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AI based Solar Thermal Energy Utilisation in India

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Abstract: Fossil fuels are depleted over time from regular use, and they also contribute significantly to the atmosphere's CO_2 emissions. Solar energy has emerged as one of the most intriguing clean energy options for generating heat and power through solar technology for a variety of industrial and domestic applications. India, the third-largest power consumer, and third-largest producer of sustainably generated power in the globe, has many opportunities for advancement in the solar thermal energy utilisation sector. India is eventually going toward its maximization because of its many advantages and uses in a variety of applications, which will help to reduce pollution to a greater extent. In accordance with suitable environmental conditions and researched statistical data reviewed by earlier researchers, the research paper demonstrates how solar thermal energy's horizon is widening, right from household usages like solar cookers to industrial applications like air conditioning, process heating, and power generation. It also discusses advantages, limitations, and ways to overcome them. The use of solar thermal energy has increased across a variety of goods, processes, and industries because of the Indian government's acceptance of newer renewable energy policies. The current study examines India's massive demand for energy generation in the upcoming decades and the need for solar thermal energy utilisation, which is critical to creating suitable and sustainable choices for power generation soon. The results show techniques for properly utilising this abundantly available energy and its identification, as well as ideas for the amalgamation of existing technologies to curb environmental issues and increase efficiency. Storage, a major challenge in the solar energy utilisation sector, is also reviewed. This is depicted from India's point of view.

Keywords: *Incentives, India, Policies, Potential, Solar Thermal Energy*

1. Introduction

Solar power is useful energy that is derived from the sun and is capable of being created as electrical or thermal energy. It is one of the best available energies that is beneficial to the environment, clean and renewable. Section I gives a brief introduction about solar energy, along with review of existing literature stating advantages and disadvantages. Section II discusses usage of solar energy in India, and important government acts. Section III explores applications in this field covering topics like solar drying, distillation, desalination, SIPH, CSP, etc. Finally, Section IV reviews its storage future scope of this topic along with conclusion.

Kishor S Rambhad et al., [1] has given a general overview of Power scenario, energy potential, solar thermal power generation, Government Support, Opportunities. Vijayaraja Loganathan et al., [2] has done a case study on Development of a Thermoelectric Model for Alternative Energy Resources, Demand of Power, and Strategies in the States of Southern India. Ch. Mohan Sai Kumar et al., [3] discussed India's market and society integrating solar energy along with other ideas given by the government of India and about the impact of Solar energy on the economy of the country. Singh. J et al.,

[4] has reviewed the renewable and sustainable aspect of solar energy, while Singh. R [5] has briefed about thermal power production in India, along with its status, challenges, and opportunities in his paper. The website of the Ministry of New and Renewable Energy et al., [6] has information on the latest solar energy schemes which include the National Solar Mission.

Helman (2014) examines the cost effective and reliability benefits of macro-scale solar plants, highlighting how they can reduce electricity costs and enhance grid reliability through their dispatchability [7]. Kumar et al. (2022) investigates the economics of executing solar thermal systems for heating in the textile industry, showing that the systems have potential for cost savings and environmental benefits [8]. Nagpal et al. (2020) review energy storage setup for solar thermal power plants, highlighting their potential for improving grid stability and reducing the intermittency of solar energy [9]. Singh et al. (2019) reviews the use of phase change materials for solar thermal energy storage, highlighting their advantages over other storage methods such as pumped hydro and batteries [10].

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Jha et al. (2020) explores compressed air energy storage (CAES) as an efficient way for grid integration of renewable energy sources, showing that CAES can provide a cost-effective and scalable solution for energy storage [11]. Sharma and Tyagi (2021) provide a comprehensive review on energy storage for renewable energy sources, outlining the advantages, challenges, and future scope of different energy storage technologies [12]. To tackle the water scarcity issue, use of concentrated solar power to desalinate seawater is the recent years, graphene-based materials have been studied for solar cell applications. Due to its unique properties such as, electrical, optical, optoelectronic, and mechanical; it has been considered as one of the new energy-harvesting processes [13]. Around 97.5% salt water is present and only 2.5% is freshwater. On, a lab scale, the use of sun desalination techniques such as humidification-dehumidification distillation, solar stills, indirect desalination, electrodialysis, and so on has been tested. Solar energy in the form of thermal and electrical energy can also be used to desalinate water. This can be utilised to service water-stressed areas. [14]

The Jawaharlal Nehru National Solar Mission's (JNNSM) phase I, phase II and phase III have been initiated by the Indian Government to boost energy generation, and built India a proud global leader in solar thermal energy by deploying appropriate policies over the entire nation [15]. In order to produce more renewable energy, the government of India has set challenging targets, one of which is to have 40% of all electricity capacity come from hydrocarbon sources by 2030. Solar thermal energy could possibly play a major role in achieving these goals in this situation [16]. Targeted initiatives and rewards are required to foster the growth of solar thermal energy, but it can significantly contribute to meeting India's soaring energy needs and sustainable development [17]. While evacuated tube collectors are becoming more popular because of their higher functionality, flat-plate collectors are still highly used in India [18]. Reflective surfaces can help areas with limited water resources manage their water resources wisely and enhance the performance of solar desalination systems [19, 20].

1.1. Solar Power in India

India has plenty of promise regarding harnessing solar power due to its sunny climate and throughout the year ample sunlight. India has the capacity to generate about 20,000 TWh (20 trillion-watt hours) of solar energy annually, which is approximately seven percent of the nation's country's power needs. The NSM (National Solar Mission), JNNSM (Jawaharlal Nehru National Solar Mission), Prime Minister's Global Innovation Fund for Renewable Energy (PMGIFER), and other government programs have been established with the objective of developing and utilising this renewable energy source in India. The World Bank, the Asian Development Bank, the International Solar Alliance, and other organisations have been engaged in multiple solar electricity-related initiatives that have aided in boosting consciousness about this source of clean energy across the entire nation [1].

1.2. Literature review

Solar thermal energy is employed in a variety of ways in India, including solar water heaters, solar cookers, and solar dryers. Solar water heaters are the most common solar thermal technology in India, accounting for over 92% of total installed capacity [16]. Additionally, solar cookers and sun dryers are being utilised for cooking and drying, respectively. Solar thermal energy has numerous applications in India, including the home, industrial, and agricultural sectors. In India, solar water heaters are mostly utilised for home water heating. Solar cookers are also utilised in houses and canteens for cooking, while solar dryers are used to dry agricultural products such as fruits and vegetables [17, 18].

1.2.1. Advantages and Limitations

1) It is a neat and clean renewable power source that does not produce any of the harmful emissions, thus alleviating the nation's greenhouse gas emissions.

2) Second, India has a surplus of solar thermal energy, and using it can decrease the nation's reliance on expensively imported fossil fuels.

3) Moreover, thermal energy from the sun can offer energy security to distant and rural areas with poor grid connectivity.

4) Despite the potential advantages of solar thermal energy, there are many barriers that need to be overcome prior to this can be implemented. A solar thermal power plant, for example, is beyond the purchasing range for many investors owing to its substantial initial expenditure.

5) The solar thermal power plants must be operated and maintained, but the technology is still quite new, and there is a shortage of trained labour.

6) Continuous power supply is especially challenging because of solar energy's intermittent nature, and technologies for storing energy are expensive [4].

1.3. Usage in India

1) India positions third among nations for generation and utilisation of renewable energy in the entire world, with 136 GW of the 373 GW total installed capacity coming from green sources by the year 2020 [2].

2) India possesses an enormous potential over thermal energy from the sun, particularly around the northern and western part of the country. Overall, the country

receives from four to seven kWh/m^2/day from the sun's radiation, which can be utilised for producing hot water, steam, and power. At present, less than 1% of India's energy originates from solar thermal sources, and almost all of the energy generated is utilised for air conditioning and heating systems.

3) India wants to produce more than forty percent of its energy needs from alternatives to fossil fuels by the decade of 2030. To accomplish this end goal, the Indian ministry has passed many laws and initiatives to promote the use of thermal energy from the sun. The Jawaharlal Nehru Foundation's National Solar Mission (JNNSM) was inaugurated in 2010 in order to encourage the use of solar power throughout the entire nation. The approach attempted at producing 20 GW of solar electricity by 2022, with two thousand megawatts of that coming from thermal solar power facilities [5].

4) Following the Asian nations of China and the USA, India finished in third on Ernst and Young's (EY) 2021 Renewable Energies Nation Desirability Index. India was required to generate half of its entire pollutants for the purpose to achieve the Intended Nationally Determined Contribution objectives established by the Paris Agreement, India was obligated to produce half part of its total power from non-hydrocarbon derivative sources by 2030 [2].

1.4. Government acts

India The Indian government has placed forth several kinds of initiatives and regulations that promote the utilisation of solar thermal power in the nation. A brief description of certain of these regulations can be found below:

1) With the objective to advance solar energy production and consumption in the country, the National Solar Mission (NSM) of India was set up in 2010. Endeavour aims to produce one hundred gigawatts of renewable energy by 2022, out of which forty gigawatts will come via rooftop photovoltaic installations. Sun thermal energy, which is anticipated to be crucial for achieving that objective, has been included in the mission's scope [6].

2) Solar Energy Corporation of India (SECI): The NSM could be accomplished due to the founding of the Solar Energy Corporation of India (SECI) in 2011. SECI has concentrated on boosting the deployment of solar thermal energy and has taken on a variety of schemes to do so [4].

3) Initiatives at the local level - Many Indian governments have created specific laws aimed at encouraging the utilisation of solar thermal energy. The state of Gujarat, for example, has established a photovoltaic policy which provides subsidies and incentives in a bid to encourage the implementation of solar water heaters in both residential and commercial buildings [4].

Overall, the Indian government's strategies and initiatives have been effective in encouraging the implementation of solar thermal energy in India, as well as the innovation is expected to grow in significance in India's energy mix in the coming years.

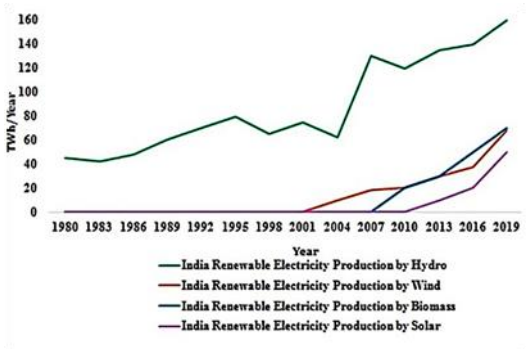

Fig. 1. Renewable Power production in India [2]

1.5. Applications

In India, solar thermal energy is utilised for an assortment of objectives, including generating of electricity, water heat, and indoor warmth/cooling. Below provides a brief overview of its applications such as

1) Electricity Generation: Solar thermal power plants redirect sunlight employing lenses or mirrors into a tiny area, heating a liquid which passes through an intricate network of pipelines resulting in steam, which operates a turbine that produces electricity. Just two of the numerous solar-powered thermal power plants are placed in India are the fifty-megawatt Dhursar solar thermal power station in Rajasthan and a ten MW Kapeli solar thermal generation plant in Gujarat. [5]

2) Solar thermal collection systems: They can be used to heat the water for both household and commercial applications. Hot water is in significant demand in India, particularly in the agricultural and hospitality industries. In India, where there are an estimated nine billion solar water heaters installed as of 2018, these are widely used.[4]

3) Building Heating and Cooling: Concentrated solar systems can be utilised to heat and cool interior spaces. Sun cooling systems employ the heat produced by solar collectors to power a cooling cycle, whilst solar air heaters can be used to warm air that is then routed via a property's ventilation system. Systems for solar space heating and cooling are enormously beneficial in rural and off-grid regions without

connectivity to the grid.[4]

Detailed description of a few of the applications are as follows –

1.5.1. Solar drying

The 2nd largest producer of vegetables, fruits and grains worldwide is India. After-harvest losses account for between 25% and 30% of output, decreasing the quantity of fresh produce each consumer has access to. Too much moisture can cause fruits and vegetables to perish, costing producers a lot of money [3]. One technique that helps farmers to keep their produce for a longer period, and at no expense, is solar drying. Farmers financially benefit from the cheaper post-harvest processing costs associated with the solar drying method, which reduces their dependence on petroleum and coal [3].

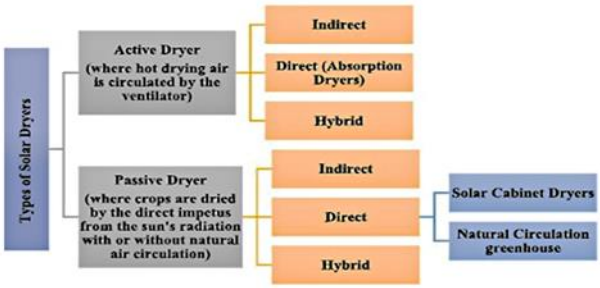

Fig.2. Types of solar dryers [3]

1.5.2. Essential oil distillation

Mint, lemongrass, palmarosa, vetiver, cinnamon, and other fragrant and medicinal plants are produced in India, a country that is mostly an agricultural nation, for use in the manufacture of essential oils. Essential oils have an important reputation on the world market, with total production of 100,000–110,000 MT and sales of $80–100 million USD [3].

1.5.3. Concentrating solar thermal power

The potential for compound operation of such CSP systems with solar and other energies is shown in Figure 3. Options for using the harvested energy without any conversion in the power circuit or transferring it to a thermal backup system are also presented. Figure 3 also provides the guidelines of action of concentrating solar technologies. CSP facilities can be compared to any conventional fuel-dependent generating station in terms of the supplies a grid operator generally needs, but with reduced or no fuel use. In hopes of guaranteeing uninterrupted electric supply, and administration in upcoming electricity transmitters that primarily use sustainable energy sources, CSP units are crucial components. Power generation capacity for CSP reactors ranges from 5 to many hundred MW [7].

1.5.4. Solar Industrial Process Heat

The normal range for Solar Industrial Process Heat (SIPH) is 50–300 °C. The combustion of fossil fuels generates this heat, which raises greenhouse gas emissions. The energy suppliers are able to use different renewable energy sources due to the necessity to reduce CO_2 emissions and the requirement for lower SIPH thermal gradients. Industries like dairy and textiles, for instance, require a lot of water that has been subjected to extreme temperatures or converted into steam. Processing heat is essential for the following steps in the textile business, comprising dyeing, whitening, and various finishing activities. The factors that influence solar thermal system technologies are global horizontal irradiance and direct normal incidence [8]. Overall, solar thermal energy has diverse applications in India, and its utilisation can help reduce the country's carbon footprint and provide energy security to remote areas [21].

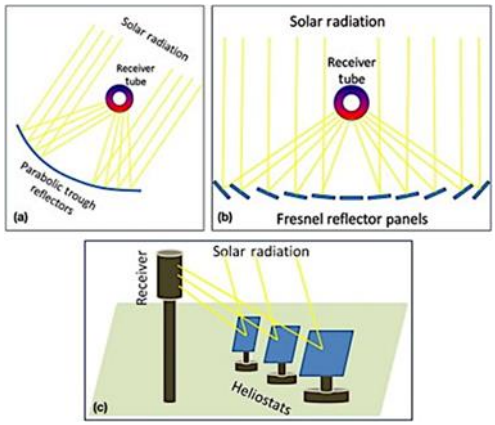

Fig.3. Concentrated solar power technologies: (a) Parabolic trough, (b) Linear Fresnel, and (c) Point concentrator [7]

1.5.5. Solar Desalination

Solar energy has a potential as a sustainable solution for water desalination, particularly in areas with limited access to freshwater. The study [20] involved designing and constructing a desalination system using solar thermal power using an evacuated tube collector (ETC), which uses solar energy to heat seawater and produce fresh water through distillation. The system was tested under various operating conditions, such as water flow rate, solar radiation, and surrounding temperature, to evaluate its ability to produce fresh water and how efficient it is at using energy[22 - 25]. The results of the study conveyed that the solar desalination system was capable of producing fresh water with a purity of up to 99%, depending on the operating conditions [26-28]. The study also showed that the system's energy efficiency increased with increasing solar radiation and decreased with increasing water flow rate [22].

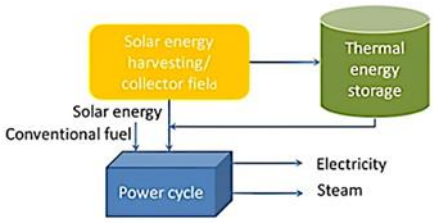

Fig.4. Energy Storage Principle [11]

1.6. Storage

Energy conservation is essential for effective utilisation of the sun's thermal power. It enables the storage of excess energy generated throughout the day for use at a later date, ensuring a consistent flow of power. Batteries, pumped hydro storage, and thermal energy storage devices are just some of the energy storage methods being investigated in the country for incorporation with solar thermal energy infrastructure. [9]. The potential for an elevated level of storage of energy density and efficiency of the salt molten thermal power storage device is one attainable technology for energy storage currently being studied in India. An additional method being investigated in India over storing energy involves compressed air storage for energy. Demand at peak times may be accomplished, and it may boost the reliability of the system [11]. Furthermore, incorporating energy storage and sources of sustainable energy may decrease greenhouse gas pollution while improving India's energy security [12].

2. Future Scope

India has huge future opportunities for using solar thermal energy since it has a wealth of solar resources that can be used to fulfil its rising energy needs. Solar thermal energy is utilized for a wide range of industrial processes, such as drying, heating, and cooling, in addition to producing electricity. This can assist to decrease the demand for fossil fuels and boost energy efficiency [29].

The construction of hybrid solar thermal power plants, which incorporate multiple technologies like photovoltaic devices, concentrated solar power, and energy storage to produce a more consistent and affordable supply of electricity [29], is one promising field for additional investigation.

Moreover, the use of cutting-edge materials in solar thermal power systems, such as graphene and nanomaterials, can increase their efficiency and lower their prices [17].

Future research should look into how solar thermal energy can be combined with other sources of sustainable energy example; biomass, geothermal, wind, ocean, and hydro to reduce the unpredictability and intermittent nature of solar power [30 -32].

Moreover, using solar thermal energy for water purification and distillation may assist India manage its rising issues with water scarcity [14].

3. Conclusion

India has a lot of confidence in solar thermal energy as a completely clean renewable energy source. In order to foster the use of thermal energy from the sun, the government of India executed an abundance of programs and regulations. India, as a nation, has tremendous potential to harness solar thermal energy owing to the vast amount of sunny days available, making it one of the best renewable energies that must be used efficiently to gain maximum benefit. The implementation of it confronts a variety of barriers, which includes expensive initial expenditures, an inadequate supply of competent workers, and energy storage systems. The government, commercial investors, and system producers must collaborate for the execution of solar thermal energy in the country to be profitable.

Author contributions

Shridhar Kedar: Conceptualization, Methodology, Detail study. **Deepak Watvisave:** Data curation, Writing-Original draft preparation, Validation, Field study. **Ajit Bhosale:** Visualization, Investigation, Writing-Reviewing and Editing. **Harish Shinde:** Visualization, Investigation, Writing-Reviewing and Editing. **Ganesh More:** Writing-Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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