International Journal of Research in Engineering and Innovation (IJREI)
journal home page: http://www.ijrei.com
ISSN (Online): 2456-6934

REVIEW ARTICLE

Study of Solar operated different hybrid thermal energy systems: A review

R.S Mishra, Rajesh Kumar, Mayank Agarwal

Department of Mechanical Engineering, Delhi Technological University Delhi, India

Article Information

Received: 16 September 2021
Revised: 09 November 2021
Accepted: 21 November 2021
Available online: 30 November 2021

Keywords:

Thermal power;
Solar power;
Thermal energy;
Solar hybrid steam

Abstract

Solar energy and other renewable sources of energy is the need of hour ,due to dependence on fixed fossil fuel reserve and growing population also add problem like shortage of fresh water availability ,interrupted electricity and high emission of carbon dioxide .although various solar tower ,solar collector, solar pond ,biogas ,wind energy ,hydel energy are being used for the production of electricity in a clean method ,various solar still, MED(multiple effect distillation) , other desalination method are regularly revised and improved to produce fresh water . In this work focus is also made upon hybrid system, hybrid system is different from original system in use as it has improved efficiency and lower losses like particle hybrid particle system with fluidized bed heat exchanger, Solar hybrid steam injected with gas turbine, solar hybrid system with hydrogen production. Review is also done for different component and their effect on efficiency of hybrid system.

1. Introduction

Energy shortage, dependence on fossil fuel, environmental pollution has restricted the society growth. solar and renewable resources can be used to solve the problem. Solar power is harnessed mainly through photovoltaic power generation and concentrating solar thermal power system [1].

There are four different types of concentrating solar thermal power generation system which is coupled and integrated with different system to form hybrid system. These are mainly tower solar thermal, trough solar thermal, linear Fresnel and disk solar thermal power generation in which tower solar system has highest efficiency. To improve the efficiency of solar hybrid system using tower solar thermal system three main technique are preferred as increasing the concentration ratio as discussed in this paper, improving the optical efficiency of receiver and its optimization, improving the heat transferring coefficient, making use of fluidized bed and solid particle [2].

2. Overview of different hybrid systems

2.1 Hybrid particle based solar plant using fluidized bed heat exchanger

Hybrid particle-based system are found to be more efficient and cost-effective CSP plants as it uses solid particle which is a better heat transfer medium compared to molten salt, therminol oil and nanoparticle with base medium like water [3].These solid particles are used in different component of hybrid system to improve overall performance as in particle receiver, Thermal energy storage and fluidized bed heat exchanger These solid particle-based systems can operate at higher temperature as compared to molten salt-based system which has operating temperature of around 600^{0}C, are free from limitation like low freezing point and corrosion and the cost. The solid particle used for heat transfer includes stable and low-cost ceramic or concrete, which can operate at high temperature about 1000^{0}C. Also, in FB heat exchanger there is

Corresponding author: R.S. Mishra
Email Address: hod.mechanical.rsm@dtu.ac.in
https://doi.org/10.36037/IJREI.2021.5609

direct contact between air and solid particle and hence lower exergy loss due to heat transfer [5] Particles used in the fluidized bed have proper fluidization ability as well as stability, efficient heat transfer ability, cost, particle size and density [6]. A high temperature fluidized bed CSP system making use of two-phase gas or solid as heat transfer medium is more effective and when this FB-CSP system is coupled with supercritical CO_2 plant cost analysis and thermodynamic analysis shows exergy loss reduction [7]. Study using simulation of granular flow pattern was made in which black body enclosed particle receiver was used in CSP plant and they highlighted that study of particle flow experiment shows a complex periodic behavior i.e., for the intermittent contact between wall and fluid particle increases the heat transfer rate [8]. In another system in which solar tower and thermal energy storage system integrated with supercritical CO_2 cycle and a solid oxide steam electrolyzer. This system produces hydrogen from solar energy. Solar energy is used to charge the thermal energy reservoir and during its discharging hydrogen energy is produced [9]. So, hybrid system based on fluidized bed produces uniform temperature, high rate of heat transfers due to solid and their mobility also they are efficient way of burning fuel with less exhaust of pollutant. Fluidized bed in air gas turbine is used for overcome the problem of large heat exchanger area and useless ash, in that case fluidized bed with small fluidized particle having low fluidization velocity provides high heat transfer and reduces the corrosion rate in the tubes [10].

2.2 Solar hybrid steam injected gas turbine with water recovery

solar hybrid steam injected gas turbine (STIGT) was developed for cogeneration purpose using inexpensive concentrating collectors for CSP plants [11]. STIGT system is produced combining the Brayton cycle with CSP which reduces the fuel combustion as well greenhouse gas emission [12]. In Steam injected gas turbine steam is injected into combustion chamber obtained from Heat recovery steam generator along with air to increase fuel energy of the system and the expansion of these product increases the overall performance of the system [13].steam injection become very difficult in arid area in which there is abundant solar energy but shortage of water as plant set up by General electric present the scenario, plant is producing 26.4 MW with injection and 19.2 MW without injection and requires a water supply of 200000m^3[14].Solar hybrid STIGT is used to collect the injected steam from the exhaust gases [15]. The work for water recovery from the boiler exhaust gas using multiple heat condensing heat exchanger and found the water recovery rate to be 10-35%. [16].

2.3 Solar, biomass hybrid system with thermochemical hydrogen production

Biomass is used for energy and hydrogen production as a renewable resource due to its low carbon emission and carbon intensity as compared to coal [17]. Odeh, [18] also found the that ash from biomass defines many important characteristics whether it is obtained from energy crop or industrial waste, the content of mineral available and their effect on different. In another work Mekonnen MM,et.al [19] studied the different methods of hydrogen production with optimization and analysis of copper chlorine cycle was done. In this work another analysis was made of electrolysis and hydrolysis integrated model using intermediary heat recovery steam generator. Winston,R.,et.al [20] proposed a solar based hydrogen production system combined with CuCl and molten salt energy storage system. In this system the efficiency of different range of solar energy in hydrogen production by CuCl cycle was analyzed and found that the heat required is larger than the heat to gain maximum temperature in CuCl cycle. In another solar biomass integrated system

Biomass is used to run the run the gas turbine and turbine exhaust is used to run the reheat Rankine cycle. In this system Cucl cycle is also used to which heat is provided through solar heliostat and electricity is provided by reheat Rankine cycle, solar heliostat energy is also utilized to run the absorption chiller. This system is being utilized to produce hydrogen, electricity, hot water for fish farming and cooling [21].

3. Conceptual description of different element of Hybrid system

3.1 Solar tower system

The solar tower is used produce electric energy from solar energy by the help of heliostat. These reflecting surfaces reflect solar radiation on to central receiver. CSP system using heliostat as a reflecting surface is used widely for high temperature application. To effectively use the solar tower system and to increase efficiency of power production system which convert the heat to electricity, search for low-cost material as a substitute wherever possible. Efficiency of solar tower system also depend upon heat collecting efficiency and heat engine efficiency as it uses solar energy collecting system and turbo generator system

The heat collecting efficiency of solar thermal tower system is given as

$$\eta_c = \eta_o - (h' (T_r - T_{a)} / C.I_a) - (\varepsilon\ \sigma_B (T_r^4 - T_a^4) / C.I_a)$$

Tr = operating temperature of heat receiver
To = ambient temperature
Ia = DNI
η_o= optical efficiency of heliostat
h′ = comprehensive heat transferring coefficient of convection and heat conduction
C = concentration Ratio
ε = surface emissivity of the heat receiver
heat engine efficiency

$\eta_t = 1- (2 T_a / T_r + T_a)$

Power generation efficiency is given as

$\eta = \eta_c * \eta_t$

3.2 Heliostat field

Heliostat field is combination of large number of flat sun tracking mirrors, these flat mirrors reflect and concentrate the beam, the amount of beam falling is measured in term of DNI (direct Normal irradiation). concentration of beam on reflector depends upon various factor as DNI, place, day time, blocking and shading, efficiency of mirror reflectivity of mirror, cosine efficiency. [5]

3.3 Solid Particle Receiver

Solar particle receiver is used to efficiently concentrate and capture solar energy and transfer it to particle moving around to the outside of tube to achieve high temperature, to increase the efficiency it is made as near black body receiver having high absorptivity of 0.99 and emissivity 0.9. In the solar particle receiver reflective and conductive losses are low. Solid particle receiver hence used to produce power at high temperature [9].

3.4 Particle TES (thermal energy reservoir

Solar energy is stored in thermal energy storage and used when solar energy is not available there are two type of thermal energy storage system direct and indirect, in direct thermal energy storage system there is direct transfer of solar energy to thermal storage tank, in case of indirect there is inter heat exchanger with two different fluids to transfer heat. In particle TES the hot and cold silo of the particle are integrated to the solar tower. These hot and cold silos of particle have intermediate role in the system. The difference in the temperature of these two silos of particle help in sensible heat transfer [10-11]. As the energy from solar rays in transferred to particle receiver and transferred to these hot silos. The benefit of particle TES is that solid particle used to store energy create insulation for itself at the boundary of the storage tank which increases the storage time of these TES [10].

3.5 Fluidized bed heat exchanger

Fluidized bed heat exchanger is the device in which there is direct heat transfer between solid and fluid it is a state of two-phase mixture. In this heat energy of the solid particle is transferred to the fluid for different purpose as in [5] it is used to heat air flowing in the Brayton cycle.

3.5.1 Use of Fluidized bed heat exchanger in Air Brayton Cycle [5]

Fluidized bed used in air Brayton cycle is having direct contact between air and solid particle so loss of exergy is less due to heat transfer is less. In this air is brought in contact to solid particle by the help of pressure pipes which creates fluid loop in heat exchanger and whole vessel gets pressurized, which bring effective heat transfer.

3.5.2 Use of Fluidized bed heat exchanger in steam Rankine cycle

In this fluidized bed heat exchanger heat transfer take place between the hot silo and the evaporator, superheater and re-heater for heating the water. In this indirect contact between hot particle and water, particle is filled in heat exchanger containing water tube [4].

3.5.3 Integrated Solar Combined Cycle with partial recuperation

Till now a very less number of integrated solar combined cycle have been in operation, which is using PTC technology. In Integrated solar combined cycle solar heat is mostly used to heat water or steam of the solar steam generator which is connected in bottom cycle of the plant with the help of heat transfer fluid which is thermal oil and molten salt [32]. It is also found that when solar thermal power is integrated at intermediate pressure level of HRSG in the integrated solar combined cycle (ISSC) with variation in temperature of heat transfer fluid then efficiency is improved [33]. It was found [34] When ISSC is analyzed with different solar concentrating technology like PTC, linear Fresnel collector and other it was found that solar technology to be more efficient in concentration when used in bottom cycle. When solar is used with gas turbine it is more efficient at electricity production. In the work [35]. ISSC is used with partial recuperation and fuel saving was seen which is equal to the amount of solar energy added to the recuperative heat exchanger in the turbine also it helps in constant production of heat. It was also seen that efficiency is improved when solar energy was available at high irradiation condition to that of conventional ISSC. When solar energy was unavailable ISSC with partial recuperation give better output as it is coupled with steam cycle which produces same power as in Combined Cycle Gas Turbine (CCGT). As CCGT is not working at part load.

4. Efficiency improvement of different hybrid system.

4.1 Optimization of solar flux distribution in solar tower using mathematical approach

The receiver is important component in concentrating solar power system. Solar energy reaches the receiver and the heat energy is transferred, but proper and fast distribution of the solar radiation is also important which depend upon the heliostat field design and optimization. The solar field distribution depends upon sun position, field configuration, shading, blocking and quality of mirror fabrication. There are two mathematical model to define the solar flux distribution of the concentrated solar irradiance, one is Monte Carlo Ray Tracing (MCRT) and other is convolution algorithm. MCRT is more computational and trace substantial bundle of random rays for accuracy, in convolution algorithm made calculation based on hypothetical solar flux distribution to make use of advantage of both methods in an evaluation, ray tracing method is used to find the shading and blocking effect and convolution method for calculation of flux distribution and both these methods decrease the computational effort as well as improve output.

4.2 Increasing the concentration ratio in solar thermal hybrid system

Concentration ratio is defined as the ratio of irradiance of the heat receiver surface to the irradiance of the heliostat surface.

C= I_r (irradiance of heat receiver surface) /I_a(irradiance of heliostat surface)

$C=(E_2/S_r)/(E_1/S_h)$

E_2 = solar energy on heat receiver
S_r = Area of heat receiver
E_1 = Solar energy on heliostat
S_h= Area of heliostat

To increase power generation capacity by increasing the concentration ratio is done by improving the tracking accuracy of the heliostat field and increase the no of heliostat used. But the drawback associated with both the process is, in case of increasing tracking accuracy of current system the cost incurred is high and increase in the no of heliostat will enlarge the light spot reflected by heliostat and light spot will overflow the surface of receiver and due to this there is increase in loss due to atmospheric attenuation. To overcome the losses a concentrator is added to the heat receiver for secondary concentration [21] .Compound parabolic concentrator was proposed for such need it is like a optical funnel and the working principle is that, all the light falling on it having angle less than maximum acceptance angle will move to middle of Compound parabolic concentrator and rays with maximum acceptance angle (the edge light) are reflected to the edge of compound parabolic concentrator and in this way heat receiver can be reduce [22]. Annular compound parabolic concentrator is more advanced to compound parabolic concentrator and is used in solar thermal power generation system in secondary concentration. The working principle is when the light falls on the concentrator from farthest heliostat and closest heliostat both have incidence angle equal to maximum acceptance angle. So the light reflected by both heliostats can be accepted by the annular compound parabolic concentrator [23]

The effect of operating temperature of heat receiver and concentration ratio studied by Saad, M. A, et.al, [24]. Increasing the concentration ratio while keeping the heat receiver at optimum temperature the different parameter to be set to appropriate value is computed by Cruz, N. C, et.al, [25].

4 Conclusions & Recommendation

Following conclusion was made by this review work

- Hybrid system are most efficient and cost effective CSP as it is making use of best available heat transfer fluid, it makes use of HRSG to reduce fuel consumption in system like steam injected gas turbine.
- Hybrid system utilizing biomass is found to be better option for hydrogen production due to its low carbon emission.
- 3.Integarted system with partial recuperation is found to have overall less efficient.
- Different Element which describe the cost and effectiveness of hybrid system are Solar tower system, heliostat field, Solid particle receiver, thermal energy reservoir. but important factor is heat collecting efficiency and heat conversion efficiency of system.
- increasing concentration ratio and optimization of solar flux distribution may be used for improvement of hybrid system

References

[1] Zhang, Y.M., Wang, J., Zhang, W.J., Sun, L.G., Liu, X.H., 2006. Tower and trough solarthermal power generation. Sol. Energy (Chinese) 2, 29–32.
[2] Hao, Y.F., Qin, C.S., Ding, C.F., 2014. The optimum operating temperature for systemefficiency of solar thermal power system. Renew. Energy 32, 1776–1780
[3] Ma, Z., Glatzmaier, G.C., Mehos, M., 2014b. Development of solid particle thermal energystorage for concentrating solar power plants that use fluidized bed technology. Energy Proc. 49, 898–907.
[4] Ma, Z., Glatzmaier, G., Mehos, M., 2014a. Fluidized bed technology for concentrating solar power with thermal energy storage. J. Sol. Energy Eng. 136,
[5] Behar, O., Khellaf, A., Mohammedi, K., 2013. A review of studies on central receiver solarthermal power plants. Renew. Sustain. Energy Rev. 031014
[6] Zhang, H., Benoit, H., Perez-Lopez, I., Flamant, G., Tan, T., Baeyens, J., 2017. High efficiency solar power towers using particle suspensions as heat carrier in the receiver and in the thermal energy storage. Renew. Energy 111, 438–446.
[7] [Ma, Z., Martinek, J., 2017. Fluidized-bed heat transfer modeling for the development ofparticle/supercritical-CO2 heat exchanger. ASME 2017 11th International Conference on Energy Sustainability, ES 2017,
[8] Martinek, J., Ma, Z., 2015. Granular flow and heat-transfer study in a near-blackbody enclosed particle receiver. J. Sol. Energy Eng. 137, 051008.
[9] AlZahrani, A.A., Dincer, I., 2016. Design and analysis of a solar tower based integrated system using high temperature electrolyzer for hydrogen production. Int. J. Hydrogen Energy 41, 8042–8056.
[10] AlZahrani, A.A., Dincer, I., 2016. Design and analysis of a solar tower based integrated system using high temperature electrolyzer for hydrogen production. Int. J. Hydrogen Energy 41, 8042–8056
[11] AlZahrani, A.A., Dincer, I., 2018. Energy and exergy analyses of a parabolic trough solar power plant using carbon dioxide power cycle. Energy Convers. Manag. 158,476–488
[12] Livshits, M., Kribus, A., 2012. Solar hybrid steam injection gas turbine (STIG) cycle. Sol. Energy 86, 190e199.

[13] Livshits, M., Kribus, A., 2012. Solar hybrid steam injection gas turbine (STIG) cycle. Sol. Energy 86, 190e199
[14] Santos, M.J., Merch_an, R.P., Medina, A., Hern_andez, A.C., 2016. Seasonal thermodynamic prediction of the performance of a hybrid solar gas-turbine power plant. Energy Convers. Manag. 115, 89e102.
[15] Wei, X., Lu, Z., Yu, W., Zhang, H. and Wang, Z. 2011. Tracking and ray tracing equations for the target-aligned heliostat for solar tower power plants. Renewable Energy 36(10): 2687-2693.
[16] Rice, I. G. (1993, May). Steam-injected gas turbine analysis: Part I—steam rates.In ASME 1993 International Gas Turbine and Aeroengine Congress and Exposition (pp. V002T09A008-V002T09A008). American Society of Mechanical Engineers
[17] Huang, Y., Ma, X., Rao, C., Liu, X., He, R., 2019. An annular compound parabolic concentrator used in tower solar thermal power generation system. Solar Energy 188, 1256–1263.
[18] Odeh, S.D., Morrison, G.L., Behnia, M., 1998. Modelling of parabolic through direct steamgeneration solar collectors. Sol. Energy 62, 395–406.
[19] Mekonnen MM, Hoekstra AY. Sustainability: Four billion people facing severe waterscarcity. Sci Adv. 2016 Feb 1;2(2): e1500323.
[20] Winston, R., Miñano, J.C., Benítez, P., 2005. Nonimaging Optics. Academic Press, Pittsburgh
[21] Samuelson, C., Bilirgen, H., Jeong, K., Kessen, M., Whitcombe, C., 2008. Recovery of Water from Boiler Flue Gas. 20 Fossil-Fueled Power Plants
[22] Sánchez-González, A. and Santana, D. 2015. Solar flux distribution on central receivers: A projection method from analytic function. Renewable Energy 74: 576-587
[23] Cruz, N. C., Redondo, J. L., Berenguel, M., Álvarez, J. D. and Ortigosa, P. M. 2017. Review of software for optical analyzing and optimizing heliostat fields. Renewable and Sustainable Energy Reviews 72: 1001-1018.
[24] Saad, M.A., Cheng, D.Y., 1997. The new LM2500 Cheng cycle for power generation and cogeneration. Energy Convers. Manag. 38, 1637-1646
[25] Cruz, N. C., Redondo, J. L., Berenguel, M., Álvarez, J. D. and Ortigosa, P. M. 2017. Review of software for optical analyzing and optimizing heliostat fields. Renewable and Sustainable Energy Reviews 72: 1001-1018

Cite this article as: R.S. Mishra, Rakesh Kumar, Mayank Agarwal, Study of Solar operated different hybrid thermal energy systems: A review, International journal of research in engineering and innovation (IJREI), vol 5, issue 6 (2021), 403-407. *https://doi.org/10.36037/IJREI.2021.5609*.