RESEARCH REVIEW OF SOLAR PHOTOVOLTAIC ELECTRICAL POWER GENERATION

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ABSTRACT

Photovoltaic (PV) is a method of generating electrical power by converting sunlight directly into direct current using semiconductors that exhibit the photovoltaic effect .The photovoltaic power generation employs solar panels composed of a number of solar cells containing a photovoltaic materials. The paper aims to collect the literature pertaining to solar photovoltaic cell, photovoltaic conversion efficiency and analysis of the literature of photovoltaic power generating plant. India lies in the sunny regions of the world. Most parts of India receive 4-7 kWh (kilowatt-hour) of solar radiation per square metre per day with 250-300 sunny days in a year. Since the invention of solar photovoltaic in the year 1839, the research has grown up. Now a day the emphasis is on the efficiency increase in SPV system and simultaneously to reduce the cost and to increase its life. The increasing costs of electricity, reducing fossil fuels, emphasis on solar energy usage etc. are a number of factors favoring the SPV research. There is a difference between the demand and supply of electricity. To fill the gap solar photovoltaic generation is one of the best solutions. The literature review is studied in this paper for research in the area.

Keywords
SPV; photovoltaic cell, Electrical efficiency, Power generation

I. INTRODUCTION

The solar photovoltaic electricity generation is the promising technologies by converting the incident solar radiation into electricity. Solar electricity generation is still not able to compare with energy conversion technology with the fossil fuels even it is comparable if subsidies. The

single junction wafer technology is limited by its relatively low efficiency and increase wafer costs. Multi junction solar cells that can be combined with a solar concentrator to increase solar radiation incident on a reduced solar cell size. Due to growing demand of renewable energy sources, the manufacturing of solar cells and photovoltaic arrays has advanced considerably in recent years. Solar Photovoltaic System or Solar Power System is a system which uses PV modules to convert sunlight into electricity. The electricity generated can be stored or used directly, fed back into grid line or combined with one or more other electricity generators or more renewable energy source. Solar PV systems are very reliable and clean source of electricity that can suit a wide range of applications such as residence, industry, agriculture, livestock, etc. India lies in the sunny regions of the world. Photovoltaic power capacity is measured as maximum power output under standardized test conditions in Wp(watts-peak).The actual output power at a particular point in the time may be different this standardized value depending upon geographical conditions. Solar photovoltaic array capacity factors are typically under 25%. Most parts of India receive 4-7 kWh (kilowatt-hour) of solar radiation per square meter per day with 250-300 sunny days in a year. The purpose of this paper is to provide research background, the literature views of photovoltaic cell, the efficiency of solar photovoltaic electricity conversion and the solar photovoltaic power generation.

II. LITERATURE SURVEY

Solar PhotoVoltaic Cell

A physical phenomenon allowing light-electricity conversion - photovoltaic effect, was discovered in 1839 by the French physicist Alexandre Edmond Becquerel. He discovered that conductance rises with illumination. The photoelectric effect has been known since 1839 but cell efficiency remained around 1% until 1950. Willoughby Smith discovered photovoltaic effect in selenium in 1873. In 1876, with his student R.E. Day, William G. Adams discovered that illuminating a junction between selenium and platinum also has a photovoltaic effect. These two discoveries were a foundation for the first selenium solar cell construction, which was built in 1877. Charles Fritts first described them in detail in 1883. In 1887, Heinrich Hertz discovered that ultraviolet light changes the voltage at which sparks between two metal electrodes would be initiated Einstein's theoretical explanation was practically proved by

Robert Millikan's experiment in 1916. In 1918, a Polish scientist Jan Czochralski discovered a method for monocrystalline silicon production, which enabled monocrystalline solar cells production. . The comprehensive theoretical work about the photovoltaic effect was presented by Albert Einstein, who described the phenomenon in 1904. For his theoretical explanation he was awarded a Nobel Prize in 1921. 1927 A new type of photovoltaic cell was developed using copper and the semiconductor copper oxide. This device also had an efficiency of less than 1%. Both the selenium and copper oxide devices were used in applications such as light meters for photography. In 1932, the photovoltaic effect in cadmium-selenide was observed. Nowadays, CdS belongs among important materials for solar cells production. The first silicon monocrystalline solar cell was constructed in 1941. In the same year Russell Ohl developed the silicon photovoltaic cell. In 1951, the first germanium solar cell have been made Dr. Dan Trivich of Wayne state university has made some theoretical calculations on solar cell efficiency with different materials and on solar spectrum wavelength in 1953.Further the refinement of the silicon photovoltaic cell enabled the researchers to obtained the 6% efficiency in director sunlight in 1954. In 1955, the preparation on satellite energy supply by solar cells began. On 17th March 1958, the first satellite powered by solar cells, Vanguard I, was launched. The system ran continuously for 8 years. Two other satellites, Explorer III and Vanguard II, were launched byAmericans, and Sputnik III by Russians. In 1959, Hoffman Electronics introduced commercially available solar cells. In 1960, Hoffman Electronics introduced yet another solar cell. In 1963, Sharp Corporation developed the first usable photovoltaic module from silicon solar cells. In 1973 a silicon solar cell of US$ 30 per W was developed. In 1976, the first amorphous silicon solar cell was developed by RCA Laboratory. In 1985, researches of University of New South Wales in Australia have constructed a solar cell with more than 20 % efficiency. In 1992, the silicon solar cell of 20% efficiency was patented. In 2000, research and development begin on triple junction compound solar cell to further improve efficiency, reduce weight and increase durability of solar cell for the space applications. In 2000, triple junction compound solar cells gains certification from Japan Aerospace Exploration Agency. In 2009, Researchers at the Frauhofer institute for solar energy system Freiburg Germany achieved a record efficiency of 41.1% for the conversion of sunlight into electricity by a factor of 454 and focused onto a small 5mm2 multi-junction solar cell made out of GaInP/GaInAs on germanium

substrate. Photovoltaic panel based on crystalline silicon modules are encountering competition in the market by panels that employ thin film solar cells which has been rapidly evolving around 31% of global installed power by 2013.

Efficiency

The story of photovoltaic begins in 1839 by the French physicist Alexandre Edmond Becquerel. Experimenting with metal electrodes and electrolyte he discovered that conductance rises with illumination. The photovoltaic effect has been known since 1839, but cell efficiencies remained around 1% until the 1950s when U. S. researchers were essentially given a blank check to develop a means of generating electricity onboard space vehicles Bell Laboratories quickly achieved 11% efficiency, Further refinement of the silicon photovoltaic cell enabled researchers to obtain 6% efficiency in direct sunlight in 1954. In 1951, the first germanium solar cells have been made. Dr. Dan Trivich of Wayne State University has made some theoretical calculation on solar cell efficiency with different materials, and on solar spectrum wavelengths in 1953. In 1954, the RCA Laboratories published a report on CdS photovoltaic effect. The Bell's Laboratories published the results of the solar cells operation with 4.5 % efficiency. In 1954 Bell Laboratories obtained 4% efficiency in a silicon photovoltaic cell. The efficiency was increased to 6 % within a few months. They soon achieved 6% and then 11%. In 1958 PV cells were first used in space on board the Vanguard satellite. In 1957, Hoffman Electronics introduced a solar cell with 8 % efficiency. In 1958, the same company introduced a solar cell with 9 % efficiency. In 1959,Hoffman Electronics introduced commercially available solar cells with 10 % efficiency. Americans launched the satellites Explorer VI with photovoltaic field of 9,600 cells and Explorer VII. In 1960, Hoffman Electronics introduced yet another solar cell with 14 % efficiency. In 1963, Sharp Corporation developed the first usable photovoltaic module from silicon solar cells. In 1985, researches of University of New South Wales in Australia have constructed a solar cell with more than 20 % efficiency In 2003, conversion efficiency 31.5% achieved at the research level for a triple junction compound solar cell. In 2007, conversion efficiency of 40.0% achieved at the research level for a triple junction compound solar cells at 1100 times concentrated sunlight. In 2009, conversion efficiency of 35.8% achieved at the research level for a triple junction compound

solar cells and Boeing Spectro lab (40.7% also using a triple layer design). In the same year 2009, Researchers at the Frauhofer institute for solar energy system Freiburg Germany achieved a record efficiency of 41.1% for the conversion of sunlight into electricity by a factor of 454 and focused onto a small 5mm2 multi-junction solar cell made out of GaInP/GaInAs on germanium substrate. In 2011, conversion efficiency of 36.90% achieved at the research level for a triple junction compound solar cells. The most efficient solar cell so far is a multi-junction concentrator solar cell with an efficiency of 43.5% produced by National Renewable Energy Laboratory in April 2011. In 2012, conversion efficiency of 43.5% achieved at the research level for a concentrated triple junction compound solar cells at 360 times concentrated sunlight.

Power & Energy

Since1950, the U.S. researchers were given advice to develop a mean of generating electricity on board space vehicles, the first sun-powered automobile was demonstrated in Chicago, Illinois on August 31st, 1955. In 1958, the Vanguard satellite employed the first practical photovoltaic generator producing a modest one watt. In the 1960s, the space program continued to demand improved photovoltaic power generation technology. Scientists needed to get as much electrical power as possible from photovoltaic collectors, and cost was of secondary importance. Without this tremendous development effort, photovoltaic power would be of little use today. A United Nation's conference on solar energy application in developing countries took place in 1961. The Defense Studies Institute organized the first photovoltaic conference the same year in Washington. In 1962, the first commercial telecommunications satellite Telstar, developed by Bell Laboratories, was launched. The photovoltaic system peak power for satellite power supply was 14 W. The second photovoltaic conference took place in Washington. The biggest photovoltaic system at the time, the 242 W module field was set up in Japan. In 1964, Americans applied a 470 W photovoltaic field in the Nimbus space project. In 1965, the Japanese scientific programme for Japanese satellite launch commenced. In 1966, an astronomic observatory with 1 kW peak power photovoltaic module field was tracked in the earthly orbit. The first commercial installation of solar power charged storage battery based off grid plant was in 1966 on ogami island in Japan .In 1968, the OVI-13 satellite with two CdS panels was launched. In 1969, Roger little established Spire Corporation, which became and still is an important producer of solar cells production equipment. In 1972, Solar Power Corporation was

established. Company started commercial business in 1973 when a sales office in Braintree, Massachusetts was opened. The French implemented a CdS photovoltaic system enabling educational TV programme broadcast in the province of Niger in 1972. A year after, in 1973, Solarex Corporation was established. At the Delaware University a photovoltaic-thermal hybrid system Solar one, one of the first photovoltaic systems for domestic application, was developed. Besides the photovoltaic system, the system incorporated also a warmth keeper of phase changeable materials. In 1974, the Japanese Sunshine project commenced. A year later, in 1975, Solec International and Solar Technology International were established. The American government encouraged JPL Laboratories research in the field of photovoltaic systems for application on Earth the same year. In 1976, under NASA protection LeRC commenced photovoltaic system installations for application on Earth, which continued until 1985 and later from 1992 until 1995. The systems were meant for refrigerator, telecommunication equipment, medical equipment, lighting and water pumping power supply as well as for other applications. NASA LeRC introduced several demonstration projects. Solec International was established. In 1977, the world production of photovoltaic modules exceeded 500 kW. NASA LeRC commenced implementing photovoltaic systems in six meteorological stations in different locations within USA. NASA LeRC introduced additional trial demonstration projects. Solar Energy Research Institute located in Golden, Colorado launched its operation. In an American Indians reservation NASA LeRC set up a 3.5 kW system - the first system ever to satisfy the demands of the entire village. It was used for water pumping and power supply of 15 households. In 1979, ARCO Solar of Camarillo, California, built the biggest solar cells and photovoltaic systems production plant premises at that time. NASA LeRC built a 1.8 kW water pumping photovoltaic system in Burkina Faso. The system peak power was enlarged to 3.6 kW the same year. In Mt. Laguna, California, a trial 60 kW hybrid diesel-photovoltaic system was built for radar station power supply. Many important events in the field of photovoltaic appeared in 1980. ARCO Solar was the first to produce photovoltaic modules with peak power of over 1 MW per year. A trial photovoltaic system installation was made in the centre of the volcano observatory in Hawaii. A new company BP appeared in the market. On behalf of Ford, Bacon & Davis, Utah company Wasatch Electric built a 105.6 kW system in the State of Utah. The modules integrated in the system were produced by Motorola, ARCO

Solar and Spectro lab. The facility is still operating and is being maintained by a National Park Service contractor and supplies power to the headquarters of Natural Bridges National Monument in Southern Utah. A year later, in 1981, NASA LeRC began to build systems for vaccine refrigerators power supply on 30 locations around the globe (the project was closed in 1984). Solar Challenger, the first plane ever powered by solar energy, took off. A system with peak power of 90.4 kW with modules produced by Solar Power Corporation was built in Square Shopping Center in Lovington, New Mexico. A similar system was built for Beverly High School in Beverly, Massachusetts. A seawater desalination system with 10.8 kW peak power was built in Jeddah, Saudi Arabia the same year. Helios Technology, the oldest European solar cells producer, was established. The world production of photovoltaic modules exceeded 9.3 MW in 1982. Solarex established Solarex Aerospace division the same year. At the Vienna conference NASA LeRC introduced a trial case of terrestrial satellite reception station and public lighting electricity supply. Volkswagen began testing photovoltaic systems placed on vehicle roofs with 160W peak power for vehicle start up. Solarex production premises rooftops in Frederick, Maryland, were equipped with photovoltaic systems with 200 kW peak power. In 1984, a 1 MW photovoltaic power plant began to operate in Sacramento, California. ARCO Solar introduced the first amorphous modules. NASA LeRC placed 17 photovoltaic systems to satisfy the demands of the local schools, lighting, medical equipment and water pumping in Gabon. BP Solar Systems with EGS donations built a 30 kW photovoltaic system connected to public electric grid nearby Southampton, Great Britain. Solarex Corporation closed the equipment supply for photovoltaic system for Georgetown University Intercultural Center demands with total peak power of 337 kW and 4,464 modules. BP Solar bought Monosolar thin film division, Nortek, Inc. In 1985, researches of University of New South Wales in Australia have constructed a solar cell with more than 20 % efficiency. BP built a power plant in Sydney, Australia and shortly after another one nearby Madrid. A photovoltaic system was built in Sulawesi, Indonesia for the purposes of a terrestrial satellite station. In 1986, ARCO Solar introduced a G-4000, the first commercial thin film photovoltaic module. Solarex has received the United Nations tender to supply a 50kW system for UN research projects needs in Pakistan. ARCO Solar increased the thin film system production capacities in Camarillo, California to 7 MW per year. ARCO Solar

opened production in Japan and Germany. BP Solar got a thin film technology patent for a solar cells production in 1989. In 1990, Energy Conversion Devices Inc. (ECD) and Canon Inc. established a joint company United Solar Systems Corporation for solar cells production. Siemens bought ARCO Solar and established Siemens Solar Industries. Solar Energy Research Institute (SERI) renamed to National Renewable Energy Laboratory (NREL). A year later, in 1991, BP Solar Systems renamed to BP Solar International (BPSI), and became an independent unit within British Petroleum concern. In 1992, a photovoltaic system of 0.5 kW was placed in Antarctica for the laboratory, lighting, personal computers and microwave ovens needs. A silicon solar cell with 20 % efficiency was patented. In 1994, the National Renewable Energy Laboratory's (NREL), and important institution in the field of renewable energy sources in USA, launched its web site on the Internet. DOE built several trial systems for the need of agriculture, hospitals, lighting, and water pumping and so on in Brazil. ASE GmbH from Germany purchased Mobil Solar Energy Corporation technology and established ASE Americas, Inc. A year later, in 1995, the first international fond for promotion of photovoltaic system commercialisation was established, which supported projects in India. The World Bank and the Indian Renewable Energy Sources Agency sponsored projects in co-operation with Siemens Solar. In 1996, BP Solar purchased APS production premises in California, and announced a commercial CIS solar cells production. Icar the plane, powered by solar energy, with 3,000 solar cells in total surface of 21 m2 flew over Germany. In 1997, Greece agreed to sponsor the first 5 MW of total planned 50 MW photovoltaic system on Crete. Due to misunderstanding among investors system was not realized. The activities, which will result in 36,400 50 W systems within the next three years, started in Indonesia. In 1999, Solar Cells, Inc. (SCI), True North Partners, and LLC of Phoenix, Arizona merged to First Solar, LLC. Mostly in Germany, some photovoltaic and renewable energy resources companies have shares listed at the stock exchange. Capital mergers in Germany led to large photovoltaic corporation establishments. During 2000 and 2001 production of Japanese producers increased significantly. Sharp and Kyocera each produce modules with peak power equivalent to the annual consumption in Germany, the most demanding European market. Sanyo is close as well. In period 2002 -2003 several large power plants were built in Germany. On April 29th 2003 at that time the world's largest photovoltaic plant was connected to the public grid in

Hemau near Regensburg (Bavaria), Germany. The peak power of the "Solar park Hemau" plant is 4 MW. Due to renewable energy law "EEG" many other large systems up to 5 MWp were built in Germany in year 2004. Some of them are Solar parks Geiseltalsee, Leipzig, B¸rstadt, G`ttelborn and others. India is densely populated and has high solar insolation, an ideal combination for using solar power in India. However, as of October 2009, India is currently ranked number one along with the United States in terms of solar energy production per watt installed. At the end of 2009, cumulative global photovoltaic (PV) installations surpassed 21GW and PV power stations are popular in Germany and Spain. Solar thermal power stations operate in the USA and Spain, and the largest of these is the354 megawatt (MW) SEGS power plant in the Mojave Desert. Solar photovoltaic was growing rapidly to a global capacity of 67.4GW at the end of 2011, representing o.5% of the world electricity demand where as the total power output of the world`s pv capacity run over a calendar year is equal to some 80 billion kwh of electricity.

Future announcements

India is already a leader in wind power generation. In the solar energy sector, some large projects have been proposed, and a 35,000 km^2 area of the Thar Desert has been set aside for solar power projects, sufficient to generate 700 GW to 2,100 GW. In July 2009, India unveiled a US$19 billion plan to produce 20 GW of solar power by 2020. Under the plan, the new addition to India’s electrical grids triples its solar power capacity. the solar park is three times larger than the Chinese Golmud Solar park, which held the record since it was finished in Oct. 2011 with a total capacity of 200MW. 15% of India`s total energy consumption should come from renewable sources of energy. the use of solar-powered equipment and applications would be made compulsory in all government buildings, as well as hospitals and hotels. On November 18, 2009, it was reported that India was ready to launch its National Solar Mission under the National Action Plan on Climate Change, with plans to generate 1,000 MW of power by 2013. With about 300 clear, sunny days in a year, India's theoretical solar power reception, on only its land area, is about 5 Petawatt-hours per year (PWh/yr) (i.e. 5 trillion kWh/yr or about 600 TW). The daily average solar energy incident over India varies from 4 to 7 kWh/m2 with about 1500-2000 sunshine hours per year (depending upon location), which is far more than current total energy consumption. For example, assuming the efficiency

of PV modules were as low as 10%, this would still be a thousand times greater than the domestic electricity demand projected for 2015. Many solar photovoltaic power stations have been built mainly in Europe. There are so many large plants under construction around the world. The country is currently at 6%.The Gujarat Solar park is very small compared to the planned TuNur project, part of the DESERTEC project. That wills be2000 MW concentrated solar power plant and is supposed to be in operation in Tunisia by 2016. The concentrated solar power market will continue to grow, even in the midst of solar PV`s rapid cost reductions. China is projected to have 1GW of concentrated solar thermal power capacity by 2015 and 3GW by 2020

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