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REVIEW ARTICLE

Solar Preheating in Power Plants: An Overview of The Current State of The Technology

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Abstract

Utilizing preheating units is one of the most critical ways to improve the performance of thermal power plants. Increasing the overall efficiency of Brayton or Rankine cycles by preheating the air or stream may result in considerable increases in output power and efficiency. When it comes to renewable energy, solar energy is an appealing alternative for use as a source of preheating since it is readily accessible. The current article discusses the use of solar energy for preheating air and steam in thermal power plants, as well as other uses. The performance of the systems is being improved, according to evaluations, as a result of a variety of elements, including the configuration of the reference system, the operating environment, the applied technology, and so on. Aside from improving the overall efficiency of the power plant, the incorporation of a solar preheating system may significantly decrease fuel usage and, as a result, carbon dioxide emissions. Furthermore, owing to the unavailability of solar energy during the night and overcast hours, thermal storage units may improve the system's dependability while also increasing the contribution of solar energy to the system's output.

Keyword: Solar energy; Preheating; Power plant; Steam turbine; Gas turbine

Introduction

While several renewable energy technologies for electricity production have been developed, traditional thermal power plants employing coal, oil, and natural gas play an important role in large-scale power generating [1]. Because of the importance of energy conservation, various ways have been developed to accomplish this goal. Improved system performance, operating conditions and system components, heat recovery from waste heat, and other techniques are among the approaches used in traditional thermal power plants to reduce energy consumption[2]. Another way for improving the overall efficiency of power generating cycles is to preheat the fuel before the process begins. Preheating may be given to either the energy or the air entering the combustion chamber in Bryton cycles that use gas turbines (GTs). When used in conjunction with Steam Turbines (STs), preheating may increase the overall thermal efficiency and output of the cycle[3]. For example, in regenerative Rankine cycles, the steam extracted from the turbine is utilized to warm the boiler feedwater, increasing the plant's overall efficiency[4].

Preheating is a technique that may be used to improve the efficiency of specific thermal cycles used in power production, as well as to reduce their fuel consumption[5]. For example, employed preheating in a 90 MW gas turbine. They found that raising the fuel gas temperature in the preheating unit from 22.5 C to 118 C resulted in less fuel being used for the same amount of power being produced. They investigated the feasibility of using a novel preheating system based on feedwater heater drainage[6]. They discovered that implementing the system in an optimized scheme at a 600 MW coal-fired power plant led to a 1.7% improvement of efficiency in the optimized plan and a reduction in coal consumption of 13.1 g/kWh. This improvement in efficiency and decreased fuel usage resulted in a reduction in generating costs of 1.85 $/MWh due to the upgrades. A unique preheating unit in which air absorbed thermal energy from flue gas, feedwater, and circulating water in multiple tubular heat exchangers was evaluated to determine its economic impact on the environment. They discovered that by switching to this preheating system instead of the usual one, the system's efficiency increased, and the busy payback time was reduced to 5.30 years, compared to the conventional method[7][8][9][10].

Due to the need to minimize the emission of hazardous gases and the limited availability of fossil fuels, renewable energy-based technologies have been widely developed in recent decades[11]. Solar photovoltaic (PV) panels, wind turbines, and other traditional technologies are some of the most common technologies that may be utilized only for the clean generation of power. Furthermore, renewable energy sources with thermal energy content, such as solar and geothermal, may be used as heat sources instead of a combustion chamber or a boiler to operate a thermal power plant. Solar and geothermal energy are examples of such sources[12]. In addition to the criteria in which these technologies have been employed exclusively, they may be integrated with traditional and current power production systems that use fossil fuels[13]. If you're looking for a way to warm air, fuel, or steam, you may turn to renewable energy sources with high thermal energy content like solar or geothermal. An overview of solar energy uses in various power plants, as well as the results of the investigations, are

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presented and summarized in a table in the current article. More information about the research and their conclusions will be given in the following sections of this article[14][15].

Solar energy is being used to preheat power plants, a new development. Brayton and Rankine cycles, respectively, may benefit from preheating the air or steam before use, which can enhance the efficiency of the plants[16]. In addition to the processes indicated above, the thermal energy content of the sun may be used for preheating in an ecologically friendly manner, and this can be employed in other systems such as fuel cells as well[17]. To preheat with the help of solar energy, appropriate media such as collectors must be utilized to concentrate the solar radiation to increase the energy density of the heat. The uses of solar preheating systems based on warmed media are discussed in further detail in the following subsections[18][19].

Discussion

Across the globe, gas turbines are extensively utilized to generate electricity for various applications. Several parameters influence the performance of gas turbines, including the mass flow rate of air, ambient temperature and pressure, the efficiency of cycle components, the geometrical characteristics of the features, the temperature of the air, and fuel entering the combustor[20][21]. Greater temperatures of the energy and philosophy at the input of the combustor are preferable since they will result in higher overall power output. Preheating of the air and fuel is carried out in particular power plants to achieve this goal[22][23]. Preheating the air may be accomplished by using renewable energy sources, which will be more ecologically friendly and long-lasting[24][25]. A gas turbine connected with an air preheating solar field was modeled using TRNSYS and Thermoflex to simulate the system's performance. They discovered that the variance in fuel usage was a function of the operational environment[26].

Examples include the observation of A significant reduction in fossil fuel use during sunny hours, which was attributed to both the solar power input and a reduction in the volume of air entering the system[27]. The integration of a solar preheating system with an intercooler gas turbine cycle[28]. This graphic shows how the preheating system was built after the high-pressure compressor following the recommended layout: The performance of this system was evaluated using a conventional gas turbine with a solar preheating system; using a preheating system, they observed that carbon dioxide emissions might be reduced; however, the corresponding number for an intercooler gas turbine with a preheating system was higher[29]. Levelized energy costs for the gas turbine without preheating, the conventional gas turbine with preheating, and the intercooler gas turbine with preheating were also 4.68 US/kWh, 5.51 US/kWh, and 4.58 US/kWh, respectively, for the three gas turbines studied. Intercooled gas turbine cycle with sun preheating systems[30]. The conventional gas turbine cycle with a solar preheating device. Several parameters, like the size of the solar field, the architecture of the system, the components used, and so on, impact the improvement in the performance of the cycles that use gas preheating. As research suggested, a solar preheating gas turbine was developed by using the collected heat of a heat transfer fluid from a solar field[31]. For the sake of comparison, two configurations based on Therminol VP-1 (VP1-SP-GT) and solar-salt (SS-SP-GT) were explored in this research. It was determined that both the compression ratio and the solar field had an impact on the system's performance, with the effect of the compression ratio being the more evident of the two[32][33].

Furthermore, it was discovered that, at a compression ratio of 7, the solar to air efficiencies of the VP1-SP-GT and SS-SP-GT were 17 percent and 15 percent, respectively, when compared to the VP1-SP-GT[34]. This percentage grew to 22 percent for SS-SP-GT when the compression ratio was raised to 23[35]. VP1SP-GT, on the other hand, was rendered infeasible due to technological limitations. By leveraging the exergy concept, which has shown to be an effective study tool for many energy systems, researchers have assessed Brayton cycles utilizing preheating systems[36]. Found that by neglecting the efficiency of the solar field, exergy efficiency of the system increased as a result of an increase in the temperature of the combustor's inlet; however, taking into account the efficiency of the solar plant resulted in a reduction in overall exergy efficiency of the system due to the relatively low efficiency of the solar field[37]. By including thermal storage units into the air preheating systems, the dependability of the methods might be increased. Using a storage unit, solar thermal energy may be saved throughout the day and then used during overcast or nighttime conditions to generate electricity. They simulated a cycle in which solar energy was used to preheat the compressed air entering the combustor and evaluated the impact of employing a storage unit to store the heat[38].

They discovered that by using the storage unit, they were able to obtain a more significant and more steady generation of power, as well as an increase in the daily average proportion of solar energy in the production of electricity[39]. It is essential to use an appropriate approach to improve systems that have an integrated storage unit. Using storage units, considered three different strategies for generating electricity: a) base-load plant, which produces electricity around the clock; b) load following plant, which response to the load curve between 9 a.m. and 11 p.m.; and c) generation of electricity under the condition that the inlet temperature of the expander reaches the design inlet temperature. They discovered that when compared to the other two scenarios, adopting scenario c had a more significant influence on power production[40][41].

In addition to primary Brayton cycles, combined heat and power systems (CCHP) may benefit from the solar preheating idea to achieve higher outputs. Conducted a 4E (Energy, Exergy, Exergoeconomic, and Environmental) study on a CCHP cycle combined with a parabolic solar trough for preheating the compressed air entering the combustor to reduce energy consumption and greenhouse gas emissions. A thermal storage tank, an absorption heater/chiller, and a thermal storage tank were all used in conjunction with the bottoming cycle of the gas turbine to create hot/chilled water for residential hot water, heating, and cooling. After testing, they discovered that the suggested system was very efficient in cooling mode. The plan had energy and exergy efficiencies of 83.6 and 24.9 percent, respectively. Furthermore, they discovered that combining the solar system with the CCHP cycle resulted in a decrease of around 41 percent in carbon emissions per unit of produced electricity[42][43].

In addition to gas turbines based on the Brayton cycle, various alternative ways of using solar energy to improve the performance of other processes, such as the Rankine cycle, have been presented in recent years. With solar energy, air for steam production may be preheated, resulting in increased temperatures of the flue gas and adiabatic flame, which leads to higher temperatures of the steam and greater efficiency of the cycle. Other advantages of utilizing solar energy for air heating in Rankine cycles include the increased temperature of the moisture and the reduction in the amount of energy used. Using solar energy, presented a boiler combustor design in which the gas was preheated using solar energy. They conducted their research using a centrifugal particle receiver. According to their findings, increasing the cycle efficiency via the use of this arrangement would result in enhanced cycle efficiency, which was ascribed to an improvement in boiler efficiency owing to a reduction in stack losses[44][45][46].

To improve the efficiency of Rankine cycles by using innovative configurations, a variety of ways have been used. Regen-Schematic representation of a centrifugal particle receiver. Operation is one of the ways that is often used to boost the efficiency of these cycles, and it is described in detail below. During the regeneration configuration, steam is removed from the turbine to raise the feedwater temperature, resulting in an improvement in overall efficiency[47]. It is possible to minimize the quantity of fuel used in the boiler by preheating the feed water in Rankine cycles. This concept of preheating the feedwater may be accomplished via various arrangements, media, and sources. To reduce greenhouse gas emissions, renewable energy sources such as solar and geothermal energy should be used wherever possible. In recent years, various researchers have looked at the possibility of using solar energy, which is a renewable and environmentally friendly energy source, to warm the water in a power plant. According to the general rule, using solar energy to aid in the preheating process, more miniature steam will be extracted, and as a result, more electricity will be created[48][49].

Furthermore, from an environmental standpoint, solar energy in thermal power plants that use fossil fuels would be advantageous. Carried out a full-day dynamic simulation on a coal-fired power station equipped with a solar preheating system. Greater use of solar energy in creating electricity results in more significant reductions in carbon dioxide emissions from power plants. After doing a full-day analysis, it was determined that the overall decrease in carbon dioxide emissions for the analyzed case study, which had a 330-megawatt capacity, was 186.7 tons per day[50].

Several variables influence the performance of power plants connected with solar preheating systems. For example, it evaluated the performance of a Rankine cycle by employing solar Fresnel collectors to preheat the boiler feedwater to improve efficiency. Several potential configurations were explored in this research, including the replacement of LP heaters with solar fields, the replacement of HP heaters with solar areas, and the combination of the replacement of HP heaters with the replacement of the boiler economizer. This study discovered that preheating the feedwater resulted in considerable fuel savings and a significant decrease in carbon dioxide emissions, with the variances in both values being highly dependent on the system setup. Another aspect that influences the output of solar preheating systems' power-generating cycles is the technology and components used in the system's construction: used solar towers, a linear Fresnel collector, and a parabolic trough collector in their experiments. The indirect preheating methods, which employed Fresnel or parabolic trough collectors, also utilized two heat transfer mediums, molten salt and thermal oil, in addition to the conventional preheating systems. It has been discovered that the use of a parabolic trough and molten salt results in the production of the most significant amount of hybrid thermal energy. Their calculations also found that with this arrangement, a total of up to 15,400 tons of coal may be avoided in a year for the studied power plant with a capacity of 320 MW, according to their findings. The performance of solar-assisted Rankine cycles was investigated, who examined the performance of two different configurations. The solar field was used in one of them to preheat the feedwater from the deaerator. This method resulted in a reduction in the amount of steam extracted for preheating. In the second arrangement, a second solar field was built in series between the boiler's reheater input side and the high-pressure cylinder output side, resulting in four solar areas deployed. In the second setup, solar energy was utilized to preheat the feed water and reheat the steam produced by the boiler. It was discovered that using the first and second configurations instead of the cycle without solar aid improved the system's overall performance; however, using the double format resulted in a more significant improvement in overall performance[51].

Another aspect that influences the performance of the solar-assisted Rankine cycle is the mass flow rate of the water fed into the system. The system's functioning may be adjusted by altering the ratio of feedwater to the collector. In addition to the operating principles and circumstances of the cycle, the efficiency of solar preheating in power plants is influenced by the kind of fuel used. Preheating has been used in subcritical, supercritical, and ultra-supercritical cycles. Implemented preheating in these cycles and discovered that the employed configuration was more suited for subcritical and supercritical cycles than ultra-supercritical cycles. In addition to the cycle operation mode, the performance of power plants equipped with solar preheating units is influenced by other factors. I looked at how well a solar double reheat system[52].

They discovered that, on average, the solar to electricity efficiency of the analyzed system in fuel-saving mode was 2–3 percent greater than the solar to electricity efficiency of the investigated system in the power-boosting method when the same load and solar energy input were used. As a bonus, they discovered that in the case of the most significant solar to electricity efficiency, 35.17 percent, the coal savings amounted to 19.14 grams per kilogram of energy generated (g/kWh), indicating substantial potential for lowering fuel use and greenhouse gas emissions. The idea of exergy would give a more in-depth understanding of the system's flaws and opportunities for enhancing its performance. It would be feasible to examine diverse energy systems more meaningfully if the exergy idea were to be used with the second rule of thermodynamics. In this context, several research used exergy analysis to analyze the cycles that used solar preheaters, and the results were promising. The usage of solar energy may result in improved exergy performance of the Rankine cycles when they are used. Using solar energy for preheating the feedwater of a regenerative Rankine cycle, discovered that by utilizing solar energy for aid in the preheating process, exergy losses in the feedwater heater may be reduced. Studied the influence of configuration on the performance of a cycle, a sugarcane cogeneration plant, using the exergy concept as a starting point. They looked at two different preheating arrangements. According to the exergy analysis, the cycle exergy efficiency of configurations A and the exergy study, B, had a 26.20 percent and a 26.17 percent efficiency, respectively. Also revealed was that the steam generator was the source of most of the exergy destruction for both cycles, with the solar field coming in second. According to the data, the exergy destruction ratios of the steam generator for configurations A and B were 84.33 percent and 85.55 percent, respectively, for both configurations. They had solar field values of 9.84 percent and 8.62.5 percent, respectively, for the two arrangements under consideration[53].

The solar-assisted plants have also been evaluated based on economic criteria, in addition to exergy analysis. The performance of systems from a financial standpoint is dependent on several elements, which are similar to those that influence technical performance. One of these elements is how the systems are configured to operate. It was shown to be economically feasible to build a 300-megawatt solar-aided power plant with preheating equipment, according to Bakos and colleagues. In their research, they took into account two different operating modes, including fuel conservation and power boost. In the fuel-saving mode, the produced power remains constant while using less fuel; however, in a power-boosting manner, the conserved steam creates greater control while keeping the fuel consumption consistent. They discovered that the expenses of energy production are 76.01 €/MWh for fuel-saving mode and 75.25 €/MWh for power-boosting method, respectively, for fuel-saving and power-boosting ways. The payback periods for the two approaches discussed above were calculated to be 5.5 years and 4.0.5 years, respectively, with net present values (NPVs) of 64,648,715 euros and 77,900,393 euros, respectively[54].

Due to the intermittent nature of solar energy, the use of storage units may increase the dependability of solar energy systems and the overall performance of the system that uses this source of energy. The use of storage units in solar power systems would extend the operating hours of the systems and allow them to be used even at night. This concept, which uses storage units, may be utilized in the Rankine cycle with the help of solar preheating. The performance of solar-assisted Rankine cycles, which use solar energy for preheating, may be improved by including thermal energy storage units into the system. This kind of arrangement allows for preheating and boiling to occur even in the presence of low or moderate quantities of solar radiation. Despite the advantages of combining thermal storage units with preheating systems, it may not be economically viable from a technical and financial standpoint. Investigated the performance of a coal-fired power plant in three modes: without solar-aided heating (Mode I), with solar heating and without storage unit (Mode II), and the system with solar heating and the design with solar-aided heating system and storage unit

(Modes III and IV) (Mode III). They discovered that by merging the solar heating system with the storage unit, the Levelized power costs of the facility rose. Also found was a relationship between the site where a solar heating system was installed and the Levelized Cost of energy. The performance of a solar-assisted power generating system, shown in Fig. 8, was studied by considering two techniques, including Steady Temperature (ST) and Stable Mass Flow (SMF) (SMF). It is necessary to modify a low-grade non-displaced extraction steam flow rate (extraction steam to feedwater heater (2) and deaerator) to maintain the feedwater outlet temperature consistent while using the first technique. In the second technique, it is not necessary to adjust the non-displaced extraction steam flow rate to respond to the integration of a solar system since it is not displaced. They discovered that the plant utilizing the ST method outperformed the plant implementing the SMF strategy in economic and technical performance[55].

Furthermore, they determined that using a storage unit increased the value of the Levelized Cost of Electricity (LCOE); nonetheless, it was more helpful in circumstances when the solar multiple was low. They also discovered that employing a storage unit had a more significant favorable impact on the plant when it was situated in a place with higher radiation and operating under the ST strategy after taking various regions into account in their research. For thermal power plants equipped with a solar preheating system and a thermal storage unit, several situations have been investigated and analyzed. Studied the performance of a power plant with a solar field and storage unit, as well as six regenerative heaters, under three different operating conditions. When the recovered steam from the high-pressure regeneration is displaced, the surplus solar energy would be discharged. The plant would operate in design condition, according to the first scenario. During the second scenario, the extrasolar power is used to charge the storage unit, then preheat the feed water if the solar energy is insufficient. Finally, in the third scenario, extrasolar energy is used for continuous preheating of feed water, resulting in a more significant temperature of feedwater entering the boiler when compared to the design point. They discovered that adopting the third scenario resulted in a decrease in the Levelized Cost of energy and an increase in the effective solar-to-electricity efficiency for the case study under consideration, Tibet in China. The Levelized costs of power in the best performance of the first, second, and third scenarios, as well as in the fuel-saving mode, were 5.3, 5.5, and 5.2 cents per kWh, respectively, while these values in the worst performance of the first, second, and third scenarios, as well as in the fuel-saving mode, were 5.3, 5.5, and 5.2 cents per kWh, respectively[56].

The cost of electricity in power boosting mode was 4.9, 5.0, and 4.7 cents per kWh, respectively. In terms of annual solar to electricity efficiency, the corresponding values of the mentioned scenarios in the fuel-saving mode were 17.8 percent, 17.9 percent, and 18.2 percent, respectively; whereas the corresponding values in a power-boosting manner were 19.3 percent, 19.4 percent, and 20.2 percent, respectively; and the corresponding values in the fuel-saving mode were 17.8 percent, 17.9 percent, and 18.2 percent, respectively. According to the previously indicated efficiency and cost figures, it can be determined that the third scenario is preferable from an economic and technical standpoint when compared to the second scenario. As previously stated in the preceding section, thermal power plants equipped with solar preheating systems may operate in a variety of modes, including power boosting and fuel, as well as under a variety of handling situations, including with and without solar energy support. In this respect, it is essential to employ a dependable control system to switch the plant's working modes correctly. Different sorts of designs might be employed as the control unit, depending on the system that is being used. Control of the flow rate of the particle was possible in research in which a centrifugal receiver was employed for preheating by altering the speed of rotation, for example. Different ways and instruments may be employed to regulate the mass flow; however, one of the most straightforward approaches is a valve. Irradiance transmitters may be used for Direct Normal Irradiance (DNI), which can respond to fluctuations in DNI in a proactive manner. In addition to using various transmitters to alter the temperature, a feedback control loop must be implemented to ensure that the desired temperature is maintained. Generally speaking, a control algorithm will be created based on the measurements taken by the sensors and transmitters that are used in the system. The values of the desired parameters are set to a constant value or to a specified range of values based on the algorithm that has been developed.

Conclusions

The present study examines solar preheating in thermal power plants that use fossil fuels to generate electricity. The following are some of the most significant findings: The integration of a solar preheating system with a thermal power plant may result in a considerable decrease in fuel consumption due to the contribution of solar energy to the production of electricity. Because fossil fuels account for a smaller proportion of total electricity production, carbon dioxide and other greenhouse gases are released lower. Variations in the performance of a thermal power plant when solar preheating is used are dependent on some variables, including the system architecture, the components used, and the operating circumstances. The use of thermal storage units in the preheating system will increase the total power production while also improving the system's overall performance in terms of dependability. However, despite the dependability advantages of the storage unit, the Levelized cost of power might be raised due to the presence of extra components. The kind of material used in the storage unit impacts the overall functioning of the facility. In addition, based on the findings of the current review study, several recommendations for future research might be generated. As a starting point, since the fuel temperature in the combustor is critical, and a higher temperature is preferred, it would be helpful to apply solar preheating to the fuel and compare the results with those obtained using conventional air preheating. Aside from that, it is preferable to use a variety of thermal energy storage technologies, each of which has the capability of storing energy at high temperatures, to evaluate the impacts of storage characteristics on the overall performance of the system.

Furthermore, geothermal energy, another sort of renewable energy source, might be used in conjunction with solar to increase the system's dependability during the nighttime hours. Furthermore, in circumstances where heat transfer mediums are used in the collectors, it would be beneficial to utilize fluids with changed heat transfer properties, such as nanofluids, to improve the efficiency of the heat transfer mediums. Sun preheating systems may be used in thermal power plants with bottoming cycles, such as Brayton-Rankine cycles, and the performance of the plants can be compared to the version of the plants without solar preheating.

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