SUSTAINABILITY OF SOLAR AND WINDENERGY SOURCES

Abstract

The demand of energy for all sector has increased year after year due to civilization and developments. Non renewable energy resources are those sources, whose formation within the earth takes several millions of years. Renewable energy sources are those take lesser time to recoup the energy resource, compared to the consumption of energy. Sustainable energy is one that can meet the current energy demands and conserve the energy to meet the demands of the future generation. In this paper the different aspects of the sustainability of solar and wind energy sources are discussed. Solar cells, made of semiconductor materials, convert sunlight directly into electricity, and considered as major sources of renewable energy sources. But they are producing electronic waste at the end of life causing environmental problems. Wind energy is converted to electricity by wind turbines, by receiving the wind energy through blades, which connected to a drive shaft, rotate the electricgenerator to produce electricity. Small wind turbine can function even at low wind speeds and can be installed even on the top of the building. Since off shore wind speeds are two times greater than those on land, offshore wind turbines could contribute much more energy. Most parts of a wind turbine except the blades can be recycled; but the blades made of resin and fiber glass and longer lengths are difficult and expensive to transport to landfill. Much attention should be given to reduce, recycle and reuse of the electronic wastes and other wastes from solar energy system and wind turbines so as to make them as sustainable energy sources. Considering the costs and efficiencies of solar system

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and wind turbines, it was concluded that both solar and wind energies are sustainable energies.

Keywords: Non renewable energy; renewable energy; sustainable energy; photovoltaic cells; solar energy system; wind turbine; off-shore wind turbine; Electronic waste;

I. INTRODUCTION

Energy is an important requirement for all developmental activities for the process, operation and maintenances. Further for the survival of the human communities also need energy. Therefore the need for energy has increased year after year as scientific developments are taking place. The two types of energy sources are non renewable energy sources and renewable energy sources. Formation of non renewable energy resources within the earth takes several millions of years. Once these resources are used up, they cannot be recouped immediately, hence these sources are known as fossil fuels. The examples of non-renewable energy sources are coal, natural gas, oil, and nuclear energy. So far most of the world's energy production was from fossil fuels. Renewable energy sources are those take short time to recoup the primary energy resource, compared to the rate at which energy is consumed. Examples of the renewable energy sources are hydro power, solar, wind and biogas.

II. RENEWABLE ENERGY AND SUSTAINABLE ENERGY

Renewable energy and sustainable energy are not different since many sustainable energy sources are renewable. However, the renewable energy comes from sources that are naturally renewing themselves at a rate to meet the energy demands. But all the renewable energies are not sustainable. Sustainable energy comes from the sources that can fulfil the current energy demands without compromising the need of the future generation. It involves the efficient collection, transformation and distribution. It includes geothermal, hydropower, solar and wind. Reliable electricity is essential to raise the standard of living of people. The provision of increasing quantum of energy is an important requirement for the economic growth of a country [1].India has an increasing energy demand for the implementation of the ongoing and proposed economic development plans. The primary objective for development of renewable energy in India is to accelerate economic development, improve energy security, and mitigate climate change. In order to achieve sustainable development use of sustainable energy, its availability and affordability must be ensured [2]. Due to development of renewable energy sources throughout the world the energy mix has changed [3,4,5], and energy mix policies must be revised taking into consideration many factors, including technical feasibility environment compatibility, social acceptance and economic viability. [6].In this paper the different aspects of the sustainability of renewable energies, in particular solar energy and wind energy are discussed.

III. SOLAR ENERGY

Sunlight is composed of photons, which are particles of solar energy, with great potential corresponding to the different wavelengths of the solar spectrum. Solar energy system is environmental friendly technology, and one of the most significant renewable and green energy sources. It plays an important role in achieving sustainable energy solutions [7].

1. **Photovoltaic Cells:** Solar energy is captured and converted into electricity through photovoltaic (PV) cells or solar cells. PV cells are electronic equipment that convert sunlight into electrical power. PV cells are manufactured from silicon or other semiconductor materials, which facilitates the conversion of sunlight into electricity. Inside view of the PV cell is illustrated in Figure 1.

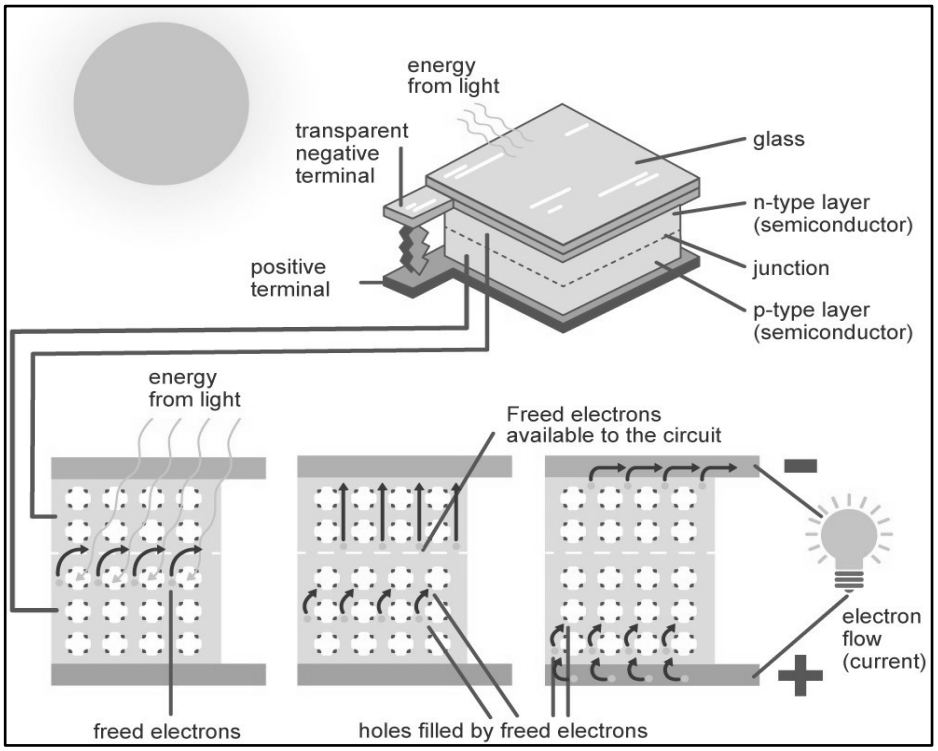

Figure 1: Inside View of the Photovoltaic cell [8**]**

The PV cell is an important item of a solar energy system. Size of each cell is vary from 12 mm to 100 mm, which can produce 1 to 2 Watts of electricity to supply for small equipment like calculators and wrist watches. PV cell consists of two or more layers of semiconductors with one layer of positive charge and the other of negative charge arrangedadjacent to each other. When photons of sun light reach the PV cell, they are absorbed by the negative layer and transferred to electrons f atoms of the cell. When the energy in the atoms increases, the electron escapes from the atom and moves to the positive layer creating a potential difference between the two layers of the cell, which are connected to an external circuit and electricity is produced.

2. **Flow of Electricity in a PV Cell:** The movement of negatively charged electrons towards the front surface of the PV cell causes an imbalance of electrical charge between the cell's surfaces. This imbalance creates a voltage potential and when connected to an electrical circuit electricity flows through the circuit. PV cells can be grouped in panels, and panels grouped into arrays of different sizes according to power requirement of different applications. Although the efficiency of the PV system has been improved through many modifications, there are few problems such as the deposition of soil, bird droppings, etc., on the PV surfaces, which can result inefficiency in the performance of the PV cells. PV cells generate direct current (DC) electricity, which can be used directly to charge batteries. Inverters are used on PV panels to convert the DC electricity to alternating current (AC) electricity, since all electricity is supplied as AC electricity. Most PV systems have panels in a fixed position that are usually facing directly south in the northern hemisphere, directly north in the southern hemisphere, and at an angle to increase the efficiency of the system.

3. **Solar Energy System:** In solar energy system the solar panel is the main component. There are three types of solar panels viz., mono crystalline solar panels, bifacial solar panels and polycrystalline solar panels with up to 300W capacities and efficiencies up to 19 percent. Today about 50 percent capacity of all *new* installations for generating electricity is coming from solar systems. In India, mono crystalline solar panels and polycrystalline solar panels are used in the solar energy systems.

4. **Cost of Solar System:** On an average the cost of standalone mono crystalline solar panels is $900 to 1300/kW and grid connected panels is $1000 to 1500/kW; bifacial solar panels is $800 to 860/kW; and polycrystalline solar panels is $710 to 740/kW [9]. The costs for different panel efficiencies are as follows:

   - **Monocrystalline Solar Panels**

     250 to 300 W capacity
   - 17 percent efficiency: $577/kWp
   - 18 percent efficiency: $614/kWp
   - 19 percent efficiency: $515/kWp

   - **Polycrystalline Solar Panels**

     0 to 50W capacity
   - 13 percent efficiency: $785/kWp
   - 14 percent efficiency: $1079/kWp
   - 15 percent efficiency: $773/kWp

     150 to 200W capacity
   - 13 percent efficiency: $638/kWp

     200 to 250W capacity
   - 14 percent efficiency: $638/kWp

     Hence, mono crystalline solar panels are most affordable solar panels [9].

5. **Unit Cost of Electricity from Solar System:** An illustration is presented below to work out the unit cost of electricity from solar system.

   - **Assumptions**
   - Capacity of solar system with mono crystalline solar panels: 20kW
   - Efficiency of the panels: 19 percent
   - Life of the system: 15 years
   - Installation cost: $515/kW for panels + 30 percent extra for other accessories

   - **Calculations**

     Total installation cost = $515 x 20 x 1.3 = $13390
     Life of the system: 15years
     Average annual installation cost = $13390/15 = $893

Annual operation and maintenance cost: 25% of annual installation costAnnual operation and maintenance cost = 0.25 x $893 = $223
Total annual cost = $893 + $223 = $1116
Annual average electricity produced = 20kW x 0.19 x 24h x 365d = 33288kWhCost per kWh electricity = $1116/33288 = $0.034kWh

6. **Efficiency of PV Systems:** The efficiency of PV systems to transform sunlight to electricity depends on the type of semiconductor material and PV cell technology. The average efficiency of available PV panels was less than 10% in the 1980s, and is now increased to about 25% due to improvements in the technology of modules. Now PV system has become an important energy system in almost all the electrical energy dependent activities with the objective of carbon reduction in satisfying the Paris climate agreement and in reaching the 2030 SDG targets [10].

7. **Applications of PV Power:** PV cells are one of the emerging renewable energy technologies with application in different fields.

- PV system is used to power water pumping system in isolated areas.
- PV-powered cathodic protection (CP) system is designed to give protection to the metallic pipes and tanks buried under ground against corrosion.
- The smallest PV systems provide power to calculators and wristwatches.
- Larger systems can provide electricity to telecommunication equipment, and power requirements of households.
- Distributed solar systems generate electricity locally for homes, commercial centres, and railway signal.
- Solar farms, using mirrors to concentrate sunlight, can generate more power for providing electricity to thousands of houses.
- Chennai Metro Rail Limited (CMRL) has installed solar power plants in the elevated spaces of metro rail stations to usethe electricity for the operation of the rails [11].

India has a plenty of solar energy throughout the year to an extent of about 750 GW. Hence, the technology that converts sunlight into electricity is dominating the energy sector. The Government of India (GoI) provides the motivation for the installation of solar system with subsidies and hence, PV cells installation would cross about 534 GW by 2030. The National Centre for Photovoltaic Research and Education (NCPRE) at IIT Mumbai is providing R&D support for India's mission of tapping solar energy [12].

8. **Advantages and Disadvantages of PV Cells**

Following are the advantages of PV cells [13]:

- PV systems can supply electricity in locations where there is no electricity distribution systems
- PV systems of any size can be installed very quickly.
- The environmental impacts of PV systems located on buildings is very minimum as they do not emit green house gases.
- The operation and maintenance costs of PV cells are very low, andhence, they are economically viable.

- Solar systems can be easily installed without causing any problem to the public.
- They can be installed even in remote locations to provide electricity at a lesser cost compared to supply from electricity grid.
- Solar energy is free and renewable.
- Since solar energy systems have no mechanical parts the cost of maintenance is very meagre.

Following are the disadvantages of PV Cells [13]:

- The efficiency of PV panels in producing electricity is low than the other renewable energy systems.
- Energy from the sun is not continuous, the power generation is less during cloudy weather.
- Transmission of electricity from solar energy to distant place is not feasible.
- For the conversion of DC current produced in PV system to AC current inverters are required.
- PV panels are delicate and likely to be get damaged very easily.

IV. WIND ENERGY

Wind energy is one of the popular renewable energy sources for generating electricity, which is required for reducing carbon emissions from the generation of electricity from non-renewable energy sources. Wind's kinetic energy is collected by the blades of the turbine and converted to electricity. Wind flows over the blades creates a lift and causes the blades to rotate, which in turn through a drive shaft rotates an electric generator for producing electricity. Wind energy systems can be connected directly to the nearby houses as well as to the electricity distribution system, then they are called grid-connected systems. A grid-connected wind turbine system can reduce the consumption of utility-supplied electricity for the household consumptions. If the wind turbine system cannot meet the energy demand of the household, the utility will make up the deficit. When the wind turbine system produces more electricity than the household demand, the excess electricity is credited and used to offset future use of utility-supplied electricity. Wind turbine system must, therefore, be paired with other generators of equivalent capacity to compensate for variations in the wind flow and for the stability of the electricity supply. This pairing-wind and the backup generator has limits to compensate the huge rapid variability of wind.

Wind power can be used in isolated area not connected to an electric distribution system. In such cases, the system can be used in combination with other system to create hybrid power systems. Hybrid power systems can provide reliable power for houses that are far away from the nearest electrical lines. The expected average life of wind turbine system is 15 years.

1. **Small Wind Turbine:** As per the International Electro technical Commission (IEC), a turbine with a rotor swept area of less than 200 m^2 and that generates 1.5kW DC current is known as a small wind turbine (SWT) [14]. SWT can function even at wind speeds of less than2m/s. They can be connected to the grid or be independent systems and can alsobe hybridised with solar. They can also be installed even on the top of building as shown if figure 2, and some of them can be transported from place to place. Certification for SWT is to be obtained through compliance with the IEC standard numbered 61400–2, [15].

Figure 2: Wind Turbine on Roof Top [15]

2. **Offshore Wind Turbines:** To tap wind energy large area of land, particularly in area where favorable wind is occurring, is required for installation of wind turbines. That much area of land is not available. While offshore wind speed in the sea is about twotimes more than that of the wind speed on the land. Hence, technology for installation of offshore wind turbines was developed. Since offshore wind turbines could produce more electricity due to consistent and strong wind than onshore wind turbine more offshore turbines are being installed nowadays. Main problem with the installation of offshore wind turbines is the construction of stable foundation. In the shallow depth area of the sea independent foundation for the wind turbine can be fixed at the sea bed as shown in Figure 3. But for deeper portion of the sea construction independent foundation for the wind turbine is difficult. In such cases floating wind turbines with turbines fixed on the floating vessel are suitable and the devices are being developed.

   Out of the global installed offshore wind turbines, China accounts for 49 percent, United Kingdom accounts for 22 percent and Germany accounts for 13 percent of the installed capacity to dominate in the world as major countries in tapping the wind energy [16]. Corrosion is a serious problem in offshore wind turbines and requires careful design and construction of them. The development of a system for remote monitoring of corrosion of wind turbines is encouraging [17].

Figure 3: Offshore Wind Turbines [16]

3. **Cost of Wind Turbine:** Cost is an important aspect in any analysis. The average cost of installation of wind turbine is $1.75million/MW. Assuming the life of the wind turbine as 15years, the annual installation cost of the wind turbine is $ 0.117million/MW. The annual operation and maintenance (O&M) cost of a wind turbine is about 20-25 percent of the annual installation cost [18].For example a wind farm of 100MW capacity with life of 15years and producing 30 percent of its annual capacity the cost of unit power can be worked out as follows.

   Cost of installation of 100MW wind farm = 100 x 1.75 = $175 millionAssuming life of the wind farm as 15years,
   Average annual installation cost of the farm = $175/15 = $11.67million
   Annual O&M cost of the wind farm = 25% of annual installation cost = $11.67 x 0.25 = $2.92million

   Total annual cost of the wind farm = $11.67 + 2.92 = $14.59millionAnnual electricity produced = 0.3 x 100 x 24 x 365 = 262800MWh
   Cost of production per kWh of electricity = (14.59 x 1000000)/(262800 x 1000) = $0.055/kWh

V. ELECTRONICWASTE FROM SOLAR ENERGY SYSTEM

Even though the solar energy is accepted as the major source of renewable energy, they are producing electronic wastes (e-waste), which are of much concern. Government of India (GoI) notified the Electronic Waste (Management) Rules, 2022 with guidelines for management the e-waste of PV system[19].

Ayush Gautam et al have reported that 21 metals of toxic nature are present in e-waste from solar energy system. India is divided into six zones for end-of-life (EOL) waste collection, which will be in the order of 12million tonnes per year.70 percent of the e-waste from solar energy system could be recovered, recycled and reused. To manage EOL solar energy wastes generated a circular economy approach by developing afresh policies for designing, recycling, and refurbishing strategy and assessment of resource efficient regulations is required. [20].

Today, India ranks 4th in the world in the installation of renewable energy systems. India's renewable energy capacity has reached the level of 40% of the country's energy mix. The COP-26 meeting has made a statement that massive use of solar power in the future for increasing the transition from coal to renewable energy is the key agenda of the COP26 [21]. Presently the power sector contributes 25 percent of global greenhouse gas emissions.

Hence, there is a need to develop large scale renewable energy systems which could reduce the green house emission considerably so as to meet the goals of the Paris Agreement. Opportunitiesare now available for generating electricity using solar and wind, which are less costly thanthermal power generation using coal. This would emphasize the need for development offacilities to reduce, reuse, disposal of EOL solar system [22].

VI. PERFORMANCE ANALYSIS OF PV PANEL

The rate of peak power generation of a PV panel in the afternoon of sunny day is expressed in kilo Watt peak (kWp). The performance analysis of a 190 kWp solar PV power plant installed at Khatkar-Kalan, India, was conducted to assess the power production and performance ratio [23]. From the analysis it was found that the power production and performance ratio are to vary from 1.45 to 2.84 kWh/kWp-day and 55–83% respectively. The actual average annual electricity production of the plant is found to be 812.76 kWh/kWp against the average annual predicted electricity production of 823 kWh/kWp derived from computer model . The predicted electricity production from the model is in close agreement with actual production with an uncertainty of 1.4%. The total estimated system losses due to various factors are found to be 31.7%.

VII. LEVELIZED COST OF ELECTRICITY

The levelized cost of electricity (LCOE) is the parameter used widely to compare the economic viability of the energy mix. This method is easy to understand and simple to apply, which makes it preferable for many energy managers. However, the method has several disadvantages: i) the LCOE approach does not consider revenue and a high-interest rate, which can affect economic competitiveness; ii) the LCOE does not consider different stakeholders, which influence the same energy sources [24].LCOE is adopted as a metric to compare competitiveness of power generation technologies [25,26]. The LCOE is an indicator used widely to compare different renewable energy sources. The LCOE is a widespread indicator used to identify the grid parity among different energy generation

technologies [27]. The LCOE value is calculated as total lifetime cost divided by total lifetime energy production [28].

The global weighted average LCOE of new onshore wind projects is reduced year after year to $0.033/kWh, while that of solar PV system is reduced to $0.048/kWh and that of offshore wind turbines to $0.075/kWh [29].

As the using of fossil fuels for electricity generation is responsible for 87% of the world's carbon dioxide emissions, usage of fossil fuels is not sustainable, they endanger the future generations and our biosphere. The annual deaths of many people n*ow* due to the air pollution from burning fossil fuels alone is six *times* the annual death toll due to all other causes [30].

VIII. WASTES FROM WIND TURBINES

Average life of the wind turbines is 15 years. At the EOL most parts of the wind turbines except blades can be recycled. The blades made of a tough mix of resin and fiber glass, similar to material from which satellite's parts are made and have no value.EOL blades are very difficult and expensive to transport as they are 30 to 100 metre long and need to be sized down onsite before transported on special trucks equipment to the landfill.

1. **Reuse and Recycling:** Erection of wind turbines requires large quantities of materials and accessories. These accessories will ultimately reach the EOL as wastes and could go to landfills, unless innovation is made. Recycling and reusing of wind turbine materials at the EOL will reduce waste to landfill and create a circular economy. Suitable technologies should be adopted from the beginning to use fewer materials, resources and energy to have longer life and using accessories at the EOL by breaking down in some other applications.

IX. CONCLUSION

According to the International Renewable Energy Agency (IRENA) renewable energies were cheaper than the cheapest fossil fuel [31]. Advantage of wind turbines over solar energy system is that wind turbines work at night and even when there are mild winds. The installation cost of wind turbine sis about $0.75 to 1.0 million/MW depending on the scale of plant and the annual O&M cost is about 25 percent of the average annual installation cost. The current cost of solar system installation is about $0.1million/MW and the operation and maintenance costs is comparatively less. The efficiency of wind turbines in converting the captured wind energy into electricity is about 30 percent, whereas the efficiency of the solar systems in converting sunlight to electricity is only 23 percent. Even though the efficiency of solar system is less they are less costly than wind turbines for installation and maintenance. Considering the above facts, it can be concluded that both solar and wind energies are sustainable energies.

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