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Review Article

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Solar Photovoltaic System: A Techno-economic Review

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Abstract

The energy of any kind becomes vital to our life, and power production also becomes hazardous for our Eco-system due to its carbon footprint. Therefore, the adoption of renewable energy is the best choice. And of all the renewable energy, solar energy is the best one. Consequently, it is to be adequately exploited to maximize its benefit. The purpose of this study is to bring all kinds of factors into consideration to make possible use. In the present study, a brief tour of the advancement of solar PV (photo-voltaic) technology in chronicle order, efficiency associated with some solar cells, and market brand with their performance are discussed. Also, some critical literature review incorporated with efficiency aspect of a different generation, different PV technology, most usable PV technology like BIPV (Building Integrated Photo-Voltaic), CPV (Concentrated Photo-Voltaic), module temperature technique and economic analysis is addressed and concluded that PCM (phase change material) cooling method is best one among passive cooling methods, first-generation PV technology is still popular, cost of the module should be minimized, recycling of solar waste should emphasize, and government policies must be revived time to time.

Keywords

Photo-voltaic technology, efficiency, Module, Temperature, Solar energy

Introduction

Solar cell technology was introduced during the 1950s and has made shapes for a long time, about 50 years journey [1]. A Brief tour of different solar cells from 1950 to till now is given in figure 1. The constant advancement of solar cells with their efficiency is also shown in table 1. To make the persistence of use of solar technology in our society/community or individual, it is necessary to inspect maximum aspect related to the performance of solar PV technology; few of them here analyses which has more contributed to degrade the use of this technology like its efficiency concern, like excess panel temperature, climatic impact, and most important its cost. Although the technical factors which affect the PV module efficiency are the type of light, i.e., frequency, wavelength, Shockley-Queisser limit of semiconductors used, air-mass ratio, irradiation, temperature, tilt angle, dust accumulation, series and parallel connection of bus bar, size and shape of a ribbon, material, and composition used in solar cell, type of design, way of manufacturing and site to sow [4]. Some factors are beyond control, but most of these can be controlled efficiently, giving lucid results, like panel temperature control. Many attempts have been made for active and passive methods of cooling. The different heat management methods are suggested by various authors like heat spraying system [5, 6], PCM cooling methods, radiative cooling, heat pipe methods, cotton wick type heat exchanger, converging heat channel [7], multi

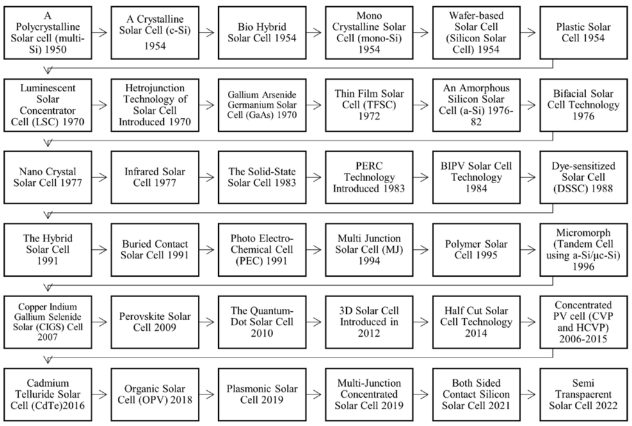

Figure 1: A concise tour of the progress of solar cells and module technology with time [2].

Table 1: Standard efficiency of some solar cells [3].

S. No.	Cell type	Efficiency (%)
1.	CdTe cell	16.7
2.	CIGS cell	19.4
3.	Dye-sensitized	9.2
4.	GaAs cell	28.8
5.	Multijunction 5 junction cell	38.8
6.	Organic polymer	5.15
7.	Perovskite cell	19.7
8.	Silicon Amorphous cell	10.1
9.	Silicon crystalline cell	26.7
10.	Si multi-crystalline	19.3

header microchannel [8], PV/T (Photo-Voltaic Thermal) air collector [9-16]. The second most significant factor is the economic aspect which is not directly connected to its price but also the value of efficiency in the context of the Levelized Cost of Electricity. Simply value of efficiency indicates the module price per square meter area for each efficiency percentage. It is observed that n-type mono-silicon has higher V_{OC} than p-type mono-silicon [17].

Some Previous Work on Solar PV Efficiency and Economics

Vasseur et al. [17]. explored the efficiency aspect of various PV modules viz a transparent monocrystalline silicon, monocrystalline silicon, polycrystalline silicon, amorphous silicon module in the efficient environment rather than standard test condition and efficiency found to be 10.4%, 9.4%, 10.3%, 4.4%, respectively. While in terms of performance ratio, monocrystalline (transparent glass) PV module leads to 85.2% compared to polycrystalline 71.8%. Eldin et al. [18]. studied the efficiency of three different generations of technology of PV modules, First-generation crystalline silicon, Second-generation thin film, and Third-generation PV technology (concentrated PV with cooling and DSSC organic, black silicon). The first-generation PV technology is relatively mature. It is also available from a wide range of manufacturers; its cost is moderately low, but it is necessary for further reduction. Second-generation technology is widely accepted due to its versatility, where efficiency doesn't matter. Third-generation technology is used where high efficiency is required, like commercial use primarily concentrated and with cooling PV technology; however, DSSC offers low efficiency even used in mobile applications. Pandey et al. [19]. explored that the efficiency of PV systems generally lies between 10 to 23%. In the study BIPV, CPV, and PV/T were taken as the most efficient performers for future challenges and feasible solutions. CPV is the most feasible and cost-effective one, and it is recommended by the authors. Allouhi et al. [20]. explore the PV market growth rate is 34% during 2010 - 2020 and study the PV development, material, market trends, engineering perspective, cell efficiency, and cost of the PV system. The 10% of efficiency reduces due to dust accumulation on the module. First-generation PV technology is feasible, while second-generation technology involves toxic material and is acceptable for commercial use. And third generation technology is also commercially used. The efficiency concern increases 26.1%, 22.1%, 22.9%, and 14% for crystalline Si, CdTe, CIGS, and amorphous Si solar cell, respectively. The cost of panels has reduced by 67% from 2000 to 2007. Dwivedi et al. [21]. explored cooling techniques to remove excess heating of panel as active and passive methods like, heat pipe, heat sink, fins, radiative cooling, microchannel, nanofluids built cooling, refrigerant built cooling, thermo-electric cooling, evaporative cooling, PCM-based cooling (conductive PCM), air gap, air based, air channel cooling, water flow, jet impingement, liquid immersion, submerging, spectrum-filter, beam-split, and hybrid cooling. This technique roughly reduces the temperature to 15 °C and increases the power up to 14 to 18%. The author concluded that active cooling methods are the easiest and most effective but sometimes not practical. Among all, PCM is the most effective method of cooling. Fuentes et al. [22]. explored the comparison in the experiment of hybrid PV/T and simple PV systems used in BIPV. However, a combined system gives the remarkable result up to 80% as a combined efficiency commercial PV/T system with BIPV does not take advantage of the cooling system as anticipated, compared to PV alone with BIPV. Udayakumar et al. [23]. studied the value chain of advanced technology's impact on the environment to minimize the carbon footprint. Solar waste is around 2 lakh tons that must be recycled, and different recycling methods are to be established by 2040. Different methodologies are adopted to reduce waste and save the Earth. Kabir et al. [24]. discussed the merits and demerits of solar energy technology. The CO_2 emission generated from solar, natural gas, and coal are estimated as 0.03 - 0.09, 0.27 - 0.91, and 0.64 - 1.63 kg per kilowatt-hour, respectively. The future scope seems to be perovskite solar cell enhancement. Solangi et al. [25]. explored the study of world solar policy. BP Statistical survey of energy 2010 says the cumulative installed capacity of solar energy was approximately 22930 MW in 2009 increase of 47% compared to 2008. All countries' policies are specific to solar energy. Some countries like the USA, Canada, China, France, Germany, Spain, and Australia are more successful in their policies. The policy includes subsidies, tax exemptions, feed-in tariffs, and incentives. The Malaysian government has several policies to enhance the solar energy program, including laws, regulations, economic encouragement, technical research, and sup-

Table 2: PV technology of different brands and its performance.

S. No.	Brand (Established Year and HQ)	PV Technology	Performance
1.	Jinko Solar (Shanghai China 2006)	Half-cell module technology	Less shading losses and less busbar length reduce resistance losses by 3% more power, about 2 °C lower temperature (38.7 °C) than the whole cell (40.1 °C).
		The Bifacial module with the transparent back sheet technology	Up to 20% power gain depending on the Proportion of Incident light and PV system design. 19% white paint, 9% sand, 7% cement and grass, and 5% water.
		Tiling Ribbon	Eliminated cell gap to increase module efficiency significantly. 9 bus bars decrease power losses.
2.	JA Solar (Beijing, China 2005)	54; 60; 72-cell; MBB Half-cell Module (mono PERC)	Efficiency 21.4%, 20.4%, and 20.2%.
3.	Trina Solar (China 1997)	132 cell monocrystalline	Maximum efficiency 21.6%.
4.	Canadian Solar (Guelph Canada 2001)	High power Dual cell PERC Module	Maximum efficiency 21.6%.
		Heterojunction cell module	Maximum efficiency 22.5%.
		Bifacial high power dual cell	30% more energy.
5.	LONGi Solar (Xian China 2000)	PERC cell	Maximum efficiency 21% to 24.06%.
		Bifacial solar module	
		Half-cut solar module	
6.	GCL Solar (China 2003)	Bifacial solar module	Maximum efficiency 21.5% to 22%.
7.	Risen (Kedah, Malesia 1986)	Mono-facial PERC solar module	Maximum efficiency is around 21.1% to 21.7%.
		Bifacial PERC module	
8.	Astronergy (Hangzhou Zhejiang, Chin 2006)	Mono-facial PERC solar module	Maximum efficiency is around 20.9% -21.4%.
		Bifacial PERC module	Maximum efficiency is around 21.4% - 21.6%.
9.	Suntec Solar (Wuxi China 2001)	N-type silicon wafer solar module	Cell efficiency over 24.5% Module coefficient with -0.3%/°C and 30 years warranty.
10.	Hanwha (Korea 1952)	1.4 GW to 5.4 GW with Q cell solar module for heavy supplier	Maximum efficiency is around 22.3%.
11.	Solar City (San Mateo, United States 2006)	Mono Bifacial and Half-cell solar module	Maximum efficiency is around 21 - 22%, with a Temperature coefficient of -0.26%/°C.
12.	REC Solar (Singapore 1996)	Half-cut, Hetero-junction solar module	Maximum efficiency is around 22.1%.
13.	SunPower (California United States 1985)	N-type IBC solar module	Maximum efficiency is around 22.8%.
14.	Panasonic (Osaka Japan 1970)	Half-cut, Hetero-junction solar module	Maximum efficiency is around 22.2%.
15.	Samsung (Seoul, South Korea 1995)	Monocrystalline and Polycrystalline Bifacial	Maximum efficiency is around 21.9%.
16.	Hyundai (Seongnam, kyonggi-do South Korea 1972)	PERC Mono-crystalline silicon solar cells	21.3%, Temperature coefficient: 0.34%/°C.
17.	Sharp (Oska Japan 1976)	Triple-junction solar module InGaP/GaAs/Ge)	Maximum Conversion efficiency is around 29%.
18.	Soligent Solar (California United States 1979)	340 - 400-Watt Mono, PERC half-cell solar module	Maximum efficiency is around 21% ± 1.9%.
19.	Sunnova (Houston United States 2012)	Half-cell, mono PERC solar module	Maximum efficiency is around 20.4% - 21.3%.
20.	CSUN (Jiangning, Jiangsu China 2004)	Half-cell, full cell, and PERC technology	21.6%, 670 Watt with 12 - 25 years of warranty.
21.	First Solar (Arizona United States 1999)	c-Si Thin film Module (CdTe) solar module	Maximum efficiency around 15.3% - 19% temperature coefficient -0.28%/°C-17% lowest.
22.	Grape Solar (Oregon United States 2009)	50, 100, 200, 300, 400, and 600-Watt monocrystalline solar panel	High-efficiency module.
23.	Kyocera Solar Corporation (Kyoto Japan 1996)	36 cell modules of 145 Watt to 275-Watt half-cell solar panel	Maximum efficiency is around 16.4%.

24.	Lumos Solar (China 2006)	Monocrystalline and Bifacial solar panel	Maximum efficiency is around 18.8% with a -3.8%/°C temperature coefficient.
25.	Vikram Solar (Kolkata India 2006)	Residential 315 - 350-Watt Perc Bifacial HC, Glass to Transparent Back sheet, and Mono PERC solar cell of different range Industrial half-cut design	Maximum efficiency is around 20 - 21%. Same efficiency for commercial panel.
26.	Yingli Solar (Baoding China 1998)	Monocrystalline half cut and Bifacial P-Type monocrystalline	Maximum efficiency is around 22 - 23% efficiency.

Table 3: Indian companies deal with solar energy [30].

S. No.	Name of Enterprise	Production (MW)	Type of PV Module
1	HHV SOLAR	40 (mono), 10 (thin film)	Monocrystalline and Thin Films
2	MOSARBAER	185 (mono and poly), 50 (thin film)	Mono, Polycrystalline and Thin Films
3	SOLAR SEMICONDUCTOR	195	Polycrystalline
4	INDOSOLAR	160	Polycrystalline
5	VIKRAM SOLAR	150	Polycrystalline
6	EMMVEE PHOTOVOLTAICS	135	Mono and Polycrystalline
7	TATA SOLAR POWER	125	Mono and Polycrystalline
8	WAAREE	110	Mono and Polycrystalline
9	GOLDI GREEN	100	Mono and Polycrystalline
10	TITAN ENERGY	100	Mono and Polycrystalline
11	ALPEX SOLAR	60	Mono and Polycrystalline
12	EMPIRE PHOTOVOLTAICS	60	Mono and Polycrystalline
13	WEBSOL	60	Monocrystalline
14	LANCO SOLAR	50	Polycrystalline
15	PREMIER SOLAR	50	Mono, Polycrystalline and Thin Films
16	SURANA VENTURES	40	Mono and Polycrystalline
17	TOPSUN	40	Mono and Polycrystalline
18	PHOTON ENERGY SYSTEMS	30	Mono and Polycrystalline
19	NOVERGY SOLAR	30	Mono and Polycrystalline
20	SHAN SOLAR	30	Mono and Polycrystalline
21	BHEL	26	Mono and Polycrystalline
22	HBL POWER SYSTEMS	25	Mono and Polycrystalline
23	JJ PV SOLAR	25	Polycrystalline
24	KOTAK URJA	25	Polycrystalline
25	ADITI SOLAR	20	Mono and Polycrystalline
26	AJIT SOLAR	20	Mono and Polycrystalline
27	EVERGREEN SOLAR SYSTEMS INDIA	20	Polycrystalline
28	LUBI ELECTRONICS SOLAR	20	Mono and Polycrystalline
29	NEASE SOLAR	20	Mono and Polycrystalline
30	CEL	13	Monocrystalline
31	SOVA SOLAR	12.5	Polycrystalline
32	ELECTROMAC SOLAR SYSTEM PRIVATE LIMITED	12	Mono and Polycrystalline
33	KL SOLAR	12	Polycrystalline
34	ECOSOL	10	Mono and Polycrystalline
35	PLEXUS SOLAR	10	Polycrystalline
36	AKSHAYA SOLAR POWER	6	Mono and Polycrystalline
37	ANDROMEDA ENERGY	5	Polycrystalline
38	REIL	2	Mono and Polycrystalline

port. Pomares-Hernandez et al. [26]. explored the methods of improving the efficiency of the PV module through active as well as passive cooling methods. In the analysis, heat transfer and fluid dynamics effect, considering a mathematical model, were presented, and concluded that better result is obtained in active and hybrid cooling rather than passive method. By hybrid cooling, the operating temperature is reduced to approximately 17 °C, while by active methods approximately 15 °C. Hasanuzzaman et al. [27]. explored the universal advancement of PV module cooling technology. Rough reduction in module temperature is about 6 °C to 20 °C by passive cooling methods, and improvement of efficiency is 15.5%, while by active cooling methods it is high up to 30 °C and efficiency improvement is 22%. And thermal efficiency as output observes 60%. In conclusion, PV/T-PCM technologies as a passive cooling system revolutionize the future, while the active cooling system is more effective for commercial use. Kar et al. [28]. revealed the challenges faced by India like an attractive investor, climate, creating making easy access to finance, developing domestic component manufacturing industry, skill development, developing transmission and distribution infrastructure in the arena of developing solar energy in the context of the development of the solar market in India because the government set the target to reach 20 GW to 100 GW by this year, i.e., 2022. Therefore, target achievement may become cumbersome unless the above-said challenges are not addressed. Tyagi et al. [29]. explored research and achievements in the progress of solar PV technology. The PV market reached 23.5 GW by 2010 and continuously increased at about 40% annually. It was 15% in the 1950s and 17% in the 1970s, continuously increasing to 28%. Monocrystalline and polycrystalline market share is 40%, with 15 - 17% efficiency [30]. Behura et al. studied the 248 kW PV power station having a total of 775 PV panels, each of 320 W and required area of 2 m^2; in this way total area occupied is 1550 m^2. It was concluded that the cost of panel per watt is 40 rupees and rate of return is 25%. The period for returning investment is 4 years [31]. Ahsan et al. focused on the designing aspect as well as on the actual performance of 1 kW off-grid PV energy system. A system of 1 kW gives a rate of return of approximately 1.7% on an investment of Rs 0.98/kWh with a life of 25 years, which means it pays back Rs 80 thousand as a Levelized cost of energy. As a result, a 1 kW PV system generates approximately 3100 kWh/year, while an average residence requires 8 kWh/day (2920 kWh/year), which is an optimum choice [32]. The observation obtained after visiting the official websites of different brands of PV modules existing all over the world is shown in table 2. Table 3 shows the type of panels manufactured by different Indian companies with their production capacity.

Conclusion

The following conclusions are obtained after studying the research on PV panels:

- Despite the huge revolution of PV technology, first-generation PV technology is still popular for domestic use.
- The cost issue remained a challenge today, especially in developing countries like India.
- Heat management is the best way to increase panel efficiency.
- The active method is the best but not so practical among the different cooling techniques. In the passive methods, PCM cooling is best and gives remarkable results, while hybrid cooling method is best for commercial purposes.
- In the newer PV technology, BIPV and CPV render good responses.
- Recycling solar waste also becomes an area of interest to minimize carbon footprint.
- Government policies concerning solar energy must be revived, like the Malaysian government's, to enhance the solar energy field.
- The market share of monocrystalline and polycrystalline PV panel is 40%, and PV module technology is continuously increasing by 28% every year.
- The panel cost is approximately 40 rupees per watt if more than 1 kW capacity is used.
- The optimum period that can return the investments is 4 years.
- Electricity given by a 1 kW panel is approximately 1500 units per year.
- For a 1 kW plant, if the unit cost of electricity is Rs. 7 then the saving per year would be Rs. 10500.
- For installing a 1 kW PV plant, the total area required is approximately 3.125 m^2.

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Conflict of Interest

The authors declare no conflict of interests that are relevant to the content of this article.

Credit Author Statement

Prashant Kumar Shalwar: Conceptualization, Methodology, Writing - original draft preparation; Bhupendra Gupta: Investigation, Visualization, Supervision; Pushpendra Singh: Writing - review and editing. All the authors read and approved the manuscript.

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