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Solar energy for future world: - A review

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ABSTRACT

World's energy demand is growing fast because of population explosion and technological advancements. It is therefore important to go for reliable, cost effective and everlasting renewable energy source for energy demand arising in future. Solar energy, among other renewable sources of energy, is a promising and freely available energy source for managing long term issues in energy crisis. Solar industry is developing steadily all over the world because of the high demand for energy while major energy source, fossil fuel, is limited and other sources are expensive. It has become a tool to develop economic status of developing countries and to sustain the lives of many underprivileged people as it is now cost effective after a long aggressive researches done to expedite its development. The solar industry would definitely be a best option for future energy demand since it is superior in terms of availability, cost effectiveness, accessibility, capacity and efficiency compared to other renewable energy sources. This paper therefore discusses about the need of solar industry with its fundamental concepts, worlds energy scenario, highlights of researches done to upgrade solar industry, its potential applications and barriers for better solar industry in future in order to resolve energy crisis.

Contents

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1. Introduction

World's energy demand increasing significantly because of population growth and industrial evolution. It is important to note that the population has increased by 2 billion just in one generation and major contribution has been given by developing countries. Preventing an energy crises in one of the most casual issues of the 21st century. Energy demand is therefore increasing fast as to meet the requirements of growing population in the world. Different countries in the world have their own strategies, plans, policies and control measures to establish themselves in the world. As of the population growth and development initiatives, resources available in the world are getting depleted [1]. Considering energy sources is therefore very important as they play a key role in satisfying the need of the world and living population. Accessible energy is not sufficient to people, because of several reasons such as developmental profile of a country, economic status of people and nature of technological advancements of the country. Ecosystem is polluted heavily because of the emission of various gases generated from burning of fossil fuel which are readily available and commonly used for satisfying energy demand of the world [2]. Developing countries are now put into pressure to search for the sources of energy as their population growth is high and they are seeking for economic development to become economically viable [3]. As economic development takes place, energy demand also increases since it is proportional to economic growth. Though many techniques are proposed for increasing energy generation capacity, many people are still living in non-electrified areas of developing countries. Introducing non renewable energy sources would not definitely meet energy demand since they are exhaustible and limited source of energy [4]. All the countries should be in a position to use the resources to recover energy for setting up an environment conducive for human survival for long time. However, it is not practiced properly at the moment to carry out such task since many countries relay on exhaustible energy sources than renewable energy sources. It is the known fact that many controversial issues, which lead to heavy disaster, are going on among countries because dominant parties tend to access the places which are abundant in fossil fuel reserves. Further, continuous use of non-renewable energy sources may lead to climate change, which may in turn end up with heavy natural disasters damaging ecosystems of the planet [5].

It is therefore vital to go for eco-friendly energy sources for the betterment of the future world [6]. Considering renewable energy sources such as solar energy, wind energy, hydropower and geothermal, is critically important in this sense as they are eco-friendly [7]. However, solar energy could be a best option for the future world because of several reasons: First, solar energy is the most abundant energy source of renewable energy and sun emits it at the rate of 3.8×10^{23} kW,out of which approximately 1.8×10^{14} kW is intercepted by the earth [8]. Solar energy reaches the earth in various forms like heat and light. As this energy travels, majority of its portion is lost by scattering, reflection and absorption by clouds. Studies revealed that global energy demand can be fulfilled by using solar energy satisfactorily as it is abundant in nature and freely available source of energy with no cost [9]. Second, it is a promising source of energy in the world because it is not exhaustible, giving solid and increasing output efficiencies than other sources of energy [10]. Solar radiation distribution and its intensity are two key factors which determine efficiency of solar PV industry. Such two parameters are highly variable over the countries. It has clearly been indicated in Fig. 1. Asian countries have highest potential to receive solar radiation compared to other temperate countries as sunshine duration in such countries is high in an year. It is important to note that much of solar radiation is not used and basically wasted [11]. In many countries, particularly developing countries, solar radiation is intrinsic in quantity which makes beneficial utility [12]. For example, Sri Lanka's average solar

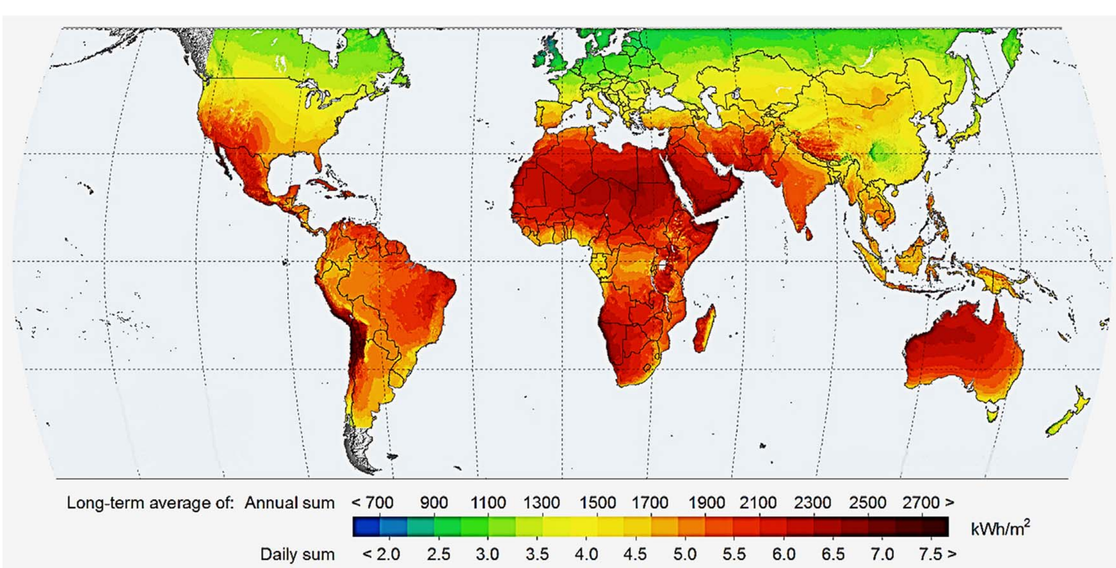

Fig. 1. Maps of global horizontal irradiation (GHI) [162].

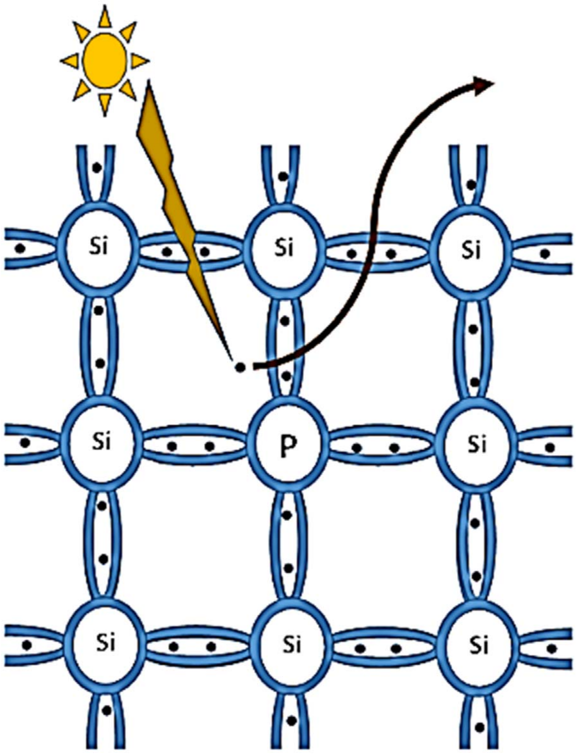

Fig. 2. n-Type silicon free electron [163].

radiation of about 15–20 MJ/m^2/day (4.2 to 5.6 kWh/m^2/day) [13] Fig. 2).

Third, utilization and tracking of solar energy do not have any harmful impact on ecosystem in which natural balance is kept consistent for the betterment of living organisms. Exploitation of fossil fuel leads to ecosystems damage which in-turn damages natural balance [14]. Forth, solar system can effectively be used for village system, industrial operations and homes, since it is easily affordable and applicable. In addition, world is now in a curry to search for solar energy because of rising independence of global population on fossil fuel for energy recovery in order to perform various activities. Use of this technology in a proper way would be a best option for future world to avoid unwanted consequences arising from energy crisis. Many researches are now under taken in order to increase efficiency of solar industry for making the future world productive in terms of energy utilization [15]. It has been indicated that such reserves will be running out in 2300 because of increasing energy demand. Its use however has already created significant CO_2 emission with an increasing trend from 1980 to 2010 as of increased energy demand, it has been indicated in Fig. 7. As indicated in Fig. 8, fuel energy are getting develop dramatically. Therefore, there is a need for renewable energy source to meet increasing demand. Solar power has got prominent mark of development. As of its promising nature to recovery of energy. It has been reported that solar PV and concentrating solar panels, and solar heaters have got highest annual growth rate in 2013 compared to other renewable energy sources as indicated in Fig. 9. Among the solar technologies solar PV got highest growth rate in 2013. Ever recorded since vast development took place in solar cell manufacturing.

Therefore, this paper trends to bring overall fundamental view of solar energy for future world with logical justification. Photovoltaic technology, world's energy scenario, remarkable research highlights of solar PV industry, application of solar energy and barriers to such industry have been discussed systematically. Readers of this paper can simply develop clear picture on solar industry and its importance for future world to be energy wise sustainable with little emissions.

2. Fundamentals of photovoltaic technology

This is a technology used to convert sunlight into electricity directly without any interface for conversion. Therefore, these devices are very simple in design and for efficient handling [16]. In addition, they have the ability to give larger outputs from smaller inputs. Hence, they are used in various applications worldwide. However, its system is still to be improved for better outputs. Photovoltaic devices commonly use semiconductor material to induce electricity, in which silicon is commonly used. The principle of this device is to activate electrons by giving additional energy. This device works on the principle that the electrons are activated from lower energy state to higher energy state as of the energy addition from sunlight. This activation will in turn create number of holes and free electrons in the semi-conductor thus giving electricity [17].

Monocrystalline silicon, polycrystalline silicon, microcrystalline silicon, copper indium diselenide and cadmium telluride are commonly used as semiconductors in photovoltaic systems. Selection of these materials is influenced by number of factors [18]. PV system consists of many components like cells, module and arrays for generating power. In addition, various means of regulating and controlling structures, electronic devices, electrical connections and mechanical devices are used for better operational efficiency. PV systems are rated in peak Kilowatts (kWp) which is an amount of electrical power delivered by a PV system when the sun is directly overhead in a clear day [19]. Number of researches have been carried out in the PV devices to increase their efficiency since long ages ago and it is important to note that it is now said to be a fast growing industry which doubles its production every two years with an average increase of 48% since 2002 [20].

In addition to PV technology, concentrating solar thermal power (CSP) and concentrating photovoltaic technology (CVT) are used to convert solar energy into electricity [21]. Typical representation of CSP has been indicated in Fig. 3. However, current generated by photovoltaic technology is fed into grid systems for better efficiency. Roughly 90% of current generating capacity from photovoltaic consists of grid field electrical systems. Grid field insulation is either ground mounted or built on the roof of the building to increase the efficiency of light capacity by PV system. PV system has to be labeled properly to indicate their capacity and durability. Usually, their capacity ranges from 10–60 MW [22]. Their durability varies according to the maintenance condition and loading. A well-developed PV panel can operate satisfactorily for up to 10 years at 90% capacity and 25 years at 80% capacity [23]. Its efficiency is not consistent as it is influenced by many

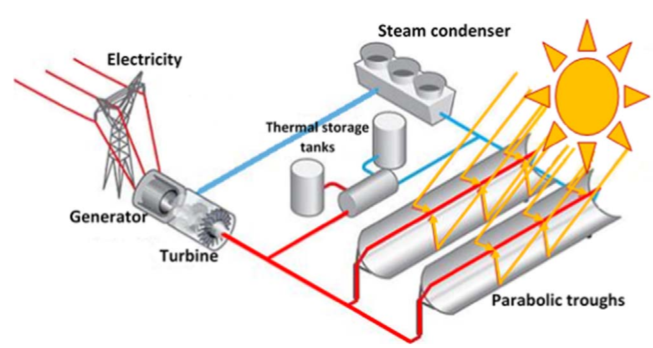

Fig. 3. Concentrating solar thermal power [164].

environmental factors, particularly by sunlight intensity. Therefore, many research sub roots have been investigated to obtain consistent energy supply with no failure.

2.1. Techniques for increasing the efficiency of PV panels

PV systems are sometimes inefficient to capture all available energy because of fluctuating solar flux. Solar tracking is the concept commonly used to increase the capture of available solar energy [24]. Solar tracking can be implemented by using one axis and two axis sun tracking systems. Tracker is a device that keeps PV photo thermal panels in an optimum position perpendicular to solar radiation during daylight hours; increases collected energy [25]. Trackers need not point directly at sun to be effective. If aim is off by 10°, the output is still 98.5% of that at full tracking maximum. Abdullah et al. designed and constructed a two-axes, open loop PLC controlled sun tracking system. They concluded that the use of two-axes tracking surfaces results in an increase in total daily collection of about 41.34% as compared to that of a fixed one [26]. Solar concentration is combined with solar trackers to grid PV panels according to the motion of solar to receive considerable sun's energy than fixed PV panels. Parabolic trough solar thermal systems belong to CSP system, which is commonly available. This system has parabolic, trough shaped mirrors to focus sunlight on tubes which are thermally efficient and set to receive concentrated sunlight. These tubes contain a heat transfer fluid which it heated to 734°F and pumped through series of heat exchanges to generate super-heated steam to power turbine generators to produce electricity [23].

In contrast to concentrating technology, solar collectors, like flat plate and evacuated tube, have been developed for heating and cooling purposes in a non-concentrated manner [27]. This technique has become popular within short time because of its efficiency and cost effectiveness [28]. It can be used in areas where weather conditions are poor and solar intensity is low [29]. This system has three mechanisms such as light absorption, transforming and storage. Copper tubes with insulation are used to absorb solar energy, where water or air is circulated and heated up before returning to storage system. An efficient modification of this system is evacuated tube collector where heat pipes are vacuum shield and 20–45% more efficient than flat plate collectors [30].

Hybrid power systems are sometimes used in areas where PV panels do struggle to generate consistent electricity for consumption. PV systems are combined with other forms of electricity generation, usually a diesel powered generator or even hydro turbine or wind turbine for the reduction of fossil fuel use and consistent electricity supply [19].

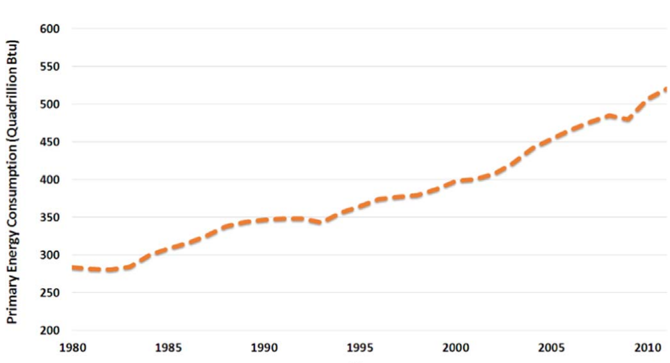

Fig. 4. Total primary energy consumption (Quadrillion Btu) [31].

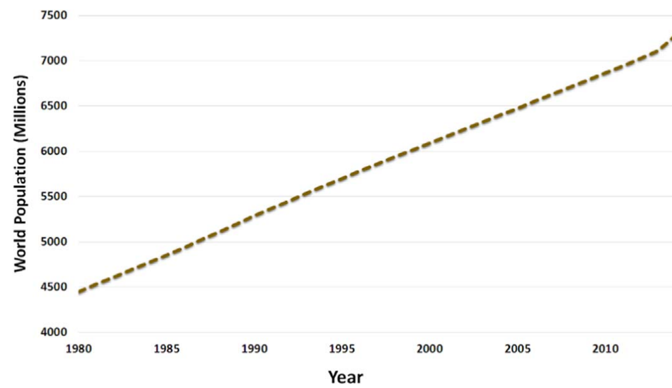

Fig. 5. World population status [32].

3. World's energy scenario, driving forces and developmental trends

World energy demand is significantly increasing. Fig. 4 shows the total energy consumption in Quadrillion Btu worldwide around 520 Quadrillion Btu has been consumed by the year 2011 [31]. The main reason for this is population growth as indicated in Fig. 5 explains around 7282.46 million people are living in the 2014 [32]. Many sources are used to meet such energy demand worldwide. Fig. 6 clearly explains various sources used for generating electricity for meeting world electricity demands. However, around 77.9% of electricity has been generated by fossil fuel and nuclear sources which are expensive and causing environmental pollution particularly through CO_2 generation, and around 0.7% has been met by solar PV [33]. Therefore, there is a huge gap for the development of PV industry to use freely available solar energy for better future. World is getting polluted and it causes damage to the living things. Fig. 7 shows that total CO_2 emissions from the consumption of energy. Around 32723 million metric tons of CO_2 has been generated in the year 2012 [31]. This generation is very heavy and leading to several environmental issues such as climate change and global warming which lead to ice melting and sea level rise. Because of environmental pollution and exhaustion of fossil fuel resources, world has to stimulate the growth of renewable energy sources for better production. Fig. 8 shows the world fossil fuel energy status. It is clear from the Fig. 8 that the energy sources will no more be available after the year 2300 [34]. Hence, many steps are now being taken to increase the use of renewable sources. Fig. 9 shows the annual average growth rate of renewable energy capacity worldwide [33]. Significant increase, around 39%, has been recorded for solar PV in the year 2013, which clearly shows its promising trends towards fulfilling world's energy need. Photovoltaic technology is developing very fast to generate more electricity for satisfying needs of people. Fig. 10 shows trends in solar electricity net generation. Significant increase has been taken place after the year 2007, as of the incorporation of new technologies such as traction, focusing and evacuated tube collectors [31].

In addition, solar thermal industry is also growing significantly. Various collectors are used to capture sunlight to generate heat with minimum loss. Fig. 11 shows the global capacity of solar water heating collectors worldwide. Around 326 GW – thermal energy has been produced by solar collectors in the year 2013 [33]. The largest installation of solar heating system occurred in China and Europe [35,36]. Brazil, by 2015, also plans to install roughly 1000 MW of solar heating system to reduce the use of fossil fuel sources for energy recovery [35]. Solar cell manufacturing was a problem due to its high cost in the past. Many researchers have been carried out to reduce such manufacturing cost for the development of better PV systems. Fig. 12 shows the price history

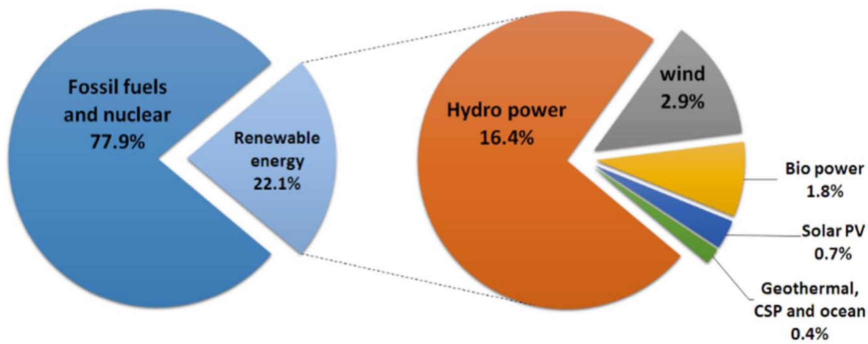

Fig. 6. Global electricity production, 2013 [33].

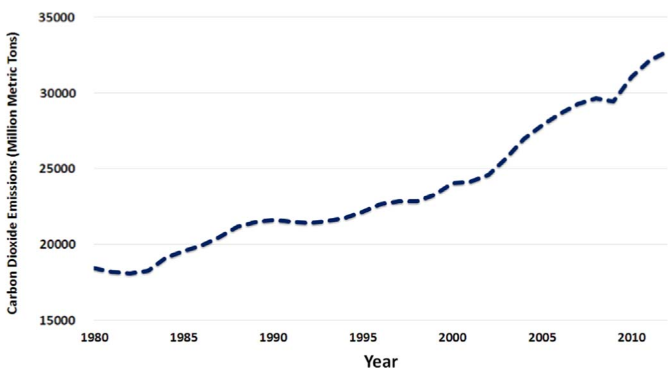

Fig. 7. Total carbon dioxide emissions from the consumption of energy (Million Metric Tons) [31].

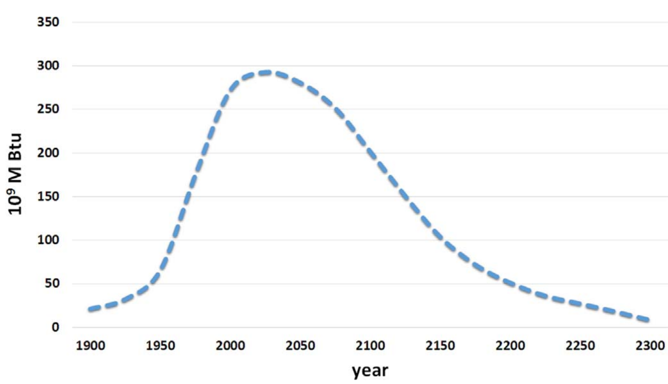

Fig. 8. World fossil fuel energy [34].

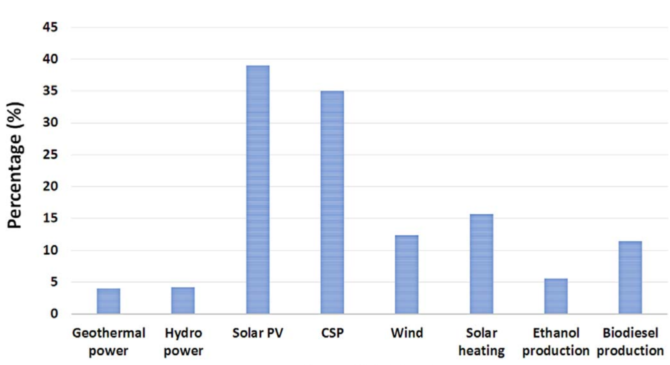

Fig. 9. Annual growth rate of renewable energy capacity in 2013 [33].

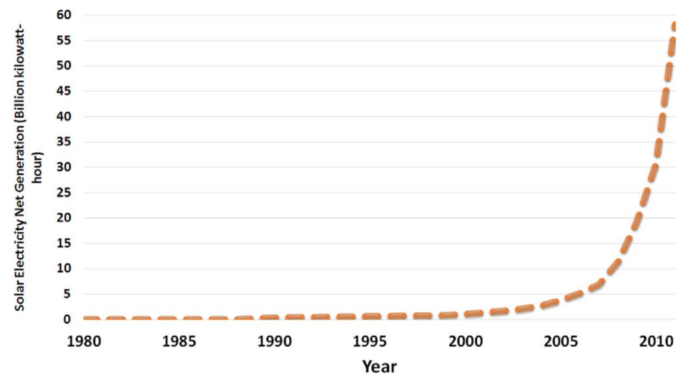

Fig. 10. Solar electricity net generation (Billion Kilowatt-Hour) [31].

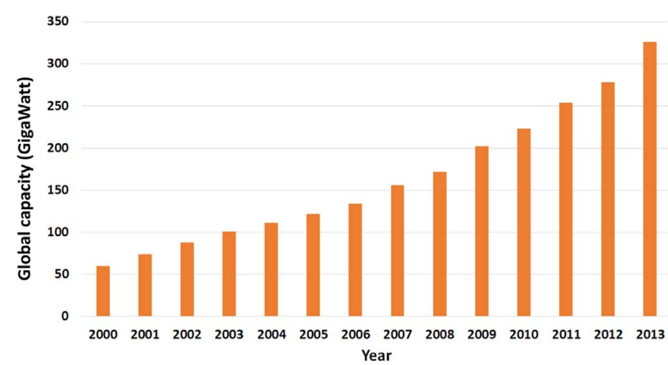

Fig. 11. Solar water heating collectors global capacity [33].

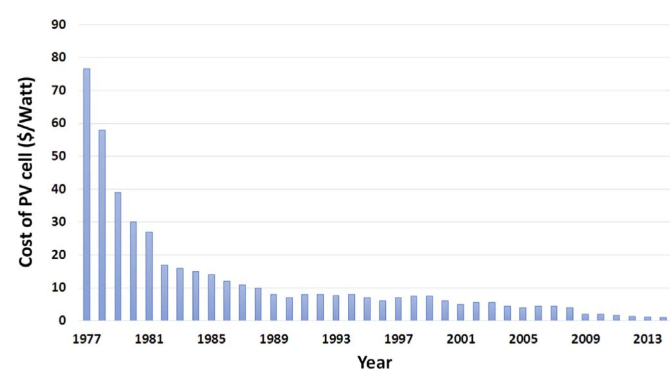

Fig. 12. Price history of silicon PV cell in $/watt [37].

of silicon PV cells in $ per watt. Silicon technology is popular in solar cell design because of its suitability and efficiency. The cost for such manufacturing has been reduced from $76.67, in year 1977, to $0.36, in year 2014, because of the incorporation of novel techniques in PV industry [37].

Many countries use renewable power to save their money used for power generation. The countries such as China, United States, Germany, Spain, Italy and India are the leading countries using

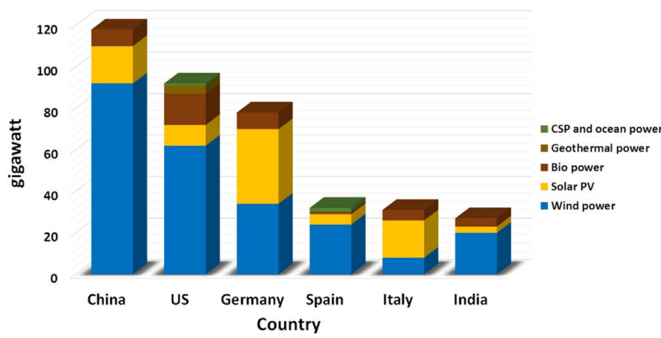

Fig. 13. Renewable power capacities in world [33].

renewable energy for power generation. Fig. 13 explains the renewable power capacity of such countries in the year 2013. Germany, among others, is the leading country using solar PV for power generation [33]. However, India one of the Asian countries, is also in the list because of its developmental trends towards solar PV for sustainable future [38]. Other developing countries should make all possible steps to upgrade solar PV technology to develop their country since solar radiation is freely available for them at high intensities compared to developed countries [39].

4. Highlights of research works done to upgrade solar industry

4.1. Solar power generation

A plant for power generation from photovoltaic technology has multiple components like solar cells arrays and modules and means of controlling or regulating systems for both electrical and mechanical connections. This system is designed in such a way that could provide higher conversion efficiencies. A grid connected system in many occasions is used to supply power in to public electricity grid; hence, this system does provide a mean of decentralized electricity generation. Following brief notes express researches done to improve solar power generation for sustainable energy world.

Barton and Infield described novel method of modeling an energy structure used to match the power output from a wind turbine and a solar PV array to a varying electrical load and validated the method against time-stepping. It showed good agreement over a wide range of store power ratings, store efficiencies, wind turbine capacities and solar PV capacities [40]. Katti and Khedkar investigated hybrid power generation plant, integrated by wind turbine and PV panels, systematically to be used at the remote areas where electricity is highly demanded. They investigated further wind-alone and solar-alone in isolation and it was compared with hybrid power generation panel [41]. Deshmukh and Deshmukh proposed methodologies to model hybrid renewable energy system components design and their evaluation. They also showed that hybrid PV/wind energy systems are becoming popular, because of their ability to provide undisturbed power generation. It is now being incorporated in various power networks for better improvement [42].

Rehman et al. investigated distribution of solar radiation and sunshine duration over Saudi Arabia, using monthly average daily global solar radiation and sun shine duration data. In addition, they further scientifically analyzed 5 MW installed capacity photovoltaic based grid connected power plant for electricity generation in terms of renewable energy production and economic evaluation [43]. Al-Hasan et al. did an experiment in Kuwait to optimize electrical load pattern using grid connected PV systems. They found that, during performance evaluation, peak load matches maximum incident solar radiation and hence use of photovoltaic station in Kuwait could be a best option to minimize the electrical load demand and peak load can be reduced significantly with grid connected PV systems [44].

Alazraki and Haselip studied the impact of PV systems installed by an energy project in homes, schools and public buildings over last six years. They showed that this attempt has given an opportunity for rural communities to receive electricity by replacing traditional energy sources [45]. Zhou et al. worked on solar chimney power plant to make economic analysis of its power generation by using cash flows during the whole service period of 100 MW power plant [46]. Muneer et al. studied long term prospects of large scale PV generation in arid and semi-arid locations around the world and its transmission using hydrogen as the energy vector [47]. Cunow and Giesler investigated advance large MW PV plant technology at the new Munich Trade Fair Center, in terms of system technology, the components employed for operation, control and cost aspects [48]. They compared renewable generators with non-renewable generators by determining their life cycle cost using net present value analysis. They showed that life cycle cost of PV energy is lower than the cost of energy from generators driven by either petrol or diesel and thus is economically feasible in such areas [49].

Zervas et al. studied photovoltaic array, electrolyzer, and metal hydride tanks and proton exchange membrane cells of hybrid power generation plant. A proton exchange membrane cells can efficiently store solar energy by transforming it to hydrogen which is the source of fuel supply to fuel cell [50]. Nelson et al. worked on sizing and economic evaluation of a hybrid wind/PV or fuel cell power generation system. They compared the cost of such system with wind/PV/battery system for a typical home in US Pacific Northwest. They also clearly pointed out that, after analyzing current cost figures as well as break even line distance comparison, traditional wind/PV/battery system is economically viable over wind/PV/fuel cell/electrolyzer system [51]. El-Shatter et al. worked on an energy system to deliver energy at optimum efficiency using Fuzzy logic control to have maximum power tracking of PV and wind energies employed there. They developed such system in a way such that PV,wind and fuel cells combined together in a systematic way to deliver the maximum power to a fixed direct current (DC) voltage bus [52].

Shaahid and Elhadidy made an attempt to assess the techno-economic feasibility of hybrid PV-diesel-battery system by analyzing long term solar radiation data of Dhahran. It was to meet the load of a residential building and they found that, increase in PV capacity decreases operational hours of diesel generators and it is further reduced by inclusion of battery storage [53]. Helal et al. investigated economic feasibility of diesel assisted PV-reverse osmosis (RO) plant, solar driven PV reverse osmosis plant and fully diesel driven reverse osmosis plant and performed detail cost analysis of such system in isolation to access the cost effectiveness of each system [54]. Schmid and Hoffmann showed that lowest energy cost could be made for the energy obtained from diesel generators connected to PV systems with battery storage by turning off the generators during day time [55]. Al Harbi et al. conducted an experiment in Saudi Arabia to evaluate hybrid system of photovoltaic/thermal (PV/T) using two different shaped materials, sheet and tube as absorber collector. They expected to use this system for the production of both electricity and hot water. They however concluded that this system is not applicable in such region because of high ambient temperature in summer season [56]. Muneer et al. explained solar PV electricity as the solution of future energy challenges to meet energy demand in the year 2025 in 6 major cities in India [57]. Feltrin et al. analyzed several photovoltaic technologies ranging from silicon to thin film, multijunction and solar concentrator system for development of existing solar cells [58].

Bitterlin made an attempt to explore the current practicalities of the combination of wind and PV power generation and an energy storage system power generation solution for cellular phone base stations [59]. Prasad et al. worked on optimization of wind, photovoltaic system with battery backup for better efficiency and they proved that hybrid power generation systems could be incorporated successfully for improving generation capacity [60]. El-Shatter et al. experimentally designed a hybrid photovoltaic fuel cell generation system with incorporation of electrolyzer for hydrogen generation. They further used Fuzzy regression model for maximum power point tracking to extract maximum available solar power from PV array under variable insulation conditions [61]. Maclay et al. proposed a model of solar hydrogen power residence in both stand-alone and grid paralleled configurations. They used Mat-lab to assess the viability of employing regenerative fuel cell in such system as an energy storage device. Further, they investigated regenerative fuel cell sizing, battery sizing, charging and discharging rates and limitations for upgrading hybrid power generation systems [62]. Jaber et al. developed a computer simulation made of the behaviors of a photovoltaic gas turbine hybrid system for better selection and efficiency [63].

All such researches mention above are to improve the capacity of solar system for satisfying increasing energy demand. Hybrid system is to make power supply consistent and to reduce effect of standalone power stations, utilize fossil fuel resources for energy recovery. Powering industrial activities and home needs could easily be met by PV technology as it has little or no harm to environment compare to other sources. Hence, if this system is associated positively with other renewable sources like hydro power plants and wind turbines, its commercialization is stabilized for reasonable expansion.

4.2. PV/T collectors

PV/T collectors are used to increase the efficiency of energy recovery from sun. PV cells are designed in such a way that produce electricity from solar radiation while thermal collectors do recover heat energy from radiation uncaptured by such cells and waste energy from PV cell. The following is the brief story of researches connected solar in PV/T system in reasonable commercialization.

Huang et al. made a study for performance evaluation of photovoltaic/thermal (PV/T) systems by comparing conventional solar water heater with photovoltaic/thermal systems which is termed as integrated PV/T system. They fabricated such PV/T system using polycrystalline PV module integrated with the thermal collector made up of corrugated polycarbonate panel made of collectors of cupper material. It has been concluded that good thermal efficiency could be obtained from such PV/T collector and further improvements can be made by proper insulation [64]. Staebler et al. conducted an experiment on amorphous-silicon (a-Si) thin film solar cell modules incorporated with hybrid flat plate PV/T module using copper pipes with tube and sheet concept and they recovered a thermal efficiency of 32.5% at the beginning of the experiments with the water output temperature of 30.2 °C and it was around 52°C at the end with 18.6% efficiency [65].

Sandnes and Rekstad made an experimental model for PV/T collector in which a polymer absorber collector is combined with single crystal silicon PV cell to make it as hybrid energy generating system. Polymer square tube of polyphenyl oxide plastic material with black surfaces was used to make the absorber collector. They compared the results with simulation results and showed almost comparable results [66]. Bakker et al. did an experiment on photovoltaic-thermal panels (PV/T),and they proposed that such panels are promising system concept for low energy housing residential areas [67]. Christandonis and Vokas did an experiment to make a simulation of photovoltaic/thermal collectors (PV/T) for domestic heating and cooling in Island of Rhodes and they compared this system with conventional solar collector [68]. Bergene and Løvvik investigated a physical model of hybrid PV system integrated with algorithms for quantitative predictions of performance. This physical model could be used to predict amount of heat drawn out of the system and power output. Further, such hybrid system was comprised of sheet and fin concepts for light absorption [69].

Chow developed an explicit dynamic model of a single glazed flat plate water heating PV collector using a sheet and tube concept and concluded that fin efficiency and bonding quality between collectors and sheet cells bring limitations to the achievable overall efficiency [70]. Boddaert and Caccavelli developed hybrid solar panel using polycrystalline silicon cell and heat exchanger and the roll-bond technology has been developed using aluminum with hallow tube in the middle of it to exchange heat efficiency [71]. Kalogirou and Tripanagnostopoulos simulated the hybrid PV/T solar system made of sheet and tube concept for domestic hot water and electricity production using TRNSYS and they used monocrystalline silicon and polycrystalline silicon to stimulate such system with minimum conduction losses from absorber by transparent cover [72]. Ibrahim et al. made a simulation of PV/T collectors with different, absorber collectors of seven design configurations for comparison. They selected shapes of the absorber collectors are of square, rectangular or round hollow tube and simulation was to analyze the parameters of solar collectors such as solar radiation, ambient temperature and mass flow rate. The stimulation results showed that the best design configuration is spiral flow design with thermal efficiency of 50.12% and cell efficiency of 11.98% [73].

Zondag et al. from Netherlands, did a comparative study to compare concepts of sheet tube, channel PV/T, free flow and two absorber PV/T collectors and concluded that combined PV collectors provide the efficiency of over 50% [74]. Zondag and Van Helden did a work on various PV/T module types such as with or without cover, air or water type, closed or open loop systems have been studied and the results are presented in system calculations for PV/T roof domestic systems and they concluded that PV/T collectors had better performance than PV/T air collectors and covered closed loop systems performed better than uncovered closed loop systems [75]. Tripanagnostopoulos et al. did a comparative experiment on hybrid PV/T system consists of PV modules with thermal collectors and they compared commercial polycrystalline silicon to amorphous silicon PV modules. In addition, this experiment was planned to compare parameters such as PV and water, PV and air, PV water with glazing and PV air with glazing. Results of experiments showed that polycrystalline silicon PV module produced higher electrical efficiency compared to amorphous silicon (a-Si) PV module and electrical efficiency of PV/water is higher by 13.3% than other systems [76].

Tonui and Tripanagnostopoulos did an experiment to develop combined water and air type PV/T collectors to produce hot air and hot water simultaneously with a specified design configurations and they investigated the effect of the channel depth, channel length and mass flow rate on electrical and thermal efficiencies of both water and air [77]. Assoa et al. investigated a simplified steady state two-dimensional mathematical model of bi-fluid PV/T (water and air) collector with metal absorber with proper simulation for comparison [78]. Fraisse et al. studied energy performance of water hybrid PV/T collectors applied to combine systems which are integrated by PV modules with thermal flow to supply hot water to a house [79]. Chow et al. conducted an experiment in

China on PV/T collector system for checking its suitability for domestic application and they used an aluminum–alloy flat box with square and rectangular tube channel in this experiment. Results showed that high efficiency on combined system achieved with primary energy saving for daily exposure approaches 65% at zero reduced temperature operation [80]. He et al. conducted an experiment on an aluminum-alloy flat box with square and rectangular shape channel together with polycrystalline silicon cells with water as a coolant and they exhibited that thermal efficiency reached around 40% when the initial temperature in the system is same as the daily mean ambient temperature [81].

Kumar and Rosen investigated performance of photovoltaic solar air heater with double pass configuration, and vertical fins in the lower channel under steady state conditions [82]. Othman et al. designed single pass PV/T collector with V-groove with air as a heat transfer medium to transfer heat out and they concluded that adding V-groove has improved the systems efficiency by 30% compared to other PV/T collectors [83]. Jin et al. did an experiment on single pass PV/T with rectangle tunnel absorber to identify suitable air flow for cooling the PV panel and they concluded that the hybrid PV/T with such design as heat absorber shows higher performance compared to conventional system [84]. Sopian et al. developed and investigated double pass PV/T solar air collector for drying applications, and they suggested that the performance of solar collector with fins can be further improved by fixing parabolic concentrators [85].

Based on above discussion, it can be summarized that many researchers worked differently in order to make this industry commercialized to have green energy. Efficiency of PV/T is high compared to normal water heating systems. Further, use of PV module and insulation can further improve its design configuration. Hybrid systems can positively be incorporated to make energy supply system consistent the time for having no interruption in day To day activities of domestic sectors. Different collector configurations and module arrangements have also been investigated for reasonable output. It has been proven that 50 percent efficiency is obtainable in combined PV collectors. It is indeed a remarkable achievement in PV/T sector.

4.3. Solar heaters

Solar energy is a freely available intermittent source of energy which is highly dependent on time. However, Conversion of solar energy into thermal energy is the easiest and widely accepted method. Therefore, the recent researches focused on the phase change materials based air heating systems, as it has high energy storage density compared to sensible heat storage. This part highlights researches conducted in this sector to increase its applicability. Fig. 11 indicates global capacity solar heating collectors. Its global capacity has been steady increased and reached its peak in 2013. There is a need for the world to incorporate renewable energy source to meet existing demand. Since definite resources are getting depleted dramatically as discussed previously in this paper. This steady increase is an observable evidence that solar heating system has been popularized. In addition to this, solar electric net generation (Billion Kilowatt-Hour) has also increased significantly with time. Highest generation has been recorded in the year 2010. Sudden steady development was recorded after 2005 because of technological advancement. It has been indicated in Fig. 10.

Mettawee and Assassa fabricated and evaluated a compact phase change maternal solar collectors based on latent heat storage material with specific design configuration [86]. Zhao et al. did an experiment in North China to study a solar heating system for building heating season and hot water supply all year with five different working modes for investigation [87]. Alkilani et al. developed indoor prediction for output air temperature due to the discharge process in a solar air heater integrated with a phase change material units with eight different values of mass flow [88]. Jain and Jain exhibited a analytical model of an inclined multipass solar air heater within built storage and attached with a deep drier to study the effect of change in the tilt angle length and breadth of collector and mass flow rate on temperature of the system [89]. Bhargava and Rizzi made a cost effective solar air heaters with partial flow channel between two glanzing to increase the efficiency with a reduction in the use of insulation material [90]. Wazed et al. designed a solar air heater using locally available a low-cost material at Bangladesh and its performance was assessed in the prospect of a developing country with high energy demand [91]. Choudhury and Garg introduced an air-based solar collectors developed using unique impingement concept to achieve high heat transfer efficiencies from absorber plate to the following air stream to improve overall efficiencies [92].

Choudhury et al. fabricated a bare plate roof air heaters using corrugated aluminum sheet in a farm shed to provide hot air for agricultural use. They reported that its performance is influenced by various design parameters [93]. Bansal and Singh evaluated cylindrical matrix type solar air heater with the effect of single and double glazing and they explained various factors influencing performance of such type [94]. Bansal and Garg did an experiment to evaluate non-porous solar absorber solar air heaters with and without fins and they have reported that air heaters with fins seem to be more efficient than heaters with no fins [95].

Naphon and Kongtragool developed mathematical model to evaluate thermal performance and employed generation of the double pass flat plate solar air heater with longitudinal fins systematically [96]. Ait Hammou and Lacroix developed hybrid thermal energy storage system using phase change material and they stored solar heat during sunny days and released as it is dull [97]. Qi et al. investigated solar pump heating system with seasonal latent heat thermal storage using a mathematical model for the system and simulated operating performances of the system [98]. Kaygusuz made an attempt to investigate performance of solar heating system with a heat pump experimentally and theoretically with an intention of saving more energy used for operation [99].

Benli and Durmuş did an experiment to study the thermal performance of solar air collectors heating system with phase change materials for space heating of a greenhouse [100]. Enibe fabricated and evaluated a single glazed flat plate collector passive solar air heating system with phase change material. Saman et al. studied the thermal performance of a phase change thermal storage unit used in solar roof integrated heating system [101]. Pawar et al. studied similar type of suspended plate solar air heater for crop drying applications systematically with experimental variables [102]. Yeh and Ho evaluated theoretical efficiency of solar air heaters with external recycle and they reported several factors influencing such efficiency [103]. Sreekumar made an economic analysis of a roof integrated solar air heating system for drying fruits and vegetables in an experimental manner [104]. Ozgen et al. made an attempt to evaluate thermal performance of double flow solar air heater made of aluminum cans into the double-pass channel [105]. Mohamad presented a novel type of solar heater with an intention of minimizing heat losses from front cover of collector and to maximize heat extraction from the absorber [106].

Above mentioned researchers are to involve the efficiency of solar heaters. Solar heating system has number of applications as indicated above. However, its operation is to be optimized to a level which acceptable solar heater and must be developed with highly efficient lights absorbing materials properly assembled. Multi-pass system has been incorporated positively in solar heating system to increase conversion efficiency. It is important to point out that 70% thermal conversion efficiency has been noted in a solar air heater made up of broken glass pieces with double glazing. Different configurations of solar heaters with number of material specifications have been investigated to increase efficiency of solar heating system.

4.4. Design improvements and sizing

Optimum sizing and improvement in design are to major considerations and for industrialization of photovoltaic technology. One of the major challenges to such industry is that high cost of manufacturing that does not yield justifiable production efficiency. Hence many researches do intensively work on techniques giving significant improvements in developing structured configuration for solar systems. This part hence summarizes remarkable works done to improve design configurations and sizing.

Koutroulis et al. suggested a methodology for optimum sizing of standalone photovoltaic wind generation systems [107]. Yang et al. made an attempt to develop the hybrid solar wind system optimization sizing model to optimize capacity sizes of different components of hybrid solar wind power generation systems [108]. Conti et al. investigated voltage profile of a low voltage feeder to assess the maximum power that can be fed into multiple load points of such feeder by PV units without any problems [109]. Paatero and Lund investigated the effects of a high level of grid connected PV in middle voltage distribution network using a multipurpose modeling tool for better operation [110]. Li et al. used luminous efficiency approach to determine solar irradiance falling on PV and investigated the operational performance and efficiency of a small PV system installed at the City University of Hong Kong [111]. Huang et al. proposed a PV system design named near- maximum power point operation that can maintain the performance very close to PV system with maximum power point tracking [112]. Wiemken et al. studied the effect of combined power generation by monitoring data obtained from PV panels for possible modification to have improved efficiencies [113]. Keogh et al. developed a new tester, used for measuring solar cells and modules, which is simple, low cost and reducing transient errors [114].

So et al. analyzed and evaluated the performance of a large scale grid connected PV system and monitoring system for better operation of such system [115]. Mahmoud and Ibrik demonstrated the reliability and flexibility of utilizing PV system by presenting test result of PV system for better operation [116]. El-Tamaly and Mohammed explained a Fuzzy logic technique to calculate and assess the reliability of index for each photovoltaic/wind energy system and hybrid electric power configuration under study [117]. Tanrioven presented and explained about a simulation methodology for reliability and cost assessment of energy sources such as wind, solar energy and fuel cells [118].

As indicated above, intensive researches done in photovoltaic hybrid system under distinct conditions gave significant result to make such system suitable for commercial application. Much emphasis has been paid on hybrid system since it makes power supply continues. Further it makes areas having no access to electricity, electrified by photovoltaic hybrid systems. Much consideration is also given to grid connected supply systems since it helps solar power to be solid if production is in excess. Therefore, this is very popular and important for researchers to work on.

4.5. Materials for efficient light absorption

Light absorbing material is required by all solar cells. Such material is present within cell structure to absorb photons and generate free electrons via photovoltaic effect. Which is the basic of the conversion of light to electricity in solar cells. Sun light, on striking a PV cell, imparts enough energy to source electrons to rise their energy level and thus making them free. A built in potential barrier in the cell acts on these electrons to produce a voltage, which in turn generates current. Creation of free electron in n-type silicon cell is indicated in Fig. 2. Sunlight intensity is highly variable in nature however, it significantly influences power generation from PV industry and its consistency. Efficient light absorption is therefore vital to produce as maximum solar power as possible from solar variation available. Various materials used to fabricate solar cells have different tendencies towards light absorption. In general monocrystalline silicon, polycrystalline silicon and amorphous silicon are commonly used in various applications. Those materials has been assembled with some advanced techniques. In order to increase such said light absorption efficiency. This part therefore gives better representation of highlighted research works done to achieve such industrial expectations In terms of light absorption.

Wei et al. explained about white organic light emitting device on exciplex with luminance and luminous efficiency [119]. Mozer and Sariciftci discussed about double cable polymers, region regular polymers and low band gap polymers which are used in technologies to improve photovoltaic performance [120]. Itoh et al. conducted an experiment on electrical output performance of democratic module photovoltaic system which is consisting of amorphous polycrystalline and crystalline silicon based solar cells [121]. Olson et al. developed hybrid poly P3HT/nanostructured ZnO devices by having solution based methods [122]. Aberle made an overall review on most promising thin film C-Si PV technologies and he discussed about SLIVER, hybrid and CSG regarding their applicability to industrial production [123].

Lipiński et al. investigated double porous silicon layers formed by acid chemical etching on the top surface of n+/p multicrystalline silicon solar cells [124]. [125]. Franklin et al. discussed about the novel Si cells made of single crystalline solar cells [126]. Ferekides et al. did a work on cadmium telluride and cadmium sulfide solar cells fabricated using close space simulation [127]. Richards and McIntosh demonstrated, using ray-tracing simulations, that the short wave length response of cadmium sulfide/ cadmium telluride PV module can be improved by the application of a luminescent down shifting layer of the PV module [128]. Braga et al. reviewed the recent trends in chemical and metrological concepts for photovoltaic silicon production and found that production of solar grade silicon is more efficient than conventional siemens [129]. Van der Zwaan and Rabl worked on single crystalline silicon, multicrystalline silicon, amorphous silicon and other thin film technologies economically interns of cost ranges for current PV production of capacity installation and electricity generation [130]. Goetzberger and Hebling briefed the history of photovoltaic materials and tried to explore future trends for light absorption with silicon [131]. Aouida et al. investigated the structural and optical stability of porous silicon layers to be used as light absorbing materials in silicon solar cells technology with UV radiations [132]. Schlemm et al. exhibited some aspects of a magnetic field enhanced linear microwave plasma source and its application for deposition of silicon nitride anti-reflective and passivation layers on photovoltaic cells [133].

Powalla and Dimmler discussed about the cost effectiveness of thin film technology to give very high output and efficiencies [134]. Ito et al. explained about the ways of TiO_2 film fabrication to be used as thin film materials [135]. Liehr and Dieguez-Campo proposed microwave plasma enhanced chemical vapor deposition of thin films [136]. Mainz et al. demonstrated that rapid thermal sulfurization of sputtered Cu/In precauser layers is suitable for industrial production of thin film photovoltaic modules [137]. Nishioka et al. discussed about the temperature dependence of electrical characteristics of InGaP and InGaAs/Ge triple junction solar cells [138]. Woods et al. described the performance, testing and problems of copper indium aluminum diselenide thin films devices [139]. Grätzel proposed the dye sensitized nanocrystalline electrochemical photovoltaic system [140]. McCann et al. exhibited that excellent bulk life times and surface passivations can be maintained with a low pressure chemical vapor deposition on silicon nitride layer deposited wafers [141]. Adamian et al. investigated the possibility of using porous Si layers as an anti-reflection coating in common silicon solar cells [142]. Lund et al. reported on laboratory and field system for investigating nature of Staebler-Wronski effect in amorphous silicon solar cells [143]. Tawada and Yamagishi developed a series of production technologies for stable 8% efficiency direct-supper-straight type modules [144]. Green et al. developed crystalline silicon on glass solar cell technology with lowest possible manufacturing cost for efficient absorption [145].

It is summarized from this part that intensive research has been conducted to developed organic solar cells, polymer technology, efficient porous silicon layer, mono- and polycrystalline silicon layers, solar cells made up of cadmium telluride and cadmium sulfide. In addition, many different configurations have also been made to different lights absorbing techniques as indicated above. It is appreciated that energy invested by researchers to reduce cost of production of solar cells with increasing conversion efficiencies has given remarkable output in meeting in such expectations. It is indeed very useful to have better solar industry in near future as many sub-roots have already been successfully investigated to manufacture highly efficient solar cell for absorbing light. Fig. 12 shows the cost of production in $/watt of PV cell to generate power with time. It was highest in 1977 and lowest in 2013. Significant reduction has been made in its cost of production as of significant research work done. This is now applicable for commercial solar cell production.

A landmark 40.4% efficiency has been measured in outdoor testing by NERL for a 287 cm^2 split spectrum concentrator sub module fabricated by the University of New South Wales (UNSW) using commercial Galn P/Galn As/Ge and Si cells manufactured by spctro lab and sun power respectively. A new record of 36.7% is reported for an 830 cm^2 photovoltaic module. Using a four cell stack [146]. This module was fabricated and measured at Fraunhofer Institute for Solar Energy Systems (FHG-ISE). This is the highest efficiency for any reasonably sized solar energy convertor to date.

5. Applications

There are various applications of solar energy since it is freely available with low damage to environment. Solar energy is now applied for heating of buildings, cooling of buildings, heat generation for industries, food refrigeration, heating of water, distillation, drying, cooking, power generation and other various processes. This part of paper describes the brief story of applications which are now being practiced due to continuous researches carried out with an intention of upgrading solar industry for better future.

5.1. Roof mounted PV-systems for building integration

Building integrated photovoltaic (BIPVs) are now becoming popular to households in areas where no grid is set for electricity supply. Arrays of PV panels are mounted on roof or walls of buildings [147]. Solar energy generated at the same premises can also be fed into the system as surplus energy is produced. This is the cheapest and promising technology for better house hold electricity consumption [148]. Ricardio Ruther et al., investigated the behaviors of grid connected building integrated photovoltaic solar energy conversion in the urban environment of Metropolitan area in Brazilian State capital [149]. Fig. 14 shows a model of building integrated photovoltaic system. This is very useful for areas, where grid electricity such supply is not accessible. This helps to electricity such areas with little or no emission.

5.2. Irrigation for agricultural crops

Solar energy is now used in various parts of the world to irrigate field crops cost effectively and in areas where no electrical grid is available. An electrical motor can be driven by microprocessor controlled solar energy system with storage energy to operate either drip or sprinkler irrigation systems for better water utilization efficiencies. Discharge rate and irrigation interval can be calculated by assessing crop water requirement. According to such requirement, microprocessor can be programmed using to MPLAB IDE for operating pumps at selected discharge based on irrigation interval and irrigation duration [150,151]. This irrigation system is active always as there is no dependency on electrical grid system for electricity. Solar water pumping system is divided into two major groups, solar photovoltaic and solar thermal. Many factors are influencing their performance, especially the influence of solar radiation, source of water, amount of water, duration of using system well characteristics and water storage conditions are of major importance. Fig. 15 demonstrates schematic at automatic solar micro irrigation system. It has major components like solar PV, battery, microprocessor and micro irrigation system. The electric motor driven water pumps can be commanded according to the soil moisture level using microprocessor. This system draws power from solar PV System. This is an effective incorporation of one of solar energy application in agriculture.

5.3. Heating and cooling

Solar water heating and air heating are very popular nowadays for better production. Many researchers are done to improve solar heating and cooling systems. Flat plate and evacuated tube solar heating and cooling systems are now commonly used with an intention of facilitating commercial and residential sectors, water and air heating systems.

Many agricultural producers are stored at very low temperature to avoid unwanted damages to produces and thus to increase their shelf life. Reducing temperature of a store using electricity, according to its cooling load, is expensive and complex. However, incorporation of solar photovoltaic technology would improve this system for better capacities. Solar thermal refrigerators are now becoming popular in agricultural sector, which are divided into sorption refrigerators, and solar thermal mechanical refrigerators with specific configurations. Many researches are being under taken by many researchers in this sector.

5.4. Solar energy for drying

Moisture content present in the agricultural producers leads to microbial spoilage of such items. It is therefore important to remove free water available in such produces with an intention of avoiding activities of spoilage organisms [152]. Many drying systems are available for crop drying. However, artificial dryers are not economically feasible. Many people in remote areas therefore use open solar drying long years ago. Hygienic nature of such system is still in question. Introduction of PV technology in this regard is now promising to design solar driven artificial dryers for better operations.

5.5. Solar energy for green houses

Green house is a structure commonly used in agriculture to grow plants with intensive care for better production. Solar energy is now used prominently to heat green house and therefore such system is labeled as solar green house where solar energy is used for both heating and lighting. The system is well to retain heat during night and cloudy days. This setup will greatly reduce the

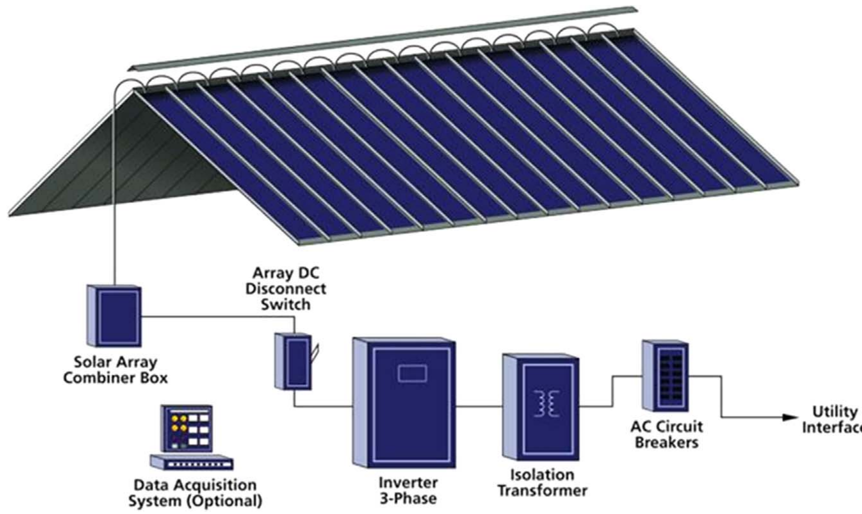

Fig. 14. Building integrated photovoltaic system [165].

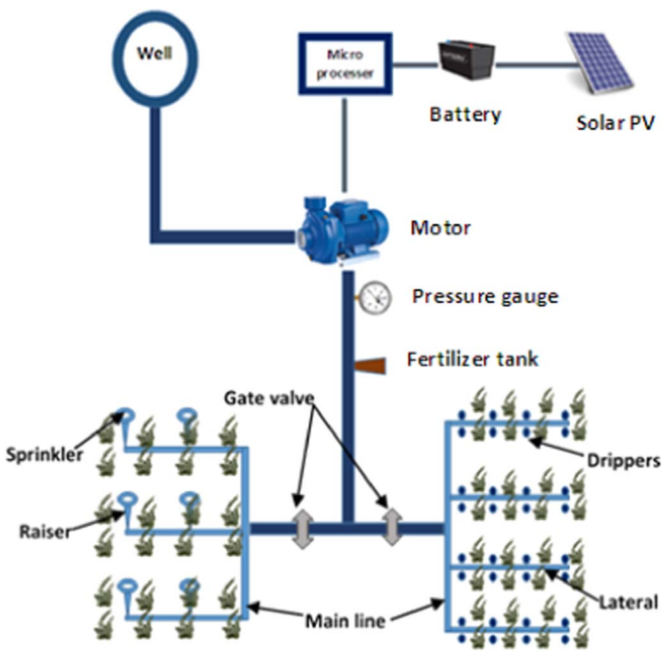

Fig. 15. Automatic solar micro irrigation system [151].

need to use fossil fuel for heating. In some greenhouse configurations, gas or oil heater is used as back up heater to release CO_2 for better plant growth [23].

5.6. Use of solar energy in other applications

PV technology is now used in remote electricity supply and they can power electrical appliance directly or current driven from storage battery. Remote can be set properly for better control. Such application is now widely used in electrical fencing, lighting and water pumping. Solar energy is further useful for charging many electronic devices used in places where plug in power is not available. Many microdevices are integrated with PV technology for charging batteries for smooth functioning and automated systems are being upgraded now.

5.7. Solar energy for wastewater treatment

Huge amount of water is used in various industrial processes and left as effluent with higher biochemical oxygen demand into environment without treatment and this causes severe damage to environment and living things [153]. Treating such strong effluent to permissible level of its parameters is complex, which utilizes higher energy for treatment and it is expensive. Therefore, many industries are unable to afford it. However, incorporation of treatment plant for wastewater is compulsory in all the countries. PV panels play a key role in supplying electricity to operate various components of treatment plant to eliminate environmental pollution and better production [154].

5.8. Solar energy for salinity removal

Fresh water is becoming a scared resource worldwide (2.5% in total water). Only 0.26% fresh water is accessible for living things [155]. However, major fraction is available in sea as salt water. Desalination is done in many countries where fresh water is limited or not accessible. However, that process is very complex and expensive. Reverse osmosis (RO) is commonly used in desalination of salt water and PV technology is well incorporated in such treatment process to manage water demand of world's population [156]. Steps are being taken for better improvement of automated PV panels for supplying electricity to desalination plants.

5.9. Space application

Space craft technology is now very popular in the world. Many researches are conducted in such field to upgrade it. Charging of space craft is the major consideration in the design of space systems. There are various computer models used for simulation. For example, NASCAP-2K can simulate space craft charging for complex geometrics and various orbits [157]. Solar energy is used for the creation of electrostatic discharge which is the most important effect in space craft changing, which can be in the form of surface discharge or in the form of bulk discharge. Photovoltaic power source has been incorporated well in earth-orbiting space crafts at low earth geo synchronous orbits because of the complex technology and environmental concerns for nuclear power sources in space craft technology. NASA is intending to incorporate solar arrays even for deep space emissions.

6. Barriers to solar industry

Though solar industry is developing fast to meet world's energy demand, it has several barriers on its way towards development.

This part of the paper briefly explains such barriers to solar industry.

First, solar photovoltaic technology is complex expensive and requiring advance technology for manufacturing and installation [158]. Second, performance of solar panels is highly influenced by number of environmental factors especially sunshine intensity, cloudiness and wind speed [159]. Third, awareness about the potential benefits of solar industry is still to be lightened to rural people all over the world, since their literacy levels are low. Fourth, potential influence and competition of other markets are also influencing solar energy projects and blocking them from quick development. Fifth, solar cells are usually made of various chemicals which are toxic to environment and disposing them into environment is a challenging task for manufacturers and consumers though solar industries have no direct impact on environmental [160]. Sixth, solar power generation is not consistent all the time. Therefore, integration of other energy sources into this grid network is essential to provide consistent supply. Seventh, some indirect effects are caused to environment by large scale PV industry. For example, birds and insects can be killed as they fly into concentrated beam of sunlight by solar collector for better efficiency [161]. Eighth, heat exchangers in the collectors have some toxic fluids. Managing them after use is also a challenging task. In addition, large amount of water is used to clean and cool turbine generators for better efficiency. This leads to wastage of water with a release of wastewater leading to water pollution. Ninth, energy generated by solar energy systems is direct current (DC) which cannot be applicable for home appliances since they use alternating current (AC) for their operation. However, it needs complex circuits and storage systems for better efficiencies which are difficult to handle.

Even though solar industry has such barriers in its development, many researches are being carried out to eliminate the influence of such barriers to the acceptable limit for better production efficiencies.

7. Conclusion

A review of solar energy for future world comprising of fundamental of photovoltaic technology world's energy scenario, driving forces and development trends, highlight of remarkable research work done in solar power generation, PV/T collectors, solar heaters, design improvements and sizing, materials for efficient light absorption to upgrade solar industry, and its potential applications and barriers to solar industry is presented briefly. This brief representation is very useful for solar system manufacturers, academics, researchers and decision makers to give significant contribution to this sector to make future world energy wise efficient.

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