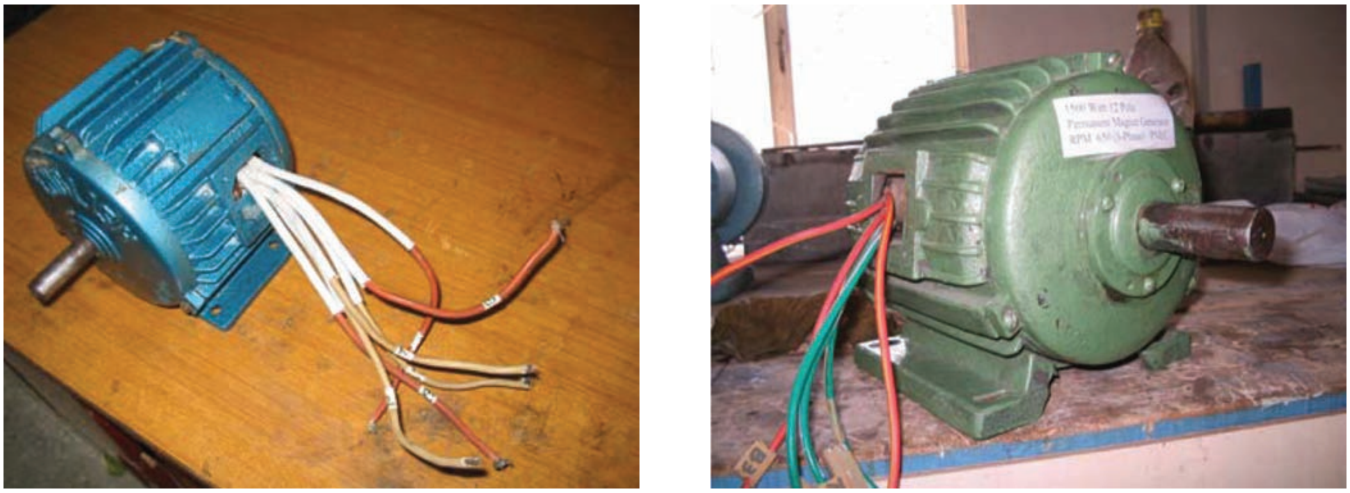

Fig. 9 Wind turbine electric generators of 500 watt and 1500 watt power capacity developed at PNEC.

Fig. 10 2 meter x 1.8 meter experimental Solar Parabolic Trough developed at PNEC, that heats the 2.3 liters of Heat Transfer Fluid (HTF) in the central tube to over 300 Co.

Fig. 11 Low cost solar water purifier

Fig. 12 Two views of a solar drier, used to dry and preserve perishable food

Fig. 13 The single vacuum tube based solar cooker

Fig. 15 Box type solar cooker with four additional booster mirrors

Fig. 14 60 cm x 45 cm Box Type solar cooker.

Such troughs are the back bones of solar thermal power plants.

A low cost solar water distillar capable of purifying 4 to 6 liters of water per day has been designed, fabricated and successfully tested (Fig. 11). It is inclined at an angle of 25^{o} to give the maximum annual output. With dimensions of 3 feet by 4 feet it ideally can be placed over the roof top of any house. Impure water is filled in the morning and 100% pure water becomes available in the evening. Water is held in small steps on treated surface, and gets converted to vapors by the solar radiation. The vapors then condense on the inside of the glass surface and slide down onto a channel, which conveys them to an outlet where they get collected in a container. It can become an Ideal source of clean water for small families. Larger sizes may be constructed as per demand.

A low cost solar drier capable of drying 4 to 5 kilograms of vegetables, fruits, fish or meat has been developed (Fig. 12). It consists of two parts – a Collector and a Chamber. The 2 feet by 6 feet glass covered collector inclined at an angle of 25^{o} with treated surface warms the air up to 60 C^{o}. The warm air rises into the chamber which contains food placed on wire shelves. The warm air passing through the food stuff is vented out through the ventilators at the top. The quantity of air flow and its temperature are controllable by opening or closing the ventilators. Many food items, specially fruits and vegetables can be dried this way during high season when they are cheap and may be consumed throughout the year. It is ideal for drying of potato, tomato, banana, apricot, grapes and other fruits and vegetables for house hold and commercial usage.

An entirely new type of solar cooker with separate Collector and Cooking chamber have been designed and fabricated in the Wind & Solar Energy Research Laboratory at PNEC (Fig. 13). The Collector supplies a constant power of 250 watts to the cooking chamber. This concept is entirely different from the conventional green house effect based solar cookers, and it permits frequent interventions during the cooking process which are not permitted in the conventional solar cookers. The plain mirrors at the bottom reflect the concentrated solar power onto the vacuum tube, where oil is heated to high temperatures like 200-300 C^o. The chamber houses a cooking pot inside it, which contains the stuff to be cooked. The mirrors at the bottom require solar tracking. The tracker is operated by a battery. The system is low cost and practical, because it allows the operator to stay in the shade, since the collector and cooking chamber may be separated from each other by a distance.

This low cost box type solar cooker (Fig. 14 and Fig. 15) utilizes the greenhouse effect for acquiring temperatures in excess of 100 C^o. It can cook one kilogram of food in about two to three hours.

Conclusions

Owing to the adverse effects of the climate change and the rapidly depleting fossil fuel reserves, the world is quickly transforming from the use of conventional energy sources to the environmental friendly renewable energy sources, for power generation. The shift has gained much momentum during the recent years. Different studies indicate that by the end of the first half of the current century, the world would have mainly shifted to different regional mixes of renewable energy sources. Wind and solar forms of these sources are likely to play the most dominant role. In view of the changing global trends and the local power crisis, renewable energy research had been initiated at the Pakistan Navy Engineering College, Karachi during the year 2000, and a 'Wind & Solar Energy Research Laboratory' was established in 2007 under a grant from HEC. All major types of wind turbines including vertical axis ones, have been designed, fabricated and extensively tested during these years and a lot of expertise has been gained. New mould free techniques have been developed for low cost manufacture of wind turbine blades, controls and electric generators. Several types of solar cookers, solar water purifiers and solar dryers have been developed with the end purpose of making these technologies user friendly and cost effective. Currently, eight patents having emerged from this work are at various stages of processing, while one patent has already been granted. A two kilowatt solar thermal power plant is in the last stages of completion. Commercialization efforts of the so developed technologies are underway.

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