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A Review on Hybrid Renewable Energy – Solar, Wind and Hydrogen Energy

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Abstract- Now-a-days renewable energy resources like solar, wind and hydrogen must be developed in order to stabilize and reduce carbon dioxide emissions. Efficiency slows down the demand growth so that rising clean energy supplies can make deep cuts in fossil fuel use. Otherwise if energy use grows too first, renewable energy development will chase receding target. Different generations of Photovoltaic (PV) cells with their efficiency rate and scope of their use, in regards to practical application with economic fall outs, were also spell out from the case study. Currently, photovoltaic (PV) panels only have the ability the ability to convert 16% of the sunlight that hits them into electricity. Many experts believe that the solar energy is not efficient enough to be economically sustainable given the cost to produce the panel themselves. Cost of PV being shown to be the main contributor in terms of deciding the economy of PV –based power generation scheme. Presently the economy evaluation of solar PV and solar heating like solar cooker, solar pond etc. were assessed here in regards to their merit and demerit.In concern with different aspects on cost evaluation for on-shore and off-shore wind energy regarding the development of wind firm at particular site were assessed. In order to avail the wind energy value per square meter at a concerned site for a particular wind speed could also be ascertained. A wind firm is a group of wind turbines in the same location used to produce electric power. A large wind farm may consist of several hundred individual wind turbines and cover an extended area of hundreds of square miles. A rigorous study in different corners on the economy of the production of hydrogen in terms of splitting water that is electrolysis was made and it was noted that the ocean thermal energy conversion system generated electricity would be the best cost effective method. On examination it has been found that H_2 fuel cell combine as transport fuel, it could be shown that a single 100 MW ocean thermal energy can cater to 30 hydrogen refueling stations, each with 250 vehicle movements per day.Feasibility study is carried out on optimized hybridization of combination of PV –wind with H_2, for uninterrupted power supply at different concerned areas.

Keywords- Solar Energy, Wind Energy, Solar Pond, PV module, Wind speed, Hydrogen energy, Electrolysis, Hybrid System

1. Introduction

Sustainable energy is the form of energy obtained from non-exhaustible resources, such that the provision of this form of energy serves the needs of the present without compromising the ability of future generations to meet their needs. Technologies that promote sustainable energy include renewable energy sources, such as hydroelectricity, solar energy, wind energy, wave power, biomass, biofuels, hydrogen, ocean energy, geothermal energy, bio-energy, tidal power and also technologies designed to improve energy efficiency.[1] Costs have fallen dramatically in recent years and continue to fall. Most of these technologies are either economically competitive or close to being so. Consider progress is being made in the energy transition from fossil fuels to ecologically sustainable systems. Renewable energy is derived from natural processes. It has various forms and can be derived from the sun, or from heat generated deep within the earth. There are electricity and heat energy generated from the renewable energy resources. From carbon equivalent gases emission inducing global warming, renewable energy(RE) systems may emerge to be competitive with fossil fuels, if the social cost of the later are taken into account.[2]

In this point of view, Solar and Wind energy are the most important source of renewable energy in recent times. They are continuously being tried to develop with constant improvement of cost component from R & D studies. Also there are trials with necessary subsidies. In order to assess any energy system’s commercial acceptability, its economic evaluation is very important for further development. For advancement of technology, several extensive research work is carried out for several decades in regards to solar and wind energy. The other renewable energy is being considered to be the most favoured by the turn of the century, particularly as the transport fuel, is the Hydrogen/Fuel cell system. One of the important form of energy is hydrogen as it is an easily transportable clean energy. Also it can be used to store electricity, producing by electrolysis using electricity, and thereafter it can be produced electricity through fuel cell.[1,2]

2. Experimental Procedure

A brief review on different aspects on energy systems, Solar and Wind and Hydrogen type fuel, have been outlined below with feasibility study of their hybridization.[3]

Solar energy

The word “Solar” comes from sol, an ancient Latin word that means “SUN”. The Sun is a huge ball of hot, swirling gases being 149 million Kilometer from Earth and its energy reaches us in about eight minutes. The diameter of SUN is 1.4 million kilometer which is 110 times of Earth and 10 lakh earth can be accommodated in Sun’s surface. The temperature of the Sun is 5500 degree centigrade. The Earth receives 4000 trillion KWh energy everyday from the Sun which is about hundred times the total energy consumption of world in a year. Scientists believe that it will be about 10 Billion years before the Sun begins to run out energy. Out of the total energy from Sun due to Alberdo effect about 30% reflected back from the Ozone Water Vapor, Carbon dioxide in the atmosphere, 15% absorbed and 55% incident on Earth 2% of Energy is in infrared mode 51% as visible spectrum and 47% is in Ultra violet mode. The Sun’s energy travels through space and reaches Earth as Light and Heat. Even if much less than 0.1% of solar energy could be used effectively to meet the entire global demand of energy many times over.[4]

Solar Cells

Photo voltaic refers to the creation of voltage from light. The solar cell used acts as a converter which changes light energy into electrical energy incident on the front surface of the solar cell passes through the surface and is absorbed. It knocks negatively charged electrons loose from their silicon atoms. The freed electron now has potential energy and this is what we call “Voltage” or electrical pressure. The flow of electrical charges with extra potential energy or voltage is what we call electrical current. Silicon is the best suited material for Solar Cell. A number of cells grouped together is called a solar module. Normally 36 Nos. of Solar Cells are grouped to\from a 12 volt module system. The modules are grouped in Panels as per requirement. The system incorporates Solar Panel, Solar Light, Pump, Battery and Charge Controller. Energy generated in the Solar Panel is stored in a Battery for night time application. Normally for Photovoltaic use, Lead Acid Tubular Plate, Ceramic Vent Plug mounted batteries are used. The charge controller protects the system from overcharging, short circuit, reverse current flow etc. For making the solar cells, it involves doping them. Doping means that it has to be contaminated with certain chemical elements that will allow flow of electricity. Hence such doping with selective chemical components produces either positive types of charge carriers (p-type semiconductor) and negative types of charge carriers (n-type semiconductor). If both of these type of semiconductors are combined, then p-n junction occurs at the boundary the layers. When light is going to fall on the p-n junction, then they are released having metallic contacts, generation of electricity from electric charge flow. The PV electricity is DC(Direct Current). The current has a polarity i.e. it flows in one direction.[5]

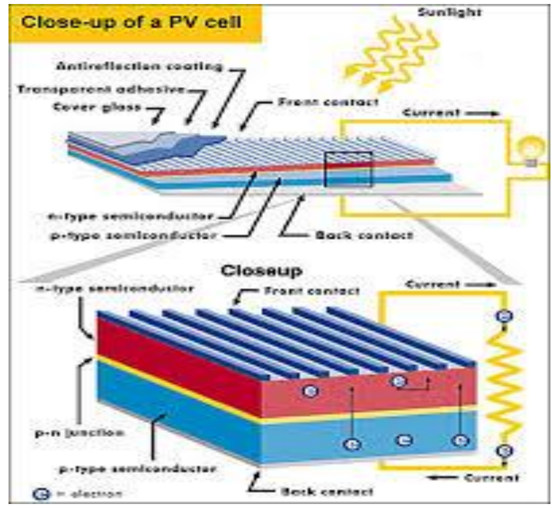

Figure 1 Close-up of a solar PV cell

There are three categories of Solar PV Cells, mainly classified as the three generation cells. Among them, the first generation belongs to polycrystalline silicon cells where as the second generation cells are polycrystalline thin film crystal structure cells which are amorphous Si: H cells. Then the third generation cells are high efficiency multi-junction concentrator solar cells like dye sensitized cells, organic cells, polymeric cells, nano-structured cells etc.

31% of the market goes to first generation single crystalline Si cells and produces the efficiency as high as 24.7%. The drawback is that it is too expensive because of very pure silicon. In regards to second generation polycrystalline cells, it has been found that they are fast growing technology and have efficiency a little less. Therefore, it has cost advantages over 1st generation crystalline Si: PV cells. The major components in second generation polycrystalline cells are amorphous Silicon, Cadmium Telluride, Copper Indium di-Selenide. Though they are quite cheaper than first generation PV cells, but in regards to the efficiency, it is lower than first generation which comes around 13% having world market around 15% - 20%.

On the other side, the third generation PV cells are having high efficiency concentrator cells consisting of Gallium Arsenide substrate having twin junction cells with Indium Gallium Phosphide made on Gallium Arsenide wafers. It is noticed that P-V junction of PV cell on an average produces 0.5V/cell. A solar module consists a number of solar cells while multiple modules make array of photovoltaic cells. Coming to history, as early as in 2000, at Sagar Islands

(Sundarbans, Westbengal, India) a PV array containing 320 modules of PV cells, with 36 solar cells in each of the module got installed providing 100 watts of power to 93 consumers. It took around the area coverage of 300 square meter for their installation. The power generated is DC which is later converted to AC using inverters and got store in battery for night supply to consumers.[4,5]

3. Results and Discussion

Figure 2 A crystalline silicon solar cells

This picture shows that a conventional crystalline silicon solar cell where electrical contacts from bus bars that is the larger strips and the fingers (the smaller ones) are printed on the silicon wafer. The operation of a photovoltaic (PV) cell requires 3 basic attributes:

- The absorption of light, generating either electron-hole pairs or excitons
- The separation of charge carriers of opposite types
- The separate extraction of those carriers to an external circuit

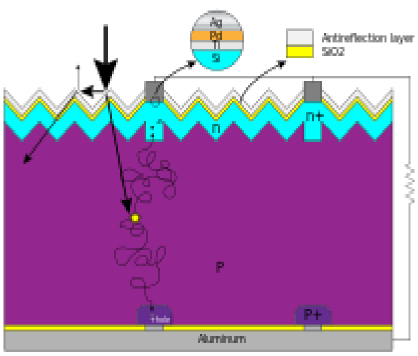

Figure 3 Cyclic process from solar cell to a PV system

This picture shows how the process happens from a solar cell to a PV System. Multiple solar cells in an integrated group, all oriented in one plane, constitute a solar photovoltaic panel or solar photovoltaic module. Photovoltaic modules often have sheet of glass on sun-facing side, allowing light to pass while protecting the semiconductor wafers. Solar cells are usually connected in series in modules, creating an additive voltage. Connecting cells in parallel yields a higher current; however, problems such as shadow effects can shut down the weaker(less illuminated) parallel string (a number of series connected cells) causing substantial power loss and possible damage because of the reverse bias applied to the shadowed cells by illuminated partners. String of series cells are usually handled independently and not connected in parallel. Although modules can be interconnected to create an array with the desired peak DC voltage and loading current capacity by using independent MPPTS(maximum power point trackers) is preferable.

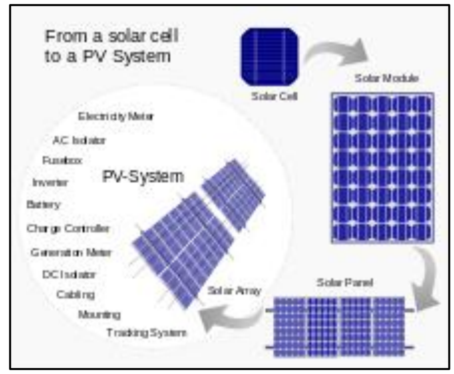

Figure 4 Working mechanism of solar cell

The solar cell works in a process as many photons in sunlight hit the solar panel and are absorbed by semiconducting materials such as silicon and electrons and protons are excited from their current molecular/atomic orbital. Once excited an electron can either dissipate the energy as heat and return to its orbital or travel through the cell until it reaches an electrode. Current flows through the material to cancel the potential and this electricity is captured. The chemical bonds of the material are vital for the process to work, and usually silicon is used in two layers. Out of them, one layer is being bonded with boron and the other one is bonded with phosphorus. An array of solar cells converts solar energy into a usable amount of direct current (DC) electricity. An inverter can convert the power to alternating current(AC). The most commonly known solar cell is configured as a large-area p-n junction made from silicon.[6]

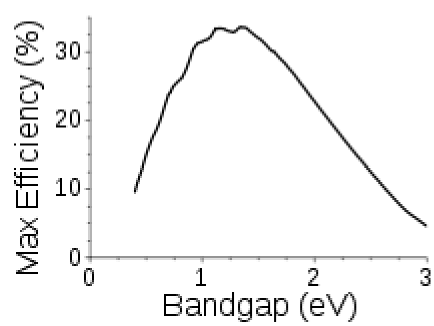

Figure 5 Shockly-Quiesser limit as max efficiency

The Shockly-Queisser limit for the theoretical maximum efficiency of a solar cell. Semiconductors with bandgap between 1 and 1.5eV, or near infrared light, have the greatest potential to form an efficient single junction cell. Solar cell efficiency may be broken down into reflectance efficiency, thermodynamic efficiency, charge carrier separation efficiency and conductive efficiency. The overall efficiency is the product of these individual metrics.Single p–n junction crystalline silicon devices are now approaching the theoretical limiting power efficiency of 33.7%, noted as the Shockley-Queisserlimit in 1961. In the extreme, with an infinite number of layers, the corresponding limit is 86% using concentrated sunlight. In December 2014, a solar cell achieved a new laboratory record with 46 percent efficiency in a French-German collaboration. In 2014, three companies broke the record of 25.6% for a silicon solar cell. Panasonic's was the most efficient. The company moved the front contacts to the rear of the panel, eliminating shaded areas. In addition they applied thin silicon films to the (high quality silicon) wafer's front and back to eliminate defects at or near the wafer surface.

Figure 6. A pictorial view of PV cell, module and array of solar panel

In September 2015, the Fraunhoferfor Solar Energy Systems (Fraunhofer ISE) announced the achievement of an efficiency above 20% for epitaxial wafer cells. The work on optimizing the atmospheric-pressure chemical vapor deposition (APCVD) in-line production chain was done in collaboration with NexWafe GmbH, a company spun off from Fraunhofer ISE to commercialize production. For triple-junction thin-film solar cells, the world record is 13.6%, set in June 2015.

Table 1 : Level of efficiency

Type/Material of PV cell	**Level of efficiency in Laboratory (%)**	**Level of efficiency in Production (%)**
Mono crystalline silicon based	24(approximate)	14-17
Polycrystalline silicon based	18(approximate)	13-15
Amorphous Silicon based	13(approximate)	5-7

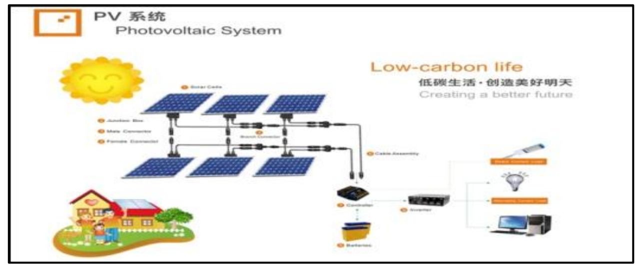

Figure7. Schematic diagram of a solar PV power plant with its outfits

The above installations subsequently made could be hybrid system along with other power grid supply line or, only stand-alone type-as per the suitability of installation site. In fact, such hybridization can also be made with wind energy supply, if applicable.

It may be relevant to add that the efficiency of crystalline SiliconPV products ranges from 15-20% with requirement space 100 sq. ft/kW; whence for thin film PV, average efficiency is 7-15% with space requirement of 200 sq.ft/kW.

PV array site is determined from the availability of space; normally 1kW requiring 8m^2 of roof/space, that faces south with slope of around 30-40^0.[7]

Panel generation factor

Panel generation factor = Solar irradiance ×sunshine hours / Standard test condition irradiance; (where, solar irradiance (kWh/m^2), depends on site concerned and sunshine hours, which is normally considered to be 9-10 hours and standard test condition irradiation is considered 1000 kWh/m^2.

Total Watt Peak Rating

Total Watt Peak Rating = Total energy requirement from the PV module (kWh/day)/Panel generation factor (PGF).

Number of PV modules required

Total watt peak rating/PV modules peak rated output;

Scope of hybridization

The hybridization of one may help the other for 24×7 power supply. In addition hydrogen generation may be tried in for storing electricity during scope of availability of excess supply, through H_2/Fuel cell route.

Solar Cooker

A report from IREDA, India, states that an amountof 6.7 million tonne of CO2 emission could be avoided if 3% of

Indiansswitch over to using Solar Cooking. It could be demonstratedbuilding a prototype of cheaper quality solar cooker (life expectancy of5-6 years) that 2-3 hours of clear sunshine in tropical country like India.[8]

Solar Pond

Solar pond entraps the heat energy from sun-light in artificially made denserwith adequate addition of common salt. Convection current of theheavier bottom layer does not move upwards to shed its heat to theupper layer of the pond and thereafter to the atmosphere as in a normalpond. Thus, heat energy received from sunlight remains stored in thebottom zone. Therefore the heat received from the sun is virtuallyentrapped in the bottom layer of such ponds, termed Solar Pond**.**

Electricity generation from solar heating

It is a power tower, which is a system for trapping solar energy from a large field of mirrors and converting it to heat at high temperature for efficient generationof electricity. All the mirrors track the sun and the heat is focused on asingle boiler thermal system. The purpose is to cover the midday loadas experienced by utilities. To counter the effect of passing cloud, thereis a thermal storage capability filled with oil.

Wind Energy

Wind Energy was in use since long mainly for grinding purposesin wind mills. Generation of Electricity with Wind Turbines, utilizingthe aerodynamic lift of the wind, is the recent trend-with global stressupon Renewable Energy Resources. Wind turbines capture the wind'senergy with two or three propeller-like blades, which are mounted ona rotor, to generate electricity. The turbines sit atop high towers, takingadvantage of the stronger and less turbulent wind at 30 meters or, moreabove ground.

In fact, the availability of wind is the most important criterion thatwould determine the deployment of wind turbine in a certain place.By availability it means the wind speed due to which it will rotatethe wind turbine so that mechanical energy of the wind is convertedinto electrical energy through generator. The wind speed decides theefficiency and economy of wind energy application for creating windfarms.Wind movement is known to be formed due to the uneven heatingof the earth from solar insolation, irregularities of the earth’s terrain,

and also from the rotation of the earth. The kinetic energy possessedby wind movement can be converted into mechanical energy, whichrotates the blade and spin a shaft of the turbine, which produceselectricity through generator. The wind turbines are of two types. Oneof them is horizontal axis wind turbine and the other is vertical axis.Since the power that a wind turbine generates is a function of thecube of the average wind speed of the site concerned; hence smalldifferences in wind speed would cause large differences in productivity

and thereby of electricity cost. Also, the swept area of a turbine rotor isa function of the square of the blade length. Hence a modest increasein blade length would enhance energy capture, and thus of the costcomponent on power generation.

Small turbine is up to 100 kilowatts while intermediate size from 100 kilowatts to 1 megawatts. So the larger one is 1 megawatt.

15000 wind turbines operate in California,USA. 3000 turbines operate in Denmark. The world’s largest horizontal – axis wind turbine is located on Oahu, in Hawaii and supplies power to 1,200 homes. Other areas with growing interest in wind energy include Canada, Northern Europe and Scandinavia. Social cost of burning fossil fuels to generate electricity is 0.03 dollar to 0.07 dollar per kilowatt hour. While wind energy produces 0.04 dollar per kilowatt hour of electricity produced.[7,8]

HydrogenEnergy

Hydrogen fuel is a zero-emission fuel when burned with oxygen or used in a contained cell also capable of ‘reversing’ the reaction if needed. It often uses electrochemical cells or combustion in internal engines, to power vehicles and electric devices. It is also used in propulsion of spacecraft and might potentially be mass produced. Hydrogen lies in the first group and first period in the periodic table i.e. it is the first element on the periodic table, making it lightest element. Since hydrogen gas is so light, it rises in the atmosphere and is therefore rarely found in its pure form, H_2 in a flame of pure hydrogen gas, burning I air, the hydrogen reacts with oxygen to form water and releases energy. Since it can be produced passing electric current in water and also be used to generate electricity through fuel cells, hence it is consideredto be instrumental in the storage of electricity, which unlike battery need not require periodic charging with power to derive power from it.[9]

The hydrogen energy can be delivered to fuel cells and generate electricity and heat, or burned to run a combustion engine. In each case hydrogen is combined with oxygen to form water. The heat in a hydrogen flame is a radiant emission from the newly formed water molecules. The water molecules are in an excited state on initial formation and then transition to a ground state; the transition unleashing thermal radiation. When burning in air, the temperature is roughly 2000°C. Historically, carbon has been the most practical carrier of energy, as more energy is packed in fossil fuels than pure liquid hydrogen of the same volume. The carbon atoms have classic storage capabilities and releases even more energy when burned with hydrogen. However, burning carbon base fuel and releasing its exhaust contributes to global warming due to the greenhouse effect of carbon gases. Pure hydrogen is the smallest element and some of it will inevitably escape from any known container or pipe in micro amounts, yet simple ventilation could prevent such leakage from ever reaching the volatile 4% hydrogen-air mixture. So long as the product is in a gaseous or liquid state, pipes are a classic and very efficient form of transportation. Pure hydrogen, though, causes metal to become brittle, suggesting metal pipes may not be ideal for hydrogen transport.[9,10]

4. Conclusion

A method could be developed from assessment of the present statusof development of solar PV, wind energy and H_2 –fuel cell combine,for effective hybridization of these renewable energy systems foravailing uninterrupted power supply with better economy and makingoptimized hybrid model of them.The parameters needed for resource assessment of wind energyfarm installation, by estimating the energy density /sq. m of the siteas per the available wind speed; and also of the requirement of PVmodules for a given power generation from PV modules, based on solarirradiation at the concerned site – could also be well defined. These measurements were noted to be important in economy assessment ofthese two RE systems, Wind/PV combine, where speed of wind at hubheight in case of wind energy and number of PV module in case of PVsystems, mainly decides their cost effectiveness.

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