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Solar Photovoltaic-Thermal (PV-T) Hybrid Technology: An Indian Perspective

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Abstract—*As per current scenario India is facing huge energy demand and pollution problem due to its increasing population. The energy demand in the country is mostly fulfilled by coal sources and predictions say that these sources will not last beyond 2050-60. So, it is time for India to concentrate on renewable energy technologies, energy efficiency and conservation of energy. India is a developing country and it needs more renewable energy capacity to provide solutions for the energy problems as well as to slow down the increasing rate of pollution. Renewable energy capacity has increased over the years but the energy demand of the country has also increased due to the growth of the population. To fulfill this surging energy demand, solar energy is a good option for providing electricity with zero emission also it can balance the supply-demand gap of energy in country. Solar energy is available in tremendous amount with free access but to convert it in electricity or in other useful form of energy economically is difficult. New solar technologies are emerging like concentrating solar power (CSP) technologies and hybrid technologies to generate electricity with better efficiencies and these technologies can be developed as future option for the production of electricity in India. In this paper energy capacity, different solar technologies, solar energy potential, and photovoltaic-thermal (PV-T) hybrid technologies are discussed with Indian perspective.*

1. INTRODUCTION

Renewable technologies are considered as clean source of energy and proper utilization of this technologies can reduce the pollution all around. Renewable energy technologies are good source of energy to mitigate greenhouse gas emission, for reducing the global warming [1]. Solar energy is a source of energy with zero emission, which can be collected using variety of technologies. Solar energy is the solution for the long-lasting energy issues, which are currently a major problem for the world and countries like India which are still developing. Solar energy can help us to improve energy security in India. It can also help us to alleviate the concern regarding environment problem, and create huge market for renewable energy in country. India needs to increase the energy production rate to cope up with the fast-growing economy and needs of the population which is approximately 1.25 billion. Population in India poses a variety of challenges like lack of awareness in people, lack of political or government support and adoption of renewable energy technologies. Energy production from renewable energy sources is increasing drastically, due to enhancement of pollution in world as well as in India. There is a need to give attention on development of projects, policy framing, and operations in solar energy technologies and their implementations in India.

2. ENERGY STATUS IN INDIA

The country stands fourth in the world in the consumption and third in the world in production of electricity. India has the aggregate capacity around 314178 MW in which 68% is from coal and only 2% is from renewable sources as shown in Fig. 1 [2].

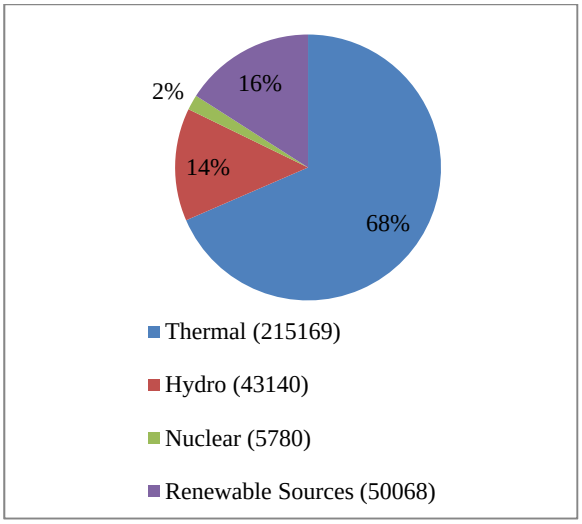

Fig. 1: Total Energy Capacity in India (MW) [2]

India has total power generation from renewable resources is around 50068 MW as of December 31, 2016, which includes wind power of 28700 MW, Solar Power of 9013 MW, bio power of 8021 MW and small hydropower of 4334 MW as shown in Fig. 2 [2].

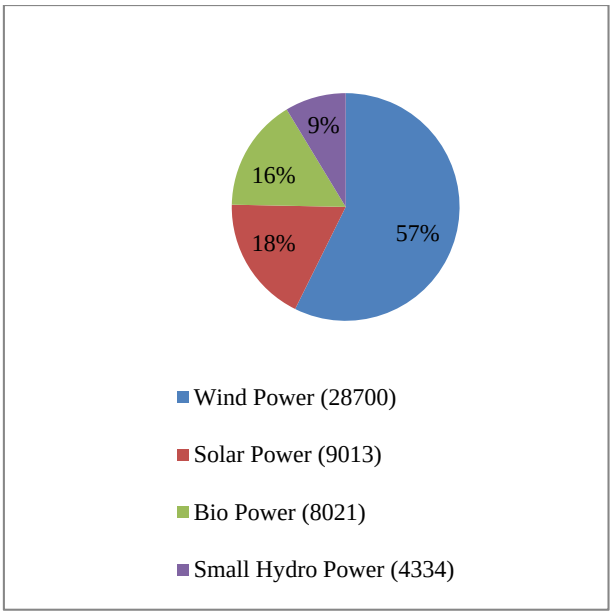

Fig. 2: Renewable Energy Capacity in India (MW) [2]

Jawaharlal Nehru national solar mission (JNNSM) which was launched in 2010 was great achievement in the history of renewable energy in India with 2 MW in 2009 and after that country's grid connected solar power capacity grew to 10MW in 2010, 37MW in 2011, 941MW in 2012, 1645MW in 2013, 2631MW in 2014, 3416MW in 2015 and 9013MW in 2016 but the country has a long way to achieve 100 GW by 2022. The Fig. 3 shows the annual growth of solar energy in India [2].

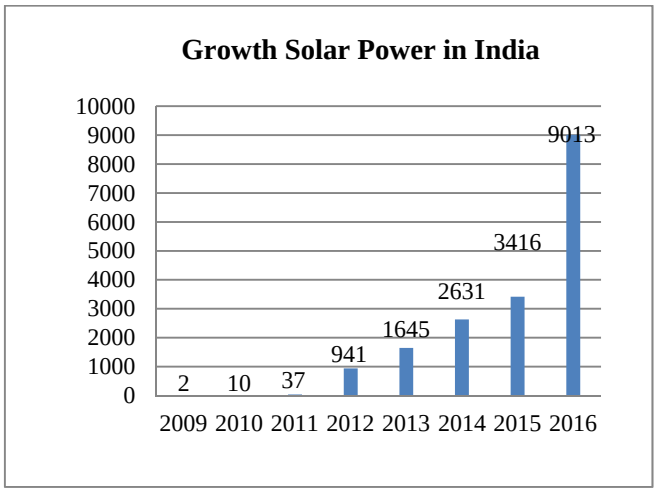

Fig. 3: Growth of Solar Power in India (MW) [2]

India has the potential to produce great solar power but currently solar energy is an underutilized source of energy in India. Proper utilization of solar energy can improve the energy security in India. Although highest annual solar energy is received in Rajasthan and northern Gujarat, but Maharashtra, Madhya Pradesh and Andhra Pradesh, also receives fairly amount of solar energy. A package has been introduced for 'solar reform' in power sector which can lead India to production of 20 GW/Year by 2020 according to the initial phase of the solar mission and in final phase of the solar mission India hopes to produce 100GW solar power [3]. The table 1 shows the renewable energy potential in India.

Table 1: Renewable Energy Potential (MW) in India [2]

SN	States	Wind Power	Small Hydro Power	Bio-Energy	Solar	Total
01	Rajasthan	5050	57	1094	142310	148518
02	Jammu & Kashmir	5685	1431	43	111050	118208
03	Maharashtra	5961	794	3424	64320	74500
04	Gujarat	35071	202	1683	35770	72726
05	Madhya Pradesh	2931	820	1442	61660	66853
06	Andhra Pradesh	14497	978	1001	38440	54916
07	Karnataka	13593	4141	1581	24700	44015
08	Himachal Pradesh	64	2398	144	33840	36446
09	Tamil Nadu	14152	660	1671	17670	34152
10	Orissa	1384	295	268	25780	27728
11	Uttar Pradesh	1260	461	3043	22830	27593
12	Telangana	-	-	-	20410	20410
13	Chhattisgarh	314	1107	260	18270	19951
14	Uttarakhand	534	1708	29	16800	19071
15	Jharkhand	91	209	100	18180	18580
16	North-East	620	2599	276	62300	65774
17	Union-Territory	489	8	140	2050	2677
18	Other	1096	1881	8888	32610	44475
	Total	102772	19749	25090	748990	896602

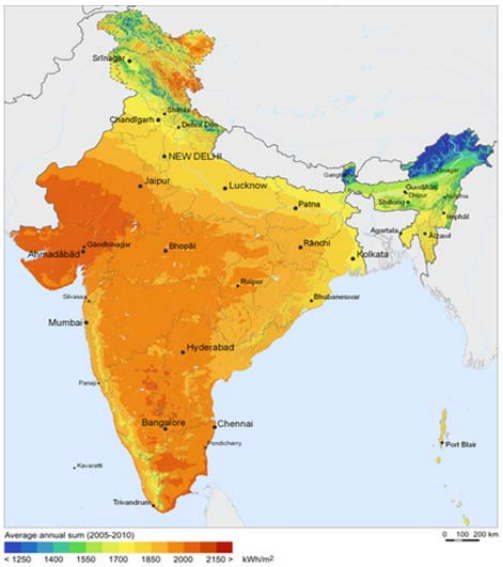

Fig. 4. Average annual sun (kWh/m^2)

3. VARIOUS SOLAR TECHNOLOGIES

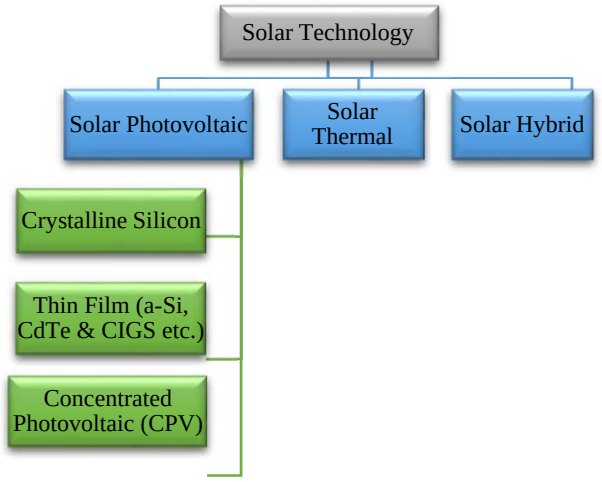

Fig. 5: Various solar technolgies

3.1 Solar Photovoltaic

Photovoltaic is a technology that reliably converts solar radiation into electricity. There are different types of photovoltaic modules depending on power ratings. Every module has a number of solar cells. Solar cells are fabricated by means of semiconductors such as silicon. Photovoltaic cells generate electricity in clean and reliable manner which is the prime concern for today's environment. Variations in temperature of the modules affects the efficiency of solar modules [4]. Due to these variations, photovoltaic technology faces enormous challenges in its power quality performance [5]. Integration of renewable energy technology is a tedious process [6]. Photovoltaic is a kind of technology which converts the sunlight directly into electricity. When bunch of light energy (i.e. solar radiation) strikes the panel (which consist of number of cell) then, the photons of sufficient energy dislodged the electrons from the atoms of cell as a result free electrons move through cell, which is creating and filling the holes in the cell. Due to this process (i.e. electrons and holes movement) it generates electricity. Capacity of sun to supply energy is so huge that it can feed all energy demand of the world. Generally, till now the conversion efficiency of solar energy into useful form of energy (i.e. electrical energy) is in between 15 to 20 percent [7]. Due to high investment cost needed in manufacturing process of the silicon cells prevented them from their widespread use. There are also few drawbacks of silicon cells that it is toxic in nature so, to eliminate these drawbacks a huge research and money is needed. Luckily energy provided by sun is huge, which is ten thousand times more than that the total energy needs, means converting 0.1% of the incident solar energy radiation with 10% efficiency can fulfill global energy needs. Concentrating photovoltaic is a new method for production of electricity by harvesting the sun's energy. To concentrate the solar light at a particular, angle the varieties of solar concentrator (parabolic mirror) are used which are mounted on solar tracker system so that the focal point remains constant while sun changes its position across the sky [8]. Recently the developments of the 2-axis tracking systems are become useful in concentrating photovoltaic [9]. By using this technology electrical output of the photovoltaic module can be improved.

3.2 Solar Thermal

Solar thermal technology is used to generate large amount of green energy (solar energy) which help to mitigate the pollution and consequently give a good living condition for human. Solar thermal energy also help to mitigate the use of fossil fuels which is primarily factor responsible for enhancing the temperature of atmosphere on earth. A solar thermal power plant produces electric power by converting large amount of sunlight energy (photons) into the high temperature heat energy with the help of various mirrors configurations [8]. Solar thermal power plant plants are used to work efficiently over a 20-year period. India can have solar thermal power plants of 5-6 GW capacity by 2020. Large amount of solar thermal power plant output is consumed by various states in North-Eastern part of India [9].

3.3 PV-T Hybrid

A PV-T hybrid is a mixture of photovoltaic and thermal technologies, hybrid technologies can not only produce electricity but can also produce high temperature thermal heat. As we know that demand of electricity is increasing, it is very important to develop such devices which can produce both solar electricity and solar heat which can further be converted into electricity. When sunlight strike at the photovoltaic cells the parts of incident rays of light are used to produce the electric energy and the rest is converted into heat energy. If temperature of the photovoltaic module increases after a certain value, the efficiency of the photovoltaic module start degrading. So, by developing methods to cool the module can improve overall efficiency of PV-T integration. PV-T system has better way to utilize solar energy as they can provide higher overall efficiency than other solar power systems. Poly-crystalline (pc-Si), mono-crystalline (c-Si), thin-film solar cells or multi-junction cells can be used as a photovoltaic material. There are many researches and development work has been carried out in this field and also there are many researches and development is going on PV-T hybrid. Due to the dual characteristics of PV-T hybrid it has huge scope in future. There are few features of the PV-T hybrid systems which are as follows [10]:

- Double purpose: single device used to generate electricity as well as heat output.
- Effectiveness and Flexibility: It is experimentally proved that the effectiveness of PV-T hybrid is always higher than the device which operate on photovoltaic and

thermal technologies independently and hybrid can be used where space is limited.

- Wide applications: The heat energy output produced by PV-T hybrid can be used for various purposes, like heating as well as cooling purposes it depends on area and season where this system is implemented.
- Low cost and practical in nature: PV-T hybrid can easily be combined or integrated with buildings and its cost is also affordable [11].

4. LITERATURE REVIEW

The PV-T hybrid systems were introduced by Kern and Russell in 1978. In their system, the absorbed energy was removed by water/air [3]. Various one dimensional models were developed by Raghuraman in 1981 for the evaluation of electrical and thermal performances of flat plate photovoltaic thermal collectors [12]. The PV-T air collector with glass covers were tested and studies were carried out to evaluate the characteristics of various solar collector with different configurations by Garg and Adhikari in 1997 [13]. Othman et al. studied experimentally and theoretically the PV-T solar air collector in 2005 [14]. PV-T solar air heater was further studied by Othman et al. in 2007. In his PV-T hybrid system c-Si solar cells were attached to one side and fins were attached at the other side of the plate surface. It was found that use of a collector system with fins can improve the total efficiency of the system [15]. Kostic et al. (2010) carried out an experiment in which the influence of reflectance from flat plate solar concentrators on exergy efficiency of PV-T collectors was investigated. Their result showed that total energy generated by PV-T collector increases with the increase of solar radiation's intensity and concentration [16]. Shahsavar & Ameri in 2010 designed a PV-T air collector to perform an experimental study under forced as well as natural convection with glass cover and without glass cover and then they compared the results with a theoretical model [17]. A detailed PV-T model was developed by Sarhaddi et al. in 2010 to estimate the electrical and thermal characteristics of a typical PV-T air collector. Sarhaddi et al. reported that the overall efficiency, thermal efficiency and electrical efficiency of PV-T air collector were about 45%, 10.01% and 17.18%, respectively [18]. A PV-T solar air heater was investigated by Kumar and Rosen in 2011. Their results showed that by extending the fin area temperature of the cell reduces considerably from 82^0C to 66^0C [19]. Siddiqui et al. (2012) & Amrizal et al. (2013) evaluate the thermal output of photovoltaic modules with cooling and without cooling by developing a three-dimensional thermal model [20, 21]. At different climates depending on their types, the photovoltaic modules convert 6% to 22% of incident solar energy into electricity. Most of the solar radiation retrieved by photovoltaic modules is transformed into heat and this excessive generated heat increases the temperature of the surface of the solar cells which decreases electrical conversion efficiency of the cells (Amori and Abd-AlRahim, 2014) [22]. Kim et al. designed an air based PV-T collector in 2014 with c-Si PV modules and analyzed the electrical and thermal performances of the collector. It was also found out that the heated air collected from the PV-T collector had, on average 50^0C higher temperatures than the outdoor air [23]. A research paper on the solar flat plate PV-T technologies was presented by Michael et al. in 2015. In their work, the advantages, efficiencies, limitations, research opportunities and applications related to PV-T technologies were discussed [24]. The optimum values of depth of the channel, air mass flow rate and diameter of distribution duct were investigated by Farshchimonfared et al. in 2015. In their investigation, it was found that the optimum depth of the channel increases the collector area and collector L/W (length/width) ratio increases [25]. To calculate performance parameters of a PV-T hybrid system, a computer simulation program was developed by Ben cheikh and hocine et al. in 2015. In results PV-T collector's thermal efficiency and electrical efficiency was found out to be 16.24% and 11.12% respectively. [26]. In a study carried out by Saeedi et al. in 2015 the optimization of PV-T active solar cell was performed and objective function and optimum value of mass flow rate were obtained [27]. Yazdanpanahi et al. performed an experiment in 2015 on exergy efficiency of a solar PV-T water collector system based on losses of exergy [28]. Hedayatizadeh et al. studied the exergy loss based efficiency optimization and carried out a detailed thermal modeling of the system in 2016 [29].

5. CONCLUSION AND FUTURE SCOPE

In India energy shortage is a big problem, as India is a developing country it needs huge additions in renewable energy capacities especially in solar energy capacities. To meet the surging energy demand PV-T solar hybrid can be used as they efficiently convert incident solar energy into electrical and thermal energy and they can also help us to slow down the increasing rate of pollution.

The literature review shows that PV-T hybrid technology can be enhanced by improvisation in the design, area of the design and development in the field of exergy output of the system. Good research and development facilities and research funds provided by governments and investors have encouraged the evolution of PV-T hybrid applications. By developing solar energy, we can improve energy security in India. it can also help in reduction of the fuel prices. In India, many of the undeveloped states have great potential for solar energy they can develop solar power systems with the help of government to increase solar energy capacities. Solar energy can provide a secure way to generate electricity with zero emission for the industrial development in country.

Also, by removing some hindrance in the field of social aspect such as the lack of information, public awareness, and social acceptance of solar technology, its future scope can be enhanced. The future study aims to reduction of the cost,

lowering the PV cells operating temperature and improvement in the efficiency and exergy output of the PV-T solar hybrid systems so that we can go further on the production and utilisation of these environmental friendly systems.

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