Recent Developments in Hybrid Solar Power Generation: A Review

Garima Singh
Ph.D Student (Mechanical Engineering)
Dr. A.P.J. Abdul Kalam Technical University, Lucknow
Lucknow, India

Prof. (Dr.) Bharat Raj Singh
Director General(Technical)
School Of Management Sciences, Lucknow
Lucknow, India

Abstract- **Solar energy is the useful energy resource available in plenty in the country like India. Harvesting this energy for maximum power generation is the area of interest to the researchers. Solar power is the conversion of sunlight into electricity, either directly using photovoltaic (PV), or indirectly using concentrated solar power (CSP).In CSP plants at locations with large amounts of direct normal irradiance, TES system is where solar thermal energy is stored during the day time and is used for electricity production during the night. Thermal Energy Storage (TES) systems when integrated into the solar cycle can address such issues related to energy efficiency, process flexibility, reducing intermittency during non-solar hours. This review work focuses and discusses upon the developments in Hybrid Solar Power Generation. The main focus is on CSP technologies, PV-CSP hybrid technology, Heat Transfer Fluid (HTF), and Phase Change Material (PCM) used for thermal energy storage. The research status and the hybrid system performance are summarized from the literature to provide a global point of view on the PV-CSP hybrid technology.**

Key Words: PV (photovoltaic), CSP (concentrated Solar Power), HTF)(Heat Transfer Fluid), TES (Thermal Energy Storage), PCM (Phase Change Material) , LCOE (Levelized Cost of Electricity)

1. INTRODUCTION

World's energy demand is growing fast because of population explosion and technological advancements. It is therefore important to go for reliable, cost effective and everlasting renewable energy source for energy demand arising in future. Solar energy, among other renewable sources of energy, is a promising and freely available energy source for managing long term issues in energy crisis. Solar industry is developing steadily all over the world because of the high demand for energy while major energy source, fossil fuel, is limited and other sources are expensive. It has become a tool to develop economic status of developing countries and to sustain the lives of many underprivileged people as it is now cost effective after long aggressive researches done to expedite its development. The solar industry would definitely be a best option for future energy demand since it is superior in terms of availability, cost effectiveness, accessibility, capacity and efficiency compared to other renewable energy sources [1]. However, solar energy could be a best option for the future world because of several reasons:First, solar energy is the most abundant energy source of renewable energy and sun emits it at the rate of 3.8×10^{23}kW, out of which approximately 1.8×10^{14} kW is intercepted by the earth [2].Second, it is a promising source of energy in the world because it is not exhaustible ,giving solid and increasing output efficiencies than other sources of energy [3].Third, utilization and tracking of solar energy do not have any harmful impact on ecosystem in which natural balance is kept consistent for the betterment of living organisms. Exploitation of fossil fuel leads to ecosystems damage which in-turn damages natural balance [4]. Forth, solar system can effectively be used for village system, industrial operations and homes, since it is easily affordable and applicable. There are mainly two different technologies for power generation using solar energy. One is the photovoltaic (PV) technology, including the flat-plate PV and concentrated PV (CPV), in which PV cells directly convert solar radiation into electrical energy by the PV effect. The other is the concentrated solar power (CSP) technology, in which solar radiation is firstly concentrated and converted into heat, and then the heat is used to generate power through a power cycle. The CSP technology is usually classified into the solar dish-Stirling technology, the solar tower technology, the solar parabolic trough technology, and the solar linear Fresnel reflector technology in terms of the optical elements employed [5]. Despite the different appearances of equipment, a CSP system typically consists of a solar concentrator system (solar island), a solar receiver system, a thermodynamic cycle power generation system (conventional island), and usually a thermal energy storage (TES) system. In the past decade, the commercialization of CSP technology was successfully pushed forward [6]. Generally, the CSP technology has the following characteristics: (i) the heat transfer fluids (HTFs) operate at around 400–600 °C or around 1000 °C, and thus the conventional island of CSP plant shares the same equipment with the fossil thermal power plant; (ii) it produces alternating current (AC) output, which is of a high power quality and matches the frequency and phase of the existing power grid. In addition, the CSP plants with integration of large scale TES can yield successfully stable and dispatchable power from the intermittent solar energy. As thus, it is expected that the CSP plants would provide flexibility and reliability for the power scheduling, as the mid-merit power plants. Moreover, the CSP plants with cheap TES would play a critical role under the future scenario of high penetration of the renewable energy resources [7]. However, the solar-to-power conversion efficiencies of CSP plants are still low, and the cost of CSP system needs to be reduced significantly. The efficiencies of commercial CSP plants are about: 15–20% for the tower system, 15% for the parabolic trough system, 8– 10% for the linear Fresnel system (which is usually much lower than others because of the low optical system efficiency), and 25–30% for the dish system (although the efficiency of dish system is much higher, it is still far from commercialization due to the high cost and unreliability of Stirling engine) [8,9]. The levelized cost of electricity (LCOE) of CSP is about 20 $ct/kWh, and even considering the merits of the dispatchability offered by CSP plants with TES and the increased variable renewable penetration in regional power markets, the LCOE of a current-generation molten-salt power tower plant with 10 h of TES is estimated to be 12 $ct/kWh [6], which is still much higher than that of utility-scale PV (about 8 $ct/kWh [10]). Therefore, there is a great demand to increase the generating efficiency and reduce the LCOE of the CSP technology. However, the utilization of PV systems is restricted by the instability and intermittent nature of solar radiation. As large scale electric energy storage technologies are still not sufficient to match the market demand, the power from PV has a great impact on the connected grid. Moreover, only photons near the band gap of solar cells can be converted to power by PV cells, and the majority of solar radiation is converted to heat, which increases the cell temperature and affects the efficiency and longevity of PV systems. With the above knowledge, it can be found that the features of the CSP technology and the PV technology are complementary to each other. These two systems can be combined together to form a PV-CSP hybrid power generation system. Recently, the PV-CSP hybrid technology has gained increasing worldwide attentions and been placed on the development agenda. The main attractions of the hybrid technology include: (i) the power output characteristics of the CSP system can provide stability in the hybrid system, which is beneficial to the power quality and will reduce the impact of PV system on the grid; (ii) the PV-CSP hybrid systems are also aimed to make full use of solar energy, such as the waste heat recovery of PV cells and the SBS of solar radiation, and thus the overall generating efficiency can be increased and the LCOE may be reduced. These improvements would be helpful to develop large scale solar power plants.

2. PHOTOVOLATIC POWER GENERATION

Chandratilleke et al. [11] tested the performance of water pumping system comprising a photovoltaic array of 1.14kW power and a centrifugal pump of 860W power and found its suitability for medium (1–4m3/h) delivery flow-rate applications, although the overall operating efficiency is low at around 1.6% . Hasnain et al. [12] proposed a simple single-effect solar still plant with a capacity of 5.8m^3 per day for the treatment of reject brine obtained from Sadous PV-powered RO desalination plant that can be configured as a 100% solar powered desalination system for any location and quality of brackish water and found that the single effect solar stills for small scale plants is more viable to use in remote area, where the land value is negligible as solar stills are easy to install and maintained and can be fabricated with locally available materials. Bansal et al. [13] developed an integration of solar photovoltaics of 25kWp capacity in an existing building of the cafeteria on the campus of the Indian Institute of Technology, Delhi by creating a solar roof covering with the photovoltaic array inclined at an angle of 15◦ from the horizontal and faces due south. Bhuiyan et al. [14] studied the economics of stand-alone photovoltaic power system to test its feasibility in remote and rural areas of Bangladesh and compared renewable generators with non-renewable generators by determining their life cycle cost using the method of net present value analysis and showed that life cycle cost of PV energy is lower than the cost of energy from diesel or petrol generators in Bangladesh and thus is economically feasible in remote and rural areas of Bangladesh. Bakos et al. [15] described the installation, technical characteristics, operation and economic evaluation of a grid-connected building integrated photovoltaic system (BIPV) and the technical and economical factors were examined using a computerized renewable energy technologies (RETs) assessment tool. Al-Hasan et al. [16] discussed optimization of the electrical load pattern in Kuwait using grid connected PV systems as the electric load demand can be satisfied from both the photovoltaic array and the utility grid and found during the performance evaluation that the peak load matches the maximum incident solar radiation in Kuwait, which would emphasize the role of using the PV station to minimize the electrical load demand and a significant reduction in peak load can be achieved with grid connected PV systems. Al-Hasan et al. [17] did an experiment in Kuwait to optimize electrical load pattern using grid connected PV systems. They found that, during performance evaluation, peak load matches maximum incident solar radiation and hence use of photovoltaic station in Kuwait could be a best option to minimize the electrical load demand and peak load can be reduced significantly with grid connected PV systems. Muneer et al. [18] explained solar PV electricity as the solution of future energy challenges to meet energy demand in the year 2025 in 6 major cities in India. Alazraki et al. [19] studied the impact of PV systems installed by an energy project in homes, schools and public buildings over last six years. They showed that this attempt has given an opportunity for rural communities to receive electricity by repla cing traditional energy sources. Rehman et al. [20] investigated distribution of solar radiation and sunshine duration over Saudi Arabia, using monthly average daily global solar radiation and sunshine duration data. In addition, they further scientifically analysed 5MW installed capacity photovoltaic based grid connected power plant for electricity generation in terms of renewable energy production and economic evaluation. Rehman et al. [21] utilized monthly average daily global solar radiation and sunshine duration data to study the distribution of radiation and sunshine duration over Saudi Arabia and also analyzed the renewable energy production and economical evaluation of a 5MWinstalled capacity photovoltaic based grid connected power plant for electricity generation. Ordenes etal. [22] analysed the potential of seven BIPV technologies implemented in a residential prototype simulated in three different cities in Brazil and performed simulations using the software tool Energy Plus integrate

PV power supply with building energy demand. V.V. Tyagi et.al [23] presented their paper on progress in solar PV technology: research and achievement. The development in solar PV technology is growing very fast in recent years due to technological improvement, cost reductions in materials and government support for renewable energy based electricity production. Photovoltaic is playing an important role to utilize solar energy for electricity production worldwide. The efficiency of solar cell is one of the important parameter in order to establish this technology in the market. Presently, extensive research work is going for efficiency improvement of solar cells for commercial use. The efficiency of monocrystalline silicon solar cell has showed very good improvement year by year. It starts with only 15% in 1950s and then increase to 17% in 1970s and continuously increases up to 28% nowadays.

2.1 Problems associated with Photovolatic Power Generation

Stuckings et al. [24]studied shading and resistive loss from the fingers of encapsulated solar cells by measuring the reflection from the front surface of encapsulated silver electroplated front contact solar cells using a spectrophotometer with integrating sphere attachment and found that the effective shading loss is about one third of the coverage fraction of the cell grid because of trapping of light reflected from the grid Thongpron et al. [25] investigated the nature of components of complex power (actual, reactive and apparent power) of a PV-grid interactive system due to low radiation, under 400W/m2 and found that actual power is available at high values of radiation from a PV array and at low radiation level when the array does not provide enough output power, reactive power is drawn from distribution transformer and fed into an inverter and loads and hence methods must be devised to capture this low radiation energy and converted into actual power. Lund et al. [26] analysed the problems of integration of electricity production from fluctuating renewable energy sources into the electricity supply illustrating the magnitude of the problem in terms of excess electricity production when different Renewable Energy Sources (RES) are integrated into a Danish reference system with a high degree of Combined Heat and Power (CHP) that takes benefit of the different patterns in the fluctuations of different renewable sources and the purpose has been to identify optimal mixtures from a technical point of view. Denholm et al. [28] examined some of the limits to large-scale deployment of solar photovoltaics (PV) in traditional electric power systems evaluating the ability of PV to provide a large fraction (up to 50%) of a utility system’s energy by comparing hourly output of a simulated large PV system to the amount of electricity actually usable and found that under high penetration levels and existing grid-operation procedures and rules, the system will have excess PV generation during certain periods of the year.

3. CONCENTRATED SOLAR POWER GENERATION

Jay prakash Bijarniye et al. [28] presented their paper on concentrated solar power technology in India: A review. Conventional power plants suffer from issues like fuel scarcity, availability of site and other environmental concerns. Alternate technologies based on renewable energy sources especially solar, wind and bio-mass are utilised to overcome these problems. Among many options available in solar technology, power generation through CSP (Concentrating Solar Power) could be the most promising one for India in the coming future. Anil Kumara et al. [29] presented the paper on a review on progress of concentrated solar power in India. The electricity generated by concentrated solar power in every year is being increased with high rate in India. India have enormous solar power potential for solar electricity generation per watt set up because it has solar radiation of 1700–1900 kW h per kilowatt peak with more than 300 clear sky days in year. Government of India set target of extra solar power generation of 100,000 MW till 2022. India has capacity of 1000 GW for the establishment of the CSP. Various CSP plants are working successfully. However, it is mostly restricted in the state of Rajasthan, Gujrat and some plants are in the Andhra Pradesh. The Indian government has establishment of JNNSM (Jawaharlal Nehru National Solar Mission) by MNRE (Ministry of New and Renewable Energy) to promote various application of the CSP and other solar applications. Concentrated solar power plant is now under development stage in India. Erik Pihl et al. [30] discussed the material constraints for concentrating solar thermal power Scaling up alternative energy systems to replace fossil fuels is a critical imperative. The need for nitrate salts ($NaNO_3$ and KNO_3), silver and steel alloys (Nb, Ni and Mo) in particular would be significant if CSP grows to be a major global electricity supply. Zhao Zhu et al. [31] discussed the electricity generation costs of concentrated solar power technologies in China based on operational plants. On this basis, this study analyses and benchmarks the costs of parabolic trough CSP, tower CSP, and dish CSP technologies in China by applying an LCOE (levelized cost of electricity) model. The current LCOE for the different CSP plants falls in a range of 1.2-2.7 RMB/kWh (0.19-0.43 US$/kWh). Among the three CSP technology variants discussed, our sensitivity analysis indicates that the tower CSP variant might have the greatest potential in China. They expect a future cost reduction potential of more than 50% in 2020 and a high share of local content manufacturing for tower CSP. Stefan Pfenninger et al. [32] comparing concentrating solar and nuclear power as base load providers using the example of South Africa. Both of these technologies are considered base load-capable with sufficient available fuel (sunlight or fissile material) to provide large amounts of nearly emissions-free electricity. We find that under a range of technological learning assumptions, CSP compares favourably against nuclear on costs in the period to 2030, and has lower investment and environmental risks. The results suggest that while nuclear power may be an important low-emissions power technology in regions with little sun, in the case of South Africa, CSP could be capable of providing a stable base load supply at lower cost than nuclear power, and may have other non-cost benefits. Rafael Soria et al. [33] discussed the modelling of concentrated solar power (CSP) in the Brazilian energy system: A soft-linked model coupling approach. Three energy planning tools, namely MESSAGE Brazil, TIMES-TiPs-B and REMIX-CEM-B, have been combined to analyze the opportunities that CSP plants offer to the power system and to the wider energy system of the country. This work shows that CSP can be a cost-effective option under stringent mitigation scenarios. CSP can provide firm energy and dispatchable capacity in the Northeast region of Brazil, optimally complementing wind and PV generations. Moreover, CSP can offer additional flexibility to the Northeast power system of the country, especially during winter, when the hydrological period is dryer. Results show synergies between CSP and other power supply technologies with small cost differences between the baseline and CSP-forced scenarios. Zhen-Yu Zhao et al. [34] discussed the levelized cost of energy modeling for concentrated solar power projects: A China study. A sensitivity analysis is conducted to examine the impact of different variables on the LCOE of CSP projects. The variables considered in this study are investment cost over the construction period, annual operation and maintenance cost, annual electricity production and the discount rate. Finally, the influence of incentive policies such as preferential loans, tax support and zero land cost for power stations is analyzed. This research offers a new method for power generation cost calculation of CSP projects and provides support for governments to formulate incentive policies for the industry. Tobias Fichter et al. [35] assessing the potential role of concentrated solar power (CSP) for the northeast power system of Brazil using a detailed power system. Model One of the technologies that stand out as an alternative to provide additional flexibility to power systems with large penetration of variable renewable energy (VRE), especially for regions with high direct normal irradiation (DNI), is concentrated solar power (CSP) plants coupled to thermal energy storage (TES) and back-up (BUS) systems. Brazil can develop this technology domestically, especially in its Northeast region, where most of VRE capacity is being deployed and where lies most of the CSP potential of the country. This work applies the Capacity Expansion Model REMix-CEM, which allows considering dispatch constraints of thermal power plants in long-term capacity expansion optimization. REMix-CEM calculates the optimal CSP plant configuration and its dispatch strategy from a central planning perspective. Results showed that the hybridization of CSP plants with jurema-preta biomass (CSP-BIO) becomes a least-cost option for Brazil by 2040. CSP-BIO contributes to the Northeast power system by regularizing the energy imbalance that results from the large-scale VRE expansion along with conventional inflexible power plants.

4. HYBRID PV POWER GENERATION

4.1Solar PV/thermal hybrid technology

4.1.1Liquid PV/T collector

T.T Chow et al. [36] has presented an experimental study of facade-integrated PV/T water-heating system .Different operating modes were performed with measurements in different seasons. Natural water circulation was found more preferable than forced circulation in this hybrid solar collector system. The thermal efficiency was found 38.9% at zero reduced temperature, and the corresponding electricity conversion efficiency was 8.56%, during the late summer of Hong Kong. With the PVT wall, the space thermal loads can be much reduced both in summer and winter, leading to substantial energy savings. Fraisse et al. [37] studied the performance of water hybrid PV/T collectors to applied for direct solar floor type combine system. Its low operating temperature level is appropriate for the operating conditions of the mono- or poly-crystalline photovoltaic modules selected in that study. They concluded that the annual photovoltaic cell efficiency is 6.8% which represents a decrease of 28% in comparison with a conventional non-integrated PV module of 9.4% annual efficiency. This is obviously due to a temperature increase related to the cover. On the other hand, without a glass cover, the efficiency is 10% which is 6% better than a standard module due to the cooling effect. Further research led to water hybrid PV/T solar collectors as a one piece component, both reliable and efficient, and including the thermal absorber, the heat exchanger and the photovoltaic functions. Touafek et al. [38] presented the experimental study on a new hybrid photovoltaic thermal collector. They proposed a new approach of design, aiming to increase the energy effectiveness of electric and thermal conversion with lowest cost as compared to the conventional hybrid collector technology already existing. The experimental results approximately similar to the theoretical ones, show that the thermal performance of the new hybrid collector has improved as compared to the classic hybrid PV–T solar collectors. Dubey and Tiwari [39] evaluated the performance of partially covered flat plate solar collectors for water heating connected in series using theoretical modeling and a PV module is used to run the DC motor to circulate water. It is observed that the collectors partially covered by PV module combines the production of hot water and electricity generation and it is beneficial for the users whose primary requirement is hot water production while the collectors can be fully covered by PV specially for the users whose primary requirement is electricity generation. They have also found that if this type of system is installed only in 10% of the total residential houses in Delhi (India) then the total carbon credit earned by PV/T water heaters in terms of thermal energy is about 44.5 millions US $ per annum and in terms of exergy it is 14.3 millions US $ per annum, respectively.

4.1.2PV/T air collector

Jai Prakash [40] presented their paper on transient analysis of photovoltaic-thermal solar collector for co-generartion of electricity hot air/water .Air and water both have been used as heat transfer fluids in practical PV/T solar collectors, yielding PVT/air and PVT/water heating systems respectively. PVT/water systems are more efficient than those of PVT/air systems due to the high thermo-physical properties of water as compared to air, However, PVT/air systems (Fig.) are utilized in many practical applications due to low construction (minimal use of material) and operating cost among others.

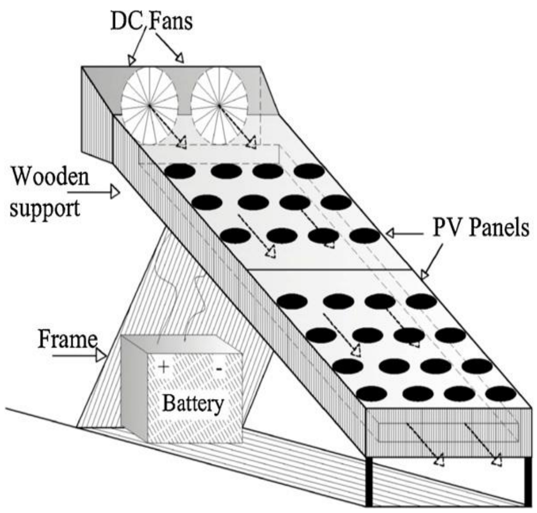

Fig.1.Schematic of the prototype of PV/ thermal air collector

Tonui and Tripanagnostopoulos [41] worked for air-cooled PV/T solar collectors with low cost performance improvements. They investigated the performance of two low cost heat extraction improvement modifications in the channel of a PV/T air system to achieve higher thermal output and PV cooling so as to keep the electrical efficiency at acceptable level. The use of thin flat metal sheet suspended at the middle or the finned back wall of an air channel in the PV/T air configuration has been suggested. A theoretical model is developed and validated against experimental data, where good agreement between the predicted results and measured data were achieved. The validated model was then used to study the effect of the channel depth, channel length and mass flow rate on electrical and thermal efficiency, PV cooling and pressure drop for both improved and typical PV/T air systems and the results were compared. Beccali et al. [42] presented a detailed analysis of the energy and economic performance of desiccant cooling systems (DEC) equipped with both single glazed standard air and hybrid photovoltaic/thermal (PV/T) collectors for applications in hot and humid climates. They showed the detailed results of simulations conducted for a set of desiccant cooling systems operating without any heat storage. System performance was investigated through hourly simulations for different systems and load combinations. Two kinds of building occupations were considered, viz. office and lecture room. Moreover, three configurations of solar-assisted air handling units (AHUs) equipped with desiccant wheels were considered and compared with standard AHUs, focusing on achievable primary energy savings. The relationship between the area of solar collectors and the specific primary energy consumption for different system configurations and building occupation patterns has been described. An outcome of their work is that solar air-cooling (SAC) systems equipped with PV/T collectors are shown to have better performance in terms of primary energy saving than that of the conventional systems fed by vapour compression chillers and coupled with PV cells. All solar air-cooling systems present good figures of merit for the primary energy consumption but the best performances is seen in systems with integrated heat pumps and small solar collector areas.

4.1.3 PV/T Concentrator

Hjothman et al. [43] presented their paper on Performance analysis of a double-pass photovoltaic/thermal (PV/T) solar collector with CPC and fins. They designed and fabricated a double-pass photovoltaic thermal solar air collector with CPC and studied the performance over a range of operating conditions. The absorber of the hybrid photovoltaic/thermal (PV/T) collector consists of an array of solar cells for generating electricity, compound parabolic concentrator (CPC) to increase the radiation intensity falling on the solar cells and fins attached to the back side of the absorber plate to improve heat transfer rate to the flowing air. The basic components of the experimental setup are as follows (Fig.). (a) Double-pass photovoltaic/thermal solar collector, (b) the air flow measurement system, (c) the temperature measurement system, (d) the wind speed measurement system, (e) the current and voltage measurement system, (f) the solar radiation measurement system and (g) the data acquisition system. The results showed that electricity production in a PV/T hybrid module decreases with increasing the temperature of the airflow. This implies that the air temperature should be kept as low as possible. On the other hand, the system should deliver hot air for other purposes.A trade off between maximizing electricity and production of hot air at reasonable high temperatures is thus necessary. The simultaneous use of hybrid PV/T, CPC and fins have a potential to significantly increase the power production and reduce the cost of photovoltaic electricity.

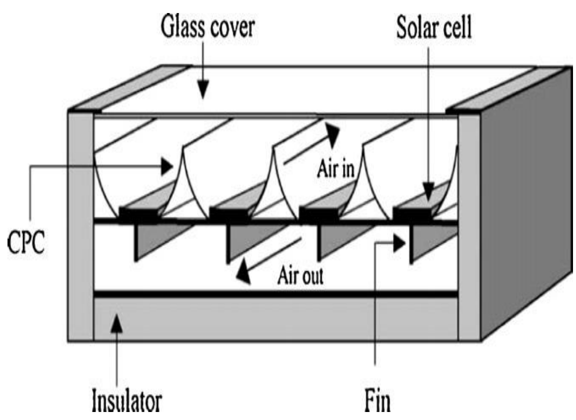

Fig.2.The schematic model of a double pass photovolatic thermal solar collector with CPC and fins

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 06, June-2019

Joe S. Coventry [44] presented their paper on performance of concentrating photovoltaic/thermal solar collector. He designed a parabolic trough photovoltaic/thermal collector with a geometric concentration ratio of 37 X at ANU Australia as shown in Fig. . The thermal and electrical efficiencies of the ANU CHAPS collector are shown under ideal conditions. A comparison was made with a flat plate thermal collector that shows that the CHAPS collector has a lower efficiency at temperatures near ambient (due to optical losses). It does not suffer the rapid increase in thermal losses as the operating temperature increases, due to the much reduced surface area. Measured results under typical operating conditions showed that the thermal and electrical efficiencies are found to be around 58% and 11% respectively, therefore a combined efficiency of 69% which is significantly high enough.

Fig.3. Prototype CHAPS collector at ANU

V.V.Tyagi et al. [45] presented their study on advancement in solar photovoltaic/thermal (PV/T) hybrid collector technology. This paper presents an overview on the research and development and application aspects for the hybrid photovoltaic/thermal (PV/T) collector systems. A major research and development work on the photovoltaic/thermal (PVT) hybrid technology has been done since last 30 years. These systems can simultaneously provide electrical and thermal energy, thus achieving a higher energy conversion rate of the absorbed solar radiation than that of simple photovoltaic system. Different types of solar thermal collector and new materials for PV cells have been developed for efficient solar energy utilization. The solar energy conversion into electricity and heat with a single device (called hybrid photovoltaic thermal (PV/T) collector) is a good advancement for future energy demand. In hot countries, PV cells are suffering to low efficiency due non availability of low ambient temperature for cooling the PVC system. Thus, by placing a solar thermal collector behind a solar photo-voltaic (PV) array, the PV cells can be cooled up some extent by circulating fluid like water or air within the solar thermal collector and at the same time the heat produced by a PVC system. At the same time, the solar collector can harvest most of the energy that passes through the array that would otherwise be lost, recovering it for productive and useful applications (solar cooling, water desalination and solar greenhouse). Xing Ju et al. [46 presented the paper on a review of concentrated photovoltaic-thermal (CPVT) hybrid solar systems with waste heat recovery (WHR). In conventional photovoltaic (PV) systems, a large portion of solar energy is dissipated as waste heat since the generating efficiency is usually less than 30%. As the dissipated heat can be recovered for various applications, the wasted heat recovery concentrator PV/thermal (WHR CPVT) hybrid systems have been developed. They can provide both electricity and usable heat by combining thermal systems with concentrator PV (CPV) module, which dramatically improves the overall conversion efficiency of solar energy. Tengfei Cui et al. [47] presented their result on experimental investigation on potential of a concentrated photovoltaic-thermoelectric system with phase change materials.Due to the limit of the band-gap of the semiconductor materials used in PV cells, there is a large portion of the solar spectrum that cannot be utilized by PV cells, lots of solar energies are wasted as heat. Therefore, the PV-TE system combined by PV cell and thermoelectric (TE) generator becomes a promising approach of realizing the utilization of full-spectrum solar energy. Proceeding from this idea, they propose a novel photovoltaic phase change material-thermoelectric (PV-PCM-TE) hybrid system, in which PCM is used to maintain the hybrid system operating on the optimal temperature. The paraffin PCM with the melting temperature $T_{melting}$ of 60 ºC is selected based on the optimal simulation of the hybrid system. The electrical and thermal efficiencies of PV cells, TE generators, pumps, hot-water in the PV-PCM-TE hybrid system are described in table 1. One can find that the efficiency of the TE modules in the hybrid system with CR (Concentration Ratio)=529 and water-cooling is the highest. This is because that in the hybrid system with CR =1156 and water-cooling, the larger area of PCM leads to the more heat loss through convection which reduces the output power of the TE modules. At the meantime, the larger hot loss also reduces the heat transferred to water, which leads to a lower thermal efficiency of the hybrid system. In the hybrid system with CR =1156 and air-cooling, a higher cold-side temperature of the TE generator makes the efficiency of the TE generator decrease.

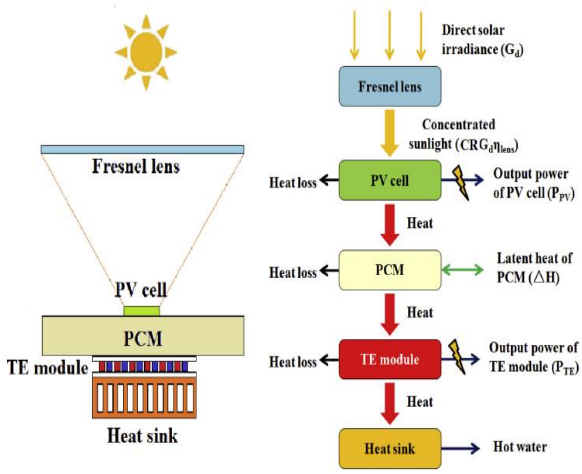

Fig.4. Experimental device of PV-PCM-TE system

Table 1. The efficiencies of the PV-PCM-TE hybrid system with different conditions

Electric/Thermal efficiency	CR=529,water cooling	CR=1156,water cooling	CR=1156,air cooling
PV cells	16.70%	12.74%	12.54%
TE generators	1.27%	0.91%	0.58%
Pumps	-0.18%	-0.20%	
Thermal efficiency (Hot-water)	35.5%	28.5%	

4.2 PV –Wind hybrid technology

El-Shatter et al. [48] designed a hybrid photovoltaic(PV)-fuel cell generation system employing an electrolyzer for hydrogen generation and applied a fuzzy regression model (FRM) for maximum power point tracking to extract maximum available solar power from PV arrays under variable insolation conditions. Maclay et al. [49] developed a model of a solar–hydrogen powered residence, in both stand-alone and grid-parallel configuration using Matlab/ Simulink that assesses the viability of employing a regenerative fuel cell (RFC) as an energy storage device to be used with photovoltaic (PV) electrical generation and investigated the design requirements of RFC sizing, battery sizing, charge/discharge rates, and state of charge limitations. Prasad et al. [50] worked on optimization of wind, photovoltaic system with battery backup for better efficiency and they proved that hybrid power generation systems could be in corporated successfully for improving generation capacity. Barton and Infield [51]described novel method of modelling an energy structure used to match the power output from a wind turbine and a solar PV array to a varying electrical load and validated the method against time-stepping. It showed good agreement over a wide range of store power ratings, store efficiencies, wind turbine capacities and solar PV capacities. Katti and Khedkar [52] investigated hybrid power generation plant, integrated by wind turbine and PV panels, systematically to be used at the remote areas where electricity is highly demanded. They investigated further wind-alone and solar-alone inisolation and it was compared with hybrid power generation panel. Sarah Becker et al. [53] described the features of a fully renewable US electricity system: Optimized mixes of wind and solar PV and transmission grid extensions. A future energy system is likely to rely heavily on wind and solar PV. To quantify general features of such a weather dependent electricity supply in the contiguous US, wind and solar PV generation data are calculated, based on 32 years of weather data with temporal resolution of 1 h and spatial resolution of 40 _ 40 km^2, assuming site-suitability-based and stochastic wind and solar capacity distributions. The regional wind-and-solar mixes matching load and generation closest on seasonal timescales cluster around 80% solar share, owing to the US summer load peak. This mix more than halves long-term storage requirements, compared to wind only. The mixes matching generation and load best on daily timescales lie at about 80% wind share, due to the nightly gap in solar production. Going from solar only to this mix reduces backup energy needs by about 50%. Furthermore, we calculate shifts in FERC (Federal Energy Regulatory Commission)-level LCOE (Levelized Costs Of Electricity) for wind and solar PV due to differing weather conditions. Regional LCOE vary by up to 29%, and LCOE-optimal mixes largely follow resource quality. A transmission network enhancement among FERC regions is constructed to transfer high penetrations of solar and wind across FERC boundaries, employing a novel least-cost optimization. Fontina Petrakopoulou et al. [54] discussed the simulation and analysis of a stand-alone solar-wind and pumped storage hydropower plant. This work presents the simulation and evaluation of a renewable hybrid power plant for off-grid fully autonomous operation on an intermediate-sized island in the Aegean Sea. A stand-alone energy system including storage facilities is simulated, optimized and analyzed relying on real-case weather and demand data of a relatively large remote community. Optimization of the power plant structure shows tha to ensure continuous off-grid energy generation, even under extreme conditions, the combination of more than one renewable technology is required. The hybrid power plant consists of a pumped-storage hydropower plant, photovoltaic cells and wind turbines. Energy surplus of the power plant is used in the incorporated electrolyzer to generate a secondary product, hydrogen. Robust operation of the plant results in 48% of the energy generated stemming from the photovoltaic system and 52% from the wind turbines. The pumped-storage hydropower plant has a mean annual power output of 1.0 MW. The total mean annual efficiency of the hybrid plant is found to be 14.4%. Although stand-alone operation was achieved with the proposed plant, this requirement led to net energy output restrictions, capacity oversizing and large storage facilities. Abbassi Abdelkader et al. [55] discussed the multi-objective genetic algorithm based sizing optimization of a stand-alone wind/PV power supply system with enhanced battery/ super capacitor hybrid energy storage. The present paper proposes a new approach to optimize the sizing of a multi-source PV/Wind with Hybrid Energy Storage System (HESS). Hence, a developed modeling of all sub-systems composing the integral system has been designed to establish the proposed optimization algorithm. Besides, a frequency management based on Discrete Fourier Transform (DFT) algorithm has been also used to distribute the power provided by the power supply system into different dynamics. Thus, many frequency channels have been obtained in order to divide the roles of each storage device and show the impact of integrating fast dynamics into renewable energies based applications. The reformulation of our optimization problem is considered by the minimization of the Total Cost of Electricity (TCE) and the Loss of Power Supply Probability (LPSP) of the load, simultaneously. In this respect, a multi-objective based Genetic Algorithm approach was used to size the developed system considering all storage dynamics. In order to achieve an optimal system configuration, different economic analysis cases were established. The obtained results show that the minimum of LPSP is achieved according to a very low TCE which introduces that the exploitation of renewable energy has a very important effect to promote the energy sector in Tunisia.

4.2 CSP hybridization stratiges with coal, natural gas, Biofuels, geothermal and wind

Juergen H. Peterseim et al. [56] described the concentrating solar power/alternative fuel hybrid plants: Annual electricity potential and ideal areas in Australia This paper investigates the generation potential and most prospective regions for 5-60 MWe CSP hybrids using forestry residues, bagasse, stubble, wood waste and refuse derived fuels in locations with a direct normal irradiance >18 MJ/m2/day. Different plant efficiencies are used to identify the overall electricity potential for single and multiple feedstocks systems. The EfB (energy from biomass) or EfW (energy from waste) components of the hybrid plants considered are assumed to allow base load operation with the CSP components providing additional capacity during the day. The total CSP-EfB & EfW hybrid potential in Australia, within 50 km of existing transmission and distribution infrastructure, is 7000 MWe which would require an investment of AU$ 39.5b to annually generate 33.5 TWh. This is equivalent to 12.8% of all electricity generated in 2008e2009 or 74% of Australia's 2020 renewable energy target. The CO2 abatement potential of CSP-EfB & EfW hybrids is up to 27 Mt or 4.8% of all 2009e10 CO2 emissions. Farshad Amiri et al. [57] design of a hybrid power plant integrated with a residential area.Power generation with high efficiency and low CO2 emission is a crucial issue for power production industry. In this research, a retrofit design for a power plant was proposed to use of solar irradiation before combustion section of gas turbine cycle. To do so, a solar tower with heliostat field was employed for compressed air preheating. A steady-state modeling of all parts of the proposed hybrid power plant was performed. Then, a coupled method of Particle Swarm Optimization and Genetic Algorithm was applied for a multi-objective optimization on the power plant performance. Based on the results, with % 62 solar share factor, fuel efficiency was increased to %85 and about 400 kg reductions in CO2 emissions were occurred. Finally, for heat recovery of exhaust gases of solar gas turbine, a CCHP system was designed to supply cooling, heating and power for more than 15,000 households in a residential area near the studied power plant. Therefore, along with effective utilization of thermal content of turbine discharging gases and according to local energy consumption pattern, 4000 MWhe per year of electricity was obtained. Moreover, 31 million cubic meters saving in natural gas consumption were approximately achieved as a result of solar-heat integration. Dimityr Popov et al. [58] discussed the innovative configuration of a hybrid nuclear-solar tower power plant. This paper proposes a combination of a nuclear and a CSP plant and performs a thermodynamic analysis of the potential benefit. Most of today's operating nuclear reactor systems are producing saturated steam at relatively low pressure. This, in turn, limits their thermodynamic efficiency. Superheating of nuclear steam with solar thermal energy has the potential to overcome this drawback. Accordingly, an innovative configuration of a hybrid nuclear-CSP plant is assembled and simulated. It brings together pressurized water reactor and solar tower. The solar heat is transferred to nuclear steam to raise its temperature. Continuous superheating is provided through thermal energy storage. The results from design point calculations show that solar superheating has the potential to increase nuclear plant electric efficiency significantly, pushing it to around 37.5%. Solar heat to electricity conversion efficiency reaches unprecedented rates of 56.2%, approaching the effectiveness of the modern combined cycle gas turbine plants.Off-design model was used to simulate 24-h operation for one year by simulating 8760 cases. Due to implementation of thermal energy storage non-stop operation is manageable. The increased efficiency leads to solar tower island installed cost reductions of up to 25% compared to the standalone CSP plant, particularly driven by the smaller solar field. Jin Han Lim et al. [59] discussed the techno-economic evaluation of modular hybrid concentrating solar power systems. This paper assesses the influence on techno-economic performance of modularising hybrid Concentrating Solar Power (CSP) systems with fossil fuel backup for both a Hybrid Solar Receiver Combustor (HSRC), which integrates a combustor into a solar cavity receiver, and a Solar Gas Hybrid (SGH) system with a similar cavity receiver and a back-up boiler. It was found that the energy losses in a system of small-sized modules, which employs molten salt as its Heat Transfer Fluid (HTF), are dominated by trace heating owing to the increased piping over their larger receiver counterpart. However, this can be reduced significantly by using alternative HTFs with a lower melting point such as sodium. In addition, for modularisation to be cost effective requires it to also enable access to alternative, lower-cost manufacturing methods. That is, the benefit of standard learning rates is insufficient to lower the Levelized Cost of Electricity (LCOE) on its own. For a plant with 30 units of 1 MWth modules the LCOE is competitive, relative to a single unit of 30 MWth, after ~10 plants are installed if the modularised components (i.e. heliostats, receivers and towers) can be decreased by >80% and >40% for molten salt and sodium as the HTF, respectively. Kody M. Powell et al. [60] presented their paper on hybrid concentrated solar thermal power systems: A review. Concentrated solar power (CSP), or solar thermal power, is an ideal technology to hybridize with other energy technologies for power generation. Advantage of CSP technology is the ability to readily store via thermal energy storage (TES), making the intermittent solar resource dispatchable. A review of CSP hybridization strategies with coal, natural gas, biofuels, geothermal, photovoltaic and wind is given. Coal, natural gas, and biofuel hybrids with CSP present many opportunities to inject solar heat at various temperatures. These combustible fuels provide reliability, dispatchability and flexibility but are not entirely renewable solutions (with the exception of biofuels). Geothermal, wind, and PV hybrid designs with CSP can be entirely renewable, but lack some of the benefits of hydrocarbon fuels. Effective geothermal-CSP hybrid designs require low temperature operation where efficiency is limited by the power cycle. Wind-CSP and PVT (photovoltaic/thermal) lack dispatchability, but have other advantages.

i.3 PV-CSP hybrid technology

A.Green et al. [61] presented their paper on high capacity factor CSP-PV hybrid systems. Tower concentrating systems with direct molten salt heat transfer and storage can deploy particularly inexpensive and scalable thermal storage, enabling cost- effective 24-hour generation using only solar energy. While typical capacity factors (CFs) for intermittent renewables are generally between 20% and 40%, the Solar Reserve Crescent Dunes project will offer above 50%. This paper discusses how Solar Reserve's CSP technology can cost-effectively produce a CF over 80%, and when hybridized with PV, can raise the CF further to roughly 90%. A detailed operational model of a hybrid system in Chile's Atacama Desert was produced, using localized data on weather and interconnection capacity. Analysis of high CF CSP-PV hybrids leads to three important conclusions. First, it was found that effective configuration of high CF systems supported selection of fixed-tilt PV at a high angle, which is optimized for winter generation in order to minimize seasonal differences. Second, when a dispatch strategy was developed which incorporated multiple priority levels and which dispatched CSP in response to PV output, it enabled higher CF CSP-PV hybrid operations than the CSP accomplished alone. Third, it was found that average annual DNI was not a sufficient metric of solar resource, and that seasonal variability and consolidation of non-optimal days were also important to high CF designs. Petrollese et. al [62] evaluated a PV-CSP hybrid system with thermal and batteries energy storage, characterized by delivering a constant power level. With the aim of providing fully dispatchable power using only solar energy, this paper focuses on a hybrid power generation system based on Concentrating Solar Power (CSP) and Photovoltaic (PV) plants. In particular, the CSP section is based on linear Fresnel collectors using thermal oil as heat transfer fluid, a two-tank direct TES system and an Organic Rankine Cycle power plant. In the PV section, the PV array is coupled with a battery bank for electrochemical storage. The study evaluates the optimal design parameters (solar field area, TES capacity and ORC nominal power for the CSP section, nominal power of the PV array and battery capacity for the PV section) that minimize the energy production cost of the hybrid CSP-PV plant while the plant is constrained to follow a power output curve characterized by a constant power level. Moreover, to assess the influence of meteorological conditions, the study considers two different locations: Ottana (Italy) and Ouarzazate (Morocco). The results demonstrate that hybridization of PV and CSP technologies becomes highly cost-effective if a constant power output is required for daily time periods longer than about 16 h, when the distinguishing feature of CSP plants of decoupling power generation from sunlight is effectively exploited, independently of the location under study. On the contrary, for production periods shorter than 8 h, the use of a PV system coupled with a proper battery bank is the most cost-effective solution for both locations evaluated Solar energy availability and unmet load fraction remarkably influence the hybrid plant design, especially for load duration periods in the range between 8 and 16 h/day. As expected, due to the lower amount of available solar energy, the hybrid solar plant located in Ottana needs larger sizes of both CSP solar field and PV arrays than the same plant located in Ouarzazate resulting in higher energy production costs. In hybrid CSP-PV system the role of the two sections is well defined as the PV plant directly supplies the load during sunlight hours while the thermal energy produced by the solar field of the CSP plant is stored in a TES system and is subsequently converted to electricity during periods of no solar energy availability. The proposed hybrid system becomes less attractive with reference to load demands with short duration periods when only-PV systems are more cost-effective. C. Parrado et al. [63] presented their paper on 2050 LCOE (Levelized Cost of Energy) projection for a hybrid PV (photovoltaic)-CSP (concentrated solar power) plant in the Atacama Desert, Chile. This study calculates the LCOE (Levelized Cost of Energy) on the PSDA (Atacama Solar Platform) for a solar-solar energy mix with the objective of evaluate new options for continuous energy delivery. LCOE was calculated for three 50 MW (megawatt) power plants: A PV (photovoltaic), a CSP (concentrated solar power) plant with 15 h TES (thermal energy storage) and a hybrid PV-CSP plant constituted with 20MW of PV and 30 MW of CSP with 15 h TES.Two scenario were evaluated up to the year 2050: Blue Map and Roadmap. The latter had a higher expectation regarding the future installation of solar technologies throughout the world. Their results show LCOE in the range of 0.079-0.1074USD/kWh for PV,0.0757-0.1493 USD/kWh for CSP and 0.074–0.138 USD/kWh for the hybrid (PV-CSP) system under the roadmap scenario. Furthermore, they mention that these systems working together can provide electricity continuously for 24 h, which is much more complicated and expensive using individual technologies. The main concern regarding solar energy is the discontinuity, intermittency of electricity production. However, the hybrid PV-CSP mix modeled is a sound solution to this problem. Rongrong Zhai et al. [64] presented their paper on the daily and annual technical-economic analysis of the thermal storage PV-CSP system in two dispatch strategies. This study aims to exploit the low-cost generation of photovoltaic (PV) plant and high-capacity and low-cost thermal energy storage (TES) system of concentrating solar power (CSP) plant. Thus, this study proposed the thermal storage PV-CSP system, that is, using low-cost TES in the CSP system to replace high-cost battery in PV system and storing fluctuant PV electricity in TES in the form of thermal energy. The annual thermal and economic performances of the thermal storage PV-CSP system were analyzed. The total annual output from the thermal storage PV-CSP system decreased slightly compared with the sum of PV and CSP systems separately in the conventional dispatch strategy. The annual output from the thermal storage PV-CSP plant increased by 6.52%, and capacity increased by 4.85% compared with the conventional PV-CSP system in the constant-output strategy, thereby indicating that the integration is helpful for fully utilizing solar energy. In the conventional dispatch strategy, the levelized cost of energy (LCOE) increased by 4.3% in the thermal storage PV-CSP system compared with the result of stand-alone PV plant but decreased by 22.6% compared with the result of standalone CSP plant. In the constant-output dispatch strategy, LCOE decreased by 19.0% in the thermal storage PV-CSP system compared with the conventional PV-CSP system. Result shows the economic efficiency of the proposed system. The power output curve is more fluid and stable in the constant-output dispatch strategy than in the conventional dispatch strategy. Storing thermal energy for these plants allows a reduction of 19% in the LCOE. J.A. Aguilar-Jiménez et al. [65] presented their analysis on techno-economic analysis of a hybrid PV-CSP system with thermal energy storage applied to isolated microgrids. In this work an economic and technical analysis on a hybrid Photovoltaic (PV) – Concentrated solar power (CSP) system, to be used as an energy source in isolated microgrids, is conducted using the microgrid in Puertecitos, Baja California, Mexico as a case study. The PV-CSP system uses a field of solar concentrators with thermal storage to activate a 30 kW organic Rankine cycle, which satisfies the community's energy demand during periods of low or no solar radiation. The PV field provides 73 kW to cover the electrical needs of the community during the daytime, the period in which the CSP field stores sensible heat in tanks for later use. An operational and economic study that compares the hybrid system to the one currently used in the microgrid is presented. The results show that, for the case study, the levelized cost of energy (LCOE) for the PV-CSP hybrid system is 0.524 USD/kWh, only 2% higher than the LCOE for the PV-Battery, 0.51 USD/kWh. However, if the PV-CSP were used in a community with an energy demand 50% larger, the LCOE would be of 0.506 USD/kWh. Furthermore, if the community's demand exceeds 500 kW, the LCOE of the PV-CSP would be 26% (0.26 USD/kWh) lower. The PV-CSP hybrid system with thermal storage is a better economic option, in terms of the LCOE, than the traditional PV-Battery systems.

5. HEAT TRANSFER FLUIDS

Thirugnanasambandam et al. [66] discussed that the solar irradiation is concentrated by using collector and then it is transmitted to a receiver by using Heat transfer fluid (HTF). This HTF may be used to operate a turbine directly or may be passed through a heat exchanger to utilising the absorbed heat. When HTF combined with heat exchanger then system divide in two cycle and the secondary cycle is used to generate steam in the turbine. The Solar thermal collectors are classified as low-medium- or high-temperature collectors in accordance with the operating temperature. High temperature collector is used for a solar thermal power cycle. Godsaonet al.[67] discussed the carbon nanotube (CNT) which is based on nano-fluids and ion nano-fluids which has very high thermal conductivity so it can be used as heat transfer fluid for high temperature application. Vignarooba et al.[68] stated that recently solar power plants havethe operating temperature range plantslying in a range of 300 - 565oC. Molten Salt can be used as HTF directly with the advantage of higher operating temperatures than synthetic oil and it can be directly used as storage material. However, it must be assured that its temperature never falls below the freezing temperature of about 221°C ($NaNO_3$/ 40% KNO_3 mixture). The use of molten salt is limited in solar power cycle due to the high corrosive nature to metal alloys. Flamant et al. [69] discussed thick suspension of silicon carbide particle used as high temperature resistant HTF. Therefore, it has been seen that different type of heat transfer fluids are used for high temperature solar collectors. These all have different properties which are the basis of selection of the type of heat transfer fluid for particular application.

6. TES TECHNOLOGIES FOR CSP APPLICATION

Xu et al.[70] discussed that the high-temperature TES system is the key element of the CSP systems. It provides the capability of providing dispatchable energy to the CSP plant by extending the generation time beyond sunset and avoiding fluctuations associated with the intermittent solar rays, etc. The thermal storage is easily integrated with CSP plant as compared to the other non-conventional power sources such as wind power and photovoltaic power. Thus, despite the additional investment, thermal storage can enhance the performance and economic viability of the power plants. Tian and Zhao [71] explained the high-temperature thermal energy storage (TES) system which has also proven their importance in CSP systems. Regarding concurrent work on the thermal storage. Lane GA. [72] discussed the various forms of energy stored in thermal storage such as sensible heat, latent heat and thermochemical or a combination type. In sensible heat thermal storage during charging and discharging process the heat stored due to change in temperature of the material.

7. PHASE CHANGE MATERIAL USED IN PCM

Solar energy is only available in the day not in the night, but with the use of phase change material, it is possible to use solar energy in non-solar hours. When solar energy is accessible in the day then PCM absorbs energy during the charging process, and in the night it releases energy during the discharging process. With this nature of PCM, it is best out of the integration of solar power with the power generation cycles. Abhat et al. [73] discussed that in latent heat storage system phase change takes place from solid to liquid and liquid to gas, during charging and discharging process respectively. Zalba et al [74] discussed the classifications of the PCMs such as organic PCMs (e.g. paraffin wax) and inorganic PCMs (e.g. salt hydrates). Various type of phase change materials (organic, inorganic and eutectic) are always accessible in the different temperature range. Hale et al.[75] discussed the thermal properties of some technical grade paraffins. George [76] discussed the eutectic mixture used as PCM. This is the mixture of two or more ingredients of the minimum-melting composition, each of which melts and freezes congruently to form crystal component due to crystallization. The greatest considerable drawback of the PCM is its low thermal conductivity, when PCMs are used in Latent Heat storage, the rate of thermal energy during charging and discharging slows down due to low thermal conductivity. Hence research on PCMs and the performance enhancement techniques have been carried out to improve the thermal performance of the LHS system which has provided the reference for the methods of enhancement in performance and optimization of LHS system.

8. CONCLUSION

Hybridization of CSP with other energy sources has many advantages, but in some instances, hybridization may hinder CSP technology. CSP-wind hybrid, don't have much synergy and are only considered hybrids in that the use of their outputs are planned together. CSP-geothermal hybrids have the potential to be an all-renewable option with dispatchability, although the low temperature power cycles required by geothermal severely limit the efficiency of the combined system. While the hybrid system has many benefits, it does not inherently enhance dispatchability as both technologies (PV and solar thermal) still rely on an intermittent solar resource. Hybridizing CSP with hydrocarbons has several benefits including enhanced dispatchability from the ability to combust fuel on demand. Using fossil fuels in a hybrid configuration prevents the system from being purely renewable and emission free, but may actually enhance the system's ability to harvest solar energy if the hybrid is designed to get higher efficiency by exploiting the synergies of the two forms of energy. Hybridization with biofuels has the potential for dispatchability and purely renewable generation, but would rely on cost-effective and abundant sources of biofuels. An ideal CSP-hybrid system would satisfy the following:

i. Increases the efficiency of CSP component compared to stand-alone plant.

ii. Reduces the LCOE of the CSP component compared to stand-alone plant.

iii. Allows for flexible operation to achieve optimum performance.

iv. Uses reliability of other energy source to achieve high capacity factor.

v. Can accommodate scalable solar field to achieve high solar share.

vi. Achieves lower emissions compared to a hydrocarbon-based plant.

The PV-CSP hybrid system has several advantages over the PV alone, CSP-alone system or hybridization of PV and CSP with other technology and the benefits can be summarized as follows:

i. Better power quality. The PV system can be used to satisfy the load demand of the power grid during the day time, while the CSP system stores thermal energy to produce electricity during the cloudy day or night time. PV and CSP complement each other well to supply dispatchable power, so that the hybrid system can satisfy base or mid-merit load demand.

ii. Higher generating efficiency. With PV-topping and SBS technologies, proper energy allocation and energy cascade utilization can be achieved, leading to improved generating efficiencies. Based on the current technologies, it is possible to realize a hybrid solar power system with an overall generating efficiency of over 40%.

iii. Lower cost. Although the economy of the PV-CSP hybrid system is still under debate, the hybrid system still shows some possibilities or potential on cost-cutting of the solar power generation. The costs of PV-CSP hybrid systems would be low because of its high CF. Under proper operating management and climate conditions, the CF would be close to that of conventional coal-fired plants and much higher than that of other intermittent renewable power generation methods. The costs may also be reduced in compact PV-CSP hybrid systems because of its high generating efficiency. To store energy in form of heat is also much cheaper than the electrochemical energy storage.

iv. Convenient final product and broad market. The only final product of the PV-CSP hybrid system is electricity, which can be transported and used conveniently. Compared with the PV/T hybrid system, it is not necessary to consider the limitation of transmission distance or to match the combined thermal and electrical energy demands of consumers.

v. Suitable to develop large-scale solar power plants. Conventional PV/T technology is engaged in small-scale energy systems providing both thermal and electrical energy for buildings, greenhouses, domestic hot water, etc. But the PV-CSP hybrid technologies are more suitable to be used in large-scale power plants which can provide dispatchable power to the grid. Furthermore, the costs would be reduced because of the scale effect. Micro-scale solar power generation system may also be developed for remote districts by the compact PV-CSP hybrid technology.

9. REFERENCES

[1] Nadarajah Kannan, Divagar Vakeesan. Solar energy for future world:- A review Renewable and Sustainable Energy Reviews 62(2016)1092–1105.
[2] Panwar N, Kaushik S, Kothari S. Role of renewable energy sources in environmental protecti on: a review. Renew Sustain Energy Rev 2011;15(3):1513– 24.
[3] Nozik AJ. Photoelectrochemistry : applications to solar energy conversion. Annual Rev Phys Chem 1978;29(1):189–222.
[4] Schlamadinger B .Towards a standard methodology for greenhouse gas balances of bio energy systems in comparison with fossil energy systems. Biomass Bioenergy1997;13(6):359–75.
[5] Technology roadmap: solar thermal electricity - 2014 edition, in, International Energy Agency (IEA) report, 2014.
[6] Technology roadmap: solar photovoltaic energy - 2014 edition, in, International Energy Agency (IEA) report, 2014.
[7] Concentrating Solar Power Projects by Technology, in, NREL, 2016.
[8] M. Mehos, C. Turchi, J. Jorgenson, P. Denholm, C.Ho, K.Armijo. On the Path to SunShot: Advancing Concentrating Solar Power Technology, Performance and Dispatchability, in, 2016.
[9] Technology roadmap: solar thermal electricity - 2010 edition, in, International Energy Agency (IEA) report, 2010.
[10] J. Graham-Cumming, The Geek Atlas: 128 places where science & technology come alive, O'Reilly Media, 2009.
[11] Chandratilleke TT, Ho JC. A study of a photovoltaic array for water pumping. Solar &Wind Technology 1986;3(1):59–71.

[12] Hasnain SM, Alajlan S. Coupling of PV powered RO brackish water desalination plant with solar stills. Desalination 1998;116: 57–64.
[13] Bansal NK, Sandeep G. Integration of photovoltaic technology in cafeteria building, at Indian Institute of Technology, New Delhi. Renewable Energy 2000;19:65–70.
[14] Bhuiyan MMH, Ali Asgar M, Mazumder RK, Hussain M. Economic evaluation of a stand-alone residential photovoltaic power system in Bangladesh. Renewable Energy 2000;21:403–10.
[15] Bakos GC, Soursos M, Tsagas NF. Techno economic assessment of a building integrated PV system for electrical energy saving in residential sector. Energy and Buildings 2003;35:757–62.
[16] Al-Hasan AY, Ghoneim AA, Abdullah AH. Optimizing electrical load pattern in Kuwait using grid connected photovoltaic systems. Energy Conversion and Management 2004;45:483–94.
[17] Al-Hasan A, Ghoneim A, Abdullah .A .Optimizing electrical load pattern in Kuwait using grid connected photovoltaic systems. Energy Conversion Management 2004;45(4):483–94.
[18] Muneer T, Asif M, Munawwar S. Sustainable production of solar electricity with particular reference to the Indian economy. Renewable and Sustainable Energy Reviews 2005;9(5):444–73
[19] Alazraki R, Haselip J. Assessing the uptake of small-scale photovoltaic electricity production in Argentina : the PERMER project .J Clean Production 2007;15(2):131–42.
[20] Rehman S, Bader MA, Al-Moallem SA. Cost of solar energy generated using PV panels. Renewable and Sustainable Energy Reviews 2007;11(8):1843–57.
[21] Rehman S, Bader Maher A, Al-Moallem Said A. Cost of solar energy generated using PV panels. Renewable and Sustainable Energy Reviews 2007;11:1843–57.
[22] Ordenes M, Marinoski DL, Braun P, Ruther R. The impact of building integrated photovoltaics on the energy demand of multi-family dwellings in Brazil. Energy and Buildings 2007;39:629–42.
[23] V.V. Tyagi, NurulA.A.Rahim , N.A.Rahim , JeyrajA./L.Selvaraj. Progress in solar PV technology. Renewable and Sustainable Energy Reviews 2013;20: 443–461.
[24] Stuckings MF, Blakers AW. A study of shading and resistive loss from the fingers of encapsulated solar cells. Solar Energy Materials & Solar Cells 1999;59:233–42.
[25] Thongpron J, Kirtikara K. Effects of low radiation on the power quality of a distributed PV-grid connected system. Solar Energy Materials & Solar Cells 2006;90:250,1–8.
[26] Lund H. Large-scale integration of optimal combinations of PV, wind and wave power into the electricity supply. Renewable Energy 2006;31:503–15.
[27] Denholm Paul, Margolis Robert M. Evaluating the limits of solar photovoltaics (PV) in traditional electric power systems. Energy Policy 2007;35:2852–61.
[28] Jay Prakash Bijarniya, K.Sudhakar, Prashant Baredar. Concentrated solar power technology in India: A review. Renewable and Sustainable Energy Reviews 63,(593–603) 2016.
[29] Anil Kumar, Om Prakash, Akarshi Dube . A review on progress of concentrated solar power in Indi. Renewable and Sustainable Energy Reviews 79, (304–307),2017.
[30] Erik Pihl, Duncan Kushnir, Björn Sandén, Filip Johnsson. Material constraints for concentrating solar thermal power. Energy 44 (2012) 944-954.
[31] Zhao Zhu, Da Zhang, Peggy Mischke, Xiliang Zhang. Electricity generation costs of concentrated solar power technologies in China based on operational plants .Energy 89 (2015) 65-74.
[32] Stefan Pfenninger, James Keirstead. Comparing concentrating solar and nuclear power as baseload providers using the example of South Africa Energy 87 (2015) 303-314.
[33] Rafael Soria , Andre F.P. Lucena , Jan Tomaschek , Tobias Fichter , Thomas Haasz ,Alexandre Szklo , Roberto Schaeffer , Pedro Rochedo , Ulrich Fahl , Jürgen Kern. Modelling concentrated solar power (CSP) in the Brazilian energy system: A soft-linked model coupling approach .Energy 116 (2016) 265-280.
[34] Zhen-Yu Zhao ,Yu-Long Chen a, John Douglas Thomson. Levelized cost of energy modeling for concentrated solar power projects: A China study .Energy 120 (2017) 117-127.
[35] Tobias Fichter , Rafael Soria , Alexandre Szklo , Roberto Schaeffer , Andre F.P. Lucena .Assessing the potential role of concentrated solar power (CSP) for the northeast power system of Brazil using a detailed power system Model Energy 121 (2017) 695-715.
[36] T.T. Chow, W.He, J.Ji. An experimental study of facade integrated photovoltaic/water-heating system. Applied Thermal Engineering 27, (37–45), 2007.
[37] Fraisse G, Menezo C, Johannes K. Energy performance of water hybrid PV/T collectors applied to combined systems of direct solar floor type. Solar Energy 2007;81:1426–38.
[38] Touafek K, Haddadi M, Malek A. Experimental study on a new hybrid photovoltaic thermal collector. Applied Solar Energy 2009;45(3):181–6.
[39] Dubey S, Tiwari GN. Analysis of PV/T flat plate water collectors connected in series. Solar Energy 2009;83:1485–98.
[40] Jai Prakash .Transient analysis of photovoltaic-thermal solar collector for co-generartion of electricity hot air/water. Energy Conversion and Management, vol-35, No-11,pp.967-972,1994.
[41] Tonui JK, Tripanagnostopoulos Y. Air-cooled PV/T solar collectors with low cost performance improvements. Solar Energy 2007;81:498–511
[42] Beccali M, Finocchiaro P, Nocke B. Energy and economic assessment of desiccant cooling systems coupled with single glazed air and hybrid PV/thermal solar collectors for applications in hot and humid climate. Solar Energy 2009;83:1828–46.
[43] Mohd. Yusof Hj. Othman, Baharudin Yatim, Kamaruzzaman Sopian, Mohd. Nazari Abu Bakar. Performance analysis of a double-passphotovoltaic/thermal (PV/T) solar collector with CPC and fins. Renewable Energy 2005;30:2005–17.
[44] Joe S. Coventry "Performance of a concentrating photovoltaic/thermal solar collector."Elesvier Solar Energy 78 , 211–222,2005.
[45] V.V. Tyagi, S.C. Kaushik, S.K. Tyagi. Advancement in solar photovoltaic/thermal (PV/T) hybrid collector technology.Renewable and Sustainable Energy Reviews 16,(1383-1398), 2012.
[46] ing Ju , Chao Xu , Zhirong Liao , Xiaoze Du , Gaosheng Wei , Zhifeng Wang , Yongping Yang .A review of concentrated photovoltaic-thermal (CPVT) hybrid solar systems with waste heat recovery (WHR). Science Bulletin 62,(1388–1426), 2017.
[47] Tengfei Cui , Yimin Xuan , Ershuai Yin , Qiang Li , Dianhong Li.Experimental investigation on potential of a concentrated photovoltaic-thermoelectric system with phase change materials. Energy 122, (94-102),2017.
[48] El-Shatter ThF, Eskandar MN, El-Hagry MT. Hybrid PV/fuel cell system design and simulation. Renewable Energy 2002;27:479–85.
[49] Maclay JD, Brouwer J, Scott Samuelsen G. Dynamic analyses of regenerative fuel cell power for potential use in renewable residential applications. International Journal of Hydrogen Energy 2006;31:994–1009.
[50] Prasad AR, Natarajan E. Optimization of integrated photovoltaic–wind power generation systems with battery storage. Energy 2006;31(12):1943–54.
[51] Barton JP, Infield DG. A probabilistic method for calculating the usefulness of a store with finite energy capacity for smoothing electricity generation from wind and solar power. J Power Sources 2006;162(2):943–8.
[52] Katti PK, Khedkar MK. Alternative energy facilities based on site matching and generation unit sizing for remote area power supply.Renewable Energy 2007;32(8):1346–62.
[53] Sarah Becker, Bethany A. Frew , Gorm B. Andresen , Timo Zeyer , Stefan Schramm, Martin Greine, Mark Z. Jacobson. Features of a fully renewable US electricity system: Optimized mixes of wind and solar PV and transmission grid extensions .Energy 72 (2014) 443-458.
[54] Fontina Petrakopoulou , Alexander Robinson , Maria Loizidou. Simulation and analysis of a stand-alone solar-wind and pumped storage hydropower plant. Energy 96 (2016) 676-683.
[55] Abbassi Abdelkader , Abbassi Rabeh , Dami Mohamed Ali , Jemli Mohamed .Multi-objective genetic algorithm based sizing optimization of a stand-alone wind/PV power supply system with enhanced battery/ supercapacitor hybrid energy storage. Energy 163 (2018) 351-363.

[56] Juergen H. Peterseim ,Alexander Herr , Sarah Miller, Stuart White, Deborah A. O'Connell. Concentrating solar power/alternative fuel hybrid plants: Annual electricity potential and ideal areas in Australia .Energy 68 (2014) 698-711.
[57] Farshad Amiri, Nassim Tahouni, Marjan Azadi, M. Hassan Panjeshahi. Design of a hybrid power plant integrated with a residential area. Energy 115 (2016) 746-755.
[58] Dimityr Popov, Ana Borissova. Innovative configuration of a hybrid nuclear-solar tower power plant . Energy 125 (2017) 736-746.
[59] Jin Han Lim, Bassam B. Dally, Alfonso Chinnici, Graham J. Nathan.Techno-economic evaluation of modular hybrid concentrating solar power systems. Energy 129 (2017) 158-170.
[60] Kody M. Powell, Khalid Rashid, Kevin Ellingwood, Jake Tuttle, Brian D. Iverson "Hybrid concentrated solar thermal power systems: A review" Elesvier, Renewable and Sustainable Energy Reviews 80, (215–237), 2017.
[61] A. Green, C. Diep, R. Dunn, J. Dent "High capacity factor CSP-PV hybrid systems International Conference on Concentrating Solar Power and Chemical Energy Systems" Solar PACES 2014 Energy Procedia ,69 ,2049 – 2059, 2015.
[62] Mario Petrollese, Daniele Cocco "Optimal design of a hybrid CSP-PV plant for achieving the full dispatchability of solar energy power plants" Elesvier, Solar Energy 137,(477–489), 2016.
[63] C. Parrado a, A. Girard , F. Simon , E. Fuentealba "2050 LCOE (Levelized Cost of Energy) projection for a hybrid PV (photovoltaic)-CSP (concentrated solar power) plant in th Atacama Desert, Chile" Elesvier, Energy 94 ,422-4300, 2016.
[64] Rongrong Zhai, Hongtao Liu, Ying Chen, Hao Wu, Yongping Yang .The daily and annual technical-economic analysis of the thermal storage PV-CSP system in two dispatch strategies. Energy Conversion and Management 154 (56–67),2017.
[65] J.A. Aguilar-Jiménez, N. Velázquez, A. Acuña, R. Cota, E. González, L. González, R. López, S. Islas "Techno-economic analysis of a hybrid PV-CSP system with thermal energy storage applied to isolated microgrids" Elesvier, Solar Energy 174 ,(55–65), 2018.
[66] Thirugnanasambandam, M., Iniyan, S. and Goic, R., 2010. A review of solar thermal technologies. Renewable and sustainable energy reviews, 14(1), pp.312-322
[67] Godson, L., Raja, B., Lal, D.M. and Wongwises, S., 2010. Enhancement of heat transfer using nanofluids—an overview. Renewable and sustainable energy reviews, 14(2), pp.629-641.
[68] Vignarooban, K., Xu, X., Arvay, A., Hsu, K. and Kannan, A.M., 2015. Heat transfer fluids for concentrating solar power systems–a review. Applied Energy, 146, pp.383-396.
[69] Flamant, G., Gauthier, D., Benoit, H., Sans, J.L., Boissière, B., Ansart, R. and Hemati, M., 2014.A new heat transfer fluid for concentrating solar systems: Particle flow in tubes. Energy Procedia, 49, pp.617-626.
[70] Xu, C., Wang, Z., He, Y., Li, X. and Bai, F., 2012. Sensitivity analysis of the numerical study on the thermal performance of a packed-bed molten salt thermocline thermal storage system. Applied Energy, 92, pp.65-75.
[71] Tian, Y. and Zhao, C.Y., 2013. A review of solar collectors and thermal energy storage in solar thermal applications. Applied energy, 104, pp.538-553.
[72] Lane, G.A., 1983. Solar heat storage: latent heat materials.
[73] Abhat, A., 1983. Low temperature latent heat thermal energy storage: heat storage materials. Solar energy, 30(4), pp.313-332.
[74] Zalba, B., Marın, J.M., Cabeza, L.F. and Mehling, H., 2003. Review on thermal energy storage with phase change: materials, heat transfer analysis and applications. Applied thermal engineering, 23(3), pp.251-283.
[75] Hale, D.V., 1971. Hoover, MJ, O'Neill, MJ. Phase change materials hand book. Alabaa: Marshal Space Flight Center.
[76] George A. (1989) Hand book of thermal design. In: Guyer C, editor. Phase change thermal storage materials. McGraw Hill Book Co.