ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 6, Issue 1, January 2019

Concentrated Solar Power for Power Generation: (Opportunities & Challenges)

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ABSTRACT: Concentrated solar energy is a system to generate power by concentrating solar energy to produce enough heat to run heat engines. It is basically combinations of different types of mirrors and lenses for concentrating light. There are different types of Solar concentrators used in it based on costs and requirements. It can be used as dispatchable source of energy which makes it different from rest. It can store its thermal energy in different materials in an adiabatic container or environment. Due to its different advantages, it has huge future scope.

KEYWORDS: Concentrated solar energy, concentrators, Thermal storage, thermal energy conversion, Efficiency.

I. INTRODUCTION TO CONCENTRATED SOLAR POWER

Concentrated Solar Power system uses the combinations of mirrors and lenses to concentrate the light falling on a larger area to a smaller area. As the sun rays are concentrated on a smaller area, this increases the intensity of light falling hence increasing the output electricity. Different combination of mirror and lenses increases the concentration by different factor.

When the concentrated solar rays fall on the smaller area, there are basically 2 ways to generate electricity from them. One is by using PV cell i.e. Photovoltaic conversion and other is by using Thermal power conversion system. Both the ways have their pro and cons in their own ways. At the present condition PV cell are more used than Thermal conversion but thermal conversion has huge future scope.

II. LITERATURE REVIEW

As being a renewable source of energy, people are working on concentrated solar power to meet energy needs replacing fossil fuels. A lot of people have given their contribution towards concentrated solar power for power generation.

In 2002, Falah Abed Alhasan M. worked on performance of CSP and calculated efficiency of the Parabolic Trough Solar Collector (PTSC). He came up with result that it can reach up to 150 degree Celsius for solar irradiance of 400-500 W/sq. metre. In 2007, Dr. Franz Trieb studied about Concentrating Solar Thermal Power (CSP) plants to control seawater desalination either by electricity or in the combined generation. The motive of the paper is to solve the water scarcity problem in the Middle-east. The results were quite impressive. In 2012, Miqdam Tariq Chaichan focused on improving the efficiency of solar concentrators by considering few changes. He colored the main target with a black colorfor better absorption and fixed a reflector with the arc from behind the target to increase the efficiency of concentrators.

Due to its high scope in India, a lot of Indian researchers are working on it. Currently a lot of government projects are going on regarding CSP which is included in Jawahar Lal Nehru National Solar Mission.

III.SOLAR ENERGY CONVERSION TECHNOLOGIES

A. Photovoltaic Energy Conversion of Solar Energy

In photovoltaic conversion of solar energy, the sun rays are concentrated through different concentrators and the concentrated high intensity solar rays fall on the PV cell which produces electricity.PV cell is a semiconductor device which creates flow of electron when photons with sufficient energy fall on it. Thus, producing current.

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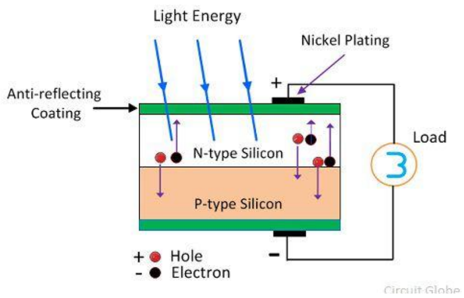

Fig. PV cell

In PV cell, when the concentrated solar rays fall on the depletion region of the p-n junction cell, it creates an exciton pair (electron-hole pair). Now as in the depletion region the electrons are at boundary of p side of depletion region and holes are at boundary of n side of depletion region. So as the electron gets attracted by holes and holes gets attracted by electron, this lead to forward biasing of the PV cell. This is how current is produced in the Photovoltaic conversion of concentrated solar rays.

B. THERMAL ENERGY CONVERSION OF SOLAR ENERGY

As we already understood about PV cell solar energy conversion. The other way of conversion of concentrated solar energy to output electricity is by Thermal conversion.
In thermal conversion of solar energy, the basic phenomenon used is heat. As solar energy is concentrated, it is made to fall on a tube containing working fluid.
Working fluid is the fluid which takes heat from the solar energy to use it further. It can be water or oil or other fluid substances based on temperature and process of conversion requirements.
Here as the concentrated solar rays fall on the tube containing the working fluid. It heats up the fluid. Then this fluid flows through the pipe where it is used to provide heat input to the heat engine which converts the heat to electricity. If the working fluid is water, the heat engine driving cycle is generally the Rankine cycle. Here with the heat the water converts to steam by absorbing heat, which is used to drive turbine to generate electricity.
The good thing about it is that here the heat energy can be easily stored to a substance in an adiabatic container which can be used later, making it a dispatchable form of energy. There are different ways in which the thermal energy is stored.

C. THERMAL STORAGE TECHNOLOGIES

There are broadly 2 ways in which thermal energy can be stored – sensible heat storage and latent heat storage.
Sensible heat storage- in sensible heat storage, the heat is stored to a substance in such a way that there is no phase change of the substance.

Mathematically, $q = mc\Delta t$ here m is mass of the substance, c is specific heat of the substance and $\Delta t$is the temperature change due to heat absorption, q is net heat stored in substance. Water is used as thermal energy absorbing fluid for low temperature ranges i.e. less than 100^0C. As at 100^0C, the water changes from liquid to vapour phase.Other fluids like oils can also be used as they have high melting point. We can also use different solid materials like rock, concrete, sand, brick etc.

Latent heat storage- in latent heat storage, the heat is stored in the substance can undergoes phase change. Here most of the thermal energy is stored in the form of latent heat.If we consider initial temperature to be t1 and final temperature to be t2 and the phase change temperature to be t0.
We get, $q= mc\ (t0 - t1) + mL + mc\ (t2 – t0)$
Here c is specific heat and L is latent heat of fusion or vaporisation of the substance depending on its initial phase.

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D. **CSP vs PV CONVERSION**

CSP uses thermal conversion to generate electricity from solar energy whereas PV conversion uses the PV cell to generate electricity.

CSP is a dispatchable form of energy whereas PV cell is generally not a dispatchable form of energy.
As per now, PV cells and conversion methods are quite cheaper than the CSP conversion.
CSP does not have Seebeck effect whereas PV cell conversion has Seebeck effect.
PV can be effectively used on smaller scale whereas CSP cannot be used on a smaller scale.
These are the few differences between CSP and PV solar power conversion.

IV. SOLAR CONCENTRATORS

The basic role of solar concentrators is to use the combination of mirror and lenses to concentrate the solar rays falling on larger area to a smaller area. This increase the intensity of falling solar rays on CSP system.

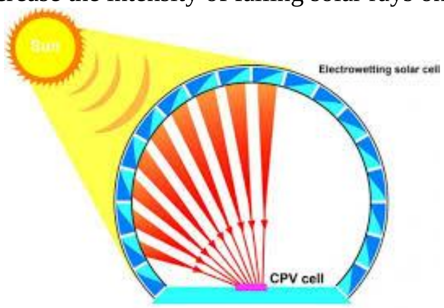

Fig. Solar Concentrator

Let the sunlight falling on atmosphere has intensity is i0. Let the larger area is A1 and smaller area is A2. Let i be the intensity of concentrated light.
Concentrating factor (c) = A1/A2
And i = c.i0 = cA1/A2.
As these concentrators increase the intensity of light and energy of light is directly proportional to its intensity. So more energy is falling on CSP system creating more heat for use. Hence, increasing the net output electricity.

A. **BASIC DESIGN OF REFLECTOR SOLAR CONCENTRATORS**

There are basically 4 reflector solar collector designs – Parabolic Trough, Dish, Solar Tower, concentrating Linear Fresnel reflector

They are broadly divided into 2 categories- Point focus collector, Linear focus collector.
Parabolic trough and concentrating Linear Fresnel collector are linear focus collector types whereas dish and solar tower are point focus collector types.
Linear focus collector types focus the solar rays on the line along which tube containing working fluid is kept. In point focus collector types focus the solar rays on a particular fixed point.
Theoretically, Linear focus collector increases the concentration by factor of 50 whereas point focus collector increases the concentration by factor of 500. But in reality, it is about one-third in both cases due non-ideal factors.

Parabolic trough-

It is straight in one dimension and parabolic in other two dimensions. When light rays parallel to its principal axis hits it, they get concentrated on a focal line which is at focal distance from the aperture point on principal axis.
The tube containing working fluid is kept along the focal line to get maximum concentration of solar rays. We can also place other things on focal line which require heat like food.There are different tracking methods that are used to

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determine the orientation of parabolic trough based on location of sun to get the maximum concentrated solar rays along focal line.Here temperature range of working fluid is 400^0C.

Dish collector-

Dish collector consists of a single parabolic mirror which focuses all the solar rays parallel to its principal axis at focal point. The heat generated is used to drive heat engine. Generally, the heat engine used here is Sterling engine. Here the working fluid temperature can go upto 700^0C. This heat is used to drive Sterling engine to generate power.
These dish solar collector systems provide high solar to electric efficiency (34% to 36%) and their modular nature provides scalability.

Concentrating Fresnel Linear reflector-

Concentrating Fresnel linear reflector consists of two components- reflectors and absorbers.
Reflectors are made of Fresnel reflectors in which the concept of Fresnel lens is used which are better than traditional parabolic trough mirror systems. These reflectors use Fresnel lens effect which allows a concentrating mirror with a large aperture and short focal length while reducing the volume of material. This reduces the cost of the system.
These reflectors are generally kept in north-south direction. But its proper orientation for maximum efficiency is done by computerised tracking system.
The absorber is kept at the focal line of the mirror. It is kept parallel and above the reflectors along their focal line to get maximum heat for the working fluid.
For maximum efficiency, heat transfer between absorber and working fluid should be maximised. This can be done by black chrome coating on the tube as black chrome has good absorbing properties.

Solar tower collector type-

The solar tower power plants also known as known as Heliostat power plant is type of a solar furnace using a tower to concentrate sunlight on it. Initially the heat absorbing substance was water but now different molten salts such as 40% KNO_3 and 60% $NaNO_3$. As these salts have higher phase change temperatures so they can store more heat.
Here generally flat glass is used instead of curved glass as they are expensive. High temperatures around 500^0C can be achieved. Generally, control systems are used to supervise and control all the plant activity.

In the above discussed concentrators, all were using reflection phenomenon to concentrate light with -
Efficiency = 1 – (heat input) / (heat output).
Now considering about all the solar concentrator made by combinations of mirrors and lenses, using reflection, refraction and other concepts, there are 7 types of solar concentrators –
Parabolic concentrator, Hyperbolic concentrator, Fresnel lens concentrator, Compound parabolic concentrator (CPC), Dielectric Total internal reflecting concentrators (DTIRC), Flat high concentration devices, Quantum dots concentrators (QDC).

They can be broadly divided into 4 categories-
Reflection based- parabolic trough, hyperbolic trough, CPC trough
Refraction based- Fresnel Lens concentrator
Hybrid- DTIRC, Flat high concentration devices
Luminescent- QDC

Parabolic concentrator:

The two-dimensional design of a parabolic concentrator is similar to a parabola. It is used as a reflecting solar concentrator. It has a distinct property that it can focus all the parallel rays from the sun to a single focus point.
It is not necessary to use the whole part of the parabola curve for the construction of concentrator. Most of the parabolic concentrator consists only a truncated portion of the parabola.

Currently, there are two available designs of parabolic concentrator.

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By rotating the two-dimensional design along the x-axis to produce a parabolic dish and By having a parabolic trough. Both of the designs act as reflectors and are used mostly in concentrating solar power system in big solar power plant. The EUCLIDES-THERMIE Plant in Tenerife, Canary Island employs the parabolic trough concentrators in the 480kW concentrator project.

The efficiency from collector to grid is (electrical output)/(solar energy input).
Efficiency (X)= 1-(qlost)/(qin)
qlost=q1+q2+q3

where q1=radiative heat loss from the surface of surface of enveloping glass cover.
q2=convective heat loss from the surface of surface of enveloping glass cover.
q3=conductive and convective heat loss of the working fluid to the surrounding

Hyperbolic concentrator:

The general design of a hyperboloid concentrator consists of two hyperbolic sections. The hyperboloid concentrator can be produced by rotating the two dimensional design along its symmetrical axis.
Here the inside wall of the hyperbolic profile is considered as a mirror. The solar rays entering the concentrator from larger area will be reflected and focused to the exit aperture at lower area.
The advantage of this concentrator is that it is very compact. As only truncated version of the concentrator needs to be used. Due to this reason it is mainly used as a secondary concentrator.

Fresnel lens concentrator:

Fresnel lens function is similar to the conventional lens, by refracting the rays and focusing them at one focal point.
It generally has two sections: a flat upper surface and a back surface that employs canted facets.
They can be used in 2 ways: a point focus Fresnel lens & a line focus Fresnel lens
The advantage of a Fresnel lens over a conventional lens is that it is thinner and requires a lesser amount of material to fabricate.One of the disadvantages of this concentrator will be due to the sharpness of the facet. Any error in the manufacturing process could create a rounder shape of the edges of the facets, causing the rays improperly focused at the receiver.

Compound Parabolic Concentrator (CPC):

The compound parabolic concentrator (CPC) has been developed and explained by Welford and Winston. It consists of two segments of parabolas. A CPC can be divided into three parts; a planar entrance aperture, a totally internally reflecting side profile and an exit aperture.
The main advantage of using a CPC is that it could offer a higher geometrical concentration gain with a narrow field of view. The disadvantages of the CPC trough concentrator will be the same as parabolic trough concentrator; it requires a good tracking system to maximise the collection of sun radiation.

Dielectric Totally Internally Reflecting Concentrator (DTIRC):

DTIRC has the ability to achieve concentrations close to the theoretical maximum limits. There are two ways in DTIRC- maximum concentration method and phase conserving method.
DTIRC consists of three parts- a curved front surface, a totally internally reflecting side profile and an exit aperture.

When the sun rays hit the front curved surface, they are refracted towards the side profile then they get totally internally reflected to the exit aperture. The front aperture is a hemisphere but can also be a parabola or a hyperbola.
The concentration gain of a DTIRC depends on both acceptance angle and the front arc angle.
The advantage of DTIRC over CPC is that it offers higher geometrical concentration gain and smaller sizes. Its disadvantage is that it cannot efficiently transfer all of the solar energy that it collects into a lower index media.

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Flat high concentration devices:

These are non-imaging concentrators which can achieve theoretical acceptance angle concentration. There are five available designs: RR, XX, XR, RX and RXI.
Here R-refraction, X-reflection, I-total internal reflection
So RXI means rays first undergo refraction followed by reflection then total internal reflection.They are devised using the Simultaneous Multiple Surface.
These concentrators have some major benefits-they are very compact and offer very high concentration. However, there are some disadvantages of this design. Due to the cell's position, it is difficult to create electrical connection and heat sinking. The cell dimension must be designed to be as minimal as possible to reduce shadowing effect.

Quantum Dot Concentrator (QDC):

Quantum dot concentrator (QDC) is a solar concentrator device that consists a transparent sheet of glass or plasticdoped with quantum dots, reflective mirrors mounted on the three edges and back surface, and an exit concentrating light on a PV cell.
QDC major advantage is that it does not require any computerised tracking system unlike other conventional concentrator. It can also make use of both direct and diffuse solar radiation. However, the drawback of the QDC is that the development of QDC is restricted to high requirements on the luminescent dyes.

B. **CALCULATION OF THEORETICAL EFFICIENCY**

Now let's discuss about the efficiency of these concentrators:

Let Xreciever be the efficiency of the solar receiver converting solar energy into heat, Xcarnot be the efficiency of the heat engine(considered as Carnot engine here with sink temperature To and input temperature achieved by concentrator TH). So for net efficiency X,
X = Xreciever .Xcarnot
Xcarnot = 1-(To/TH)
Xreciever = (Qabsorbed – Qlost)/ Qsupplied

Here Qsupplied is the heat supplied due solar heat concentration, Qabsorbed is the heat absorbed by the reciever and Qlost is the heat lost by receiver. Now if solar flux is Io, concentrating factor is c, A is the collecting area and

Xoptics is the optical efficiency.
So Qsolar = cAIoXoptics
And if a is absorbitivity then

Qabsorbed=acAIoXoptics
If e is the emissivity of the absorbing area and s is the Stefan Boltzmann constant, then
Qlost= AseTH4

Now considering s=1, e=1, Xoptics=1,a=1
We get, X=(1- (s.TH4)/(Ioc)).(1-(To/TH))
So we get,Tmax(max. temperature obtained) = (Ic/s)0.25
Also by differentiating X w.r.t T(temp) and keeping it equal to 0
We can get the value of temperature for which X would be maximum.

V. CSP MAJOR APPLICATIONS:

Heating water: The concentrators are used to concentrate solar rays thus able to reach high temperatures. This heat is used to heat water which can be used for domestic purposes.

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Solar Cooker: The concentrated solar heat can easily attain temperatures high enough too cook food. This can used is mass cooking, drying and pasteurisation. This reduces the use of non-renewable sources like LPG and is also cost effective. The temperatures in them can go more than 300oC.

Accelerating biogas production: Biogas formation process is more efficient at higher temperatures. Secondary heat can be used to speed up the process of the digestion tank turning waste into fuel. This is significant because the biogas can quickly become its own source of renewable electricity or heat or can be further processed to provide a source of renewable fuel.

Now we look at one more interesting application of concentrated solar power:

Solar Thermal Enhanced Oil recovery: Solar thermal enhanced oil recovery (solar thermal EOR) is a thermal enhanced oil recovery method used by oil producers to extract more oil from oil fields.
Solar thermal EOR uses solar thermal arrays to concentrate solar rays to heat water and produce steam. This steam is injected into an oil reservoir to reduce the viscosity of heavy crude thus improving its flow property. It is becoming a viable alternative to gas fired steam production for the oil industries. Solar EOR can also generate the same quality steam like natural gas, reaching up to temperatures of400^0C.There are hundreds of applications of concentrated solar power that can used in daily life. CSP is very effective form of energy and has huge capabilities.

VI.EXPERIENCE IN INDIA AND FUTURE SCOPE:

Due to its renewable nature and dispatchability, it has huge scope in areas of good sunfall. In areas of Africa, middle east, India, china, USA and some European countries, it can create a huge impact on the energy generation. The only thing which can considered as a problem is the price. But for large scale implementation, there will not be much problem because of its extra advantages which gives it edge over the others.

Different countries are undergoing projects based on CSP and energy generation. Saudi Arabia, Spain, Chile, US, India, China are the leading contributors towards Energy generation projects based on CSP.
In India, there is Jawahar Lal Nehru solar mission is on its implementation path in which 7 CSP projects of aggregate capacity of 470 MW is under phase 1 in it. India has currently 52.5 MW of Concentrated Solar power in operation.

REFERENCES

[1] Garg H.P. and Prakash. "Solar Energy- Fundamentals and Applications", Tata McGraw-Hill Education, First revised edition, pp.116-160 ,2000.
[2] Hans Müller-Steinhagen, Freng and Franz Trieb,"Concentrated Solar power a Review to technology", 2004.
[3] Singal R.K. and Singal Saroj. "A selective course in Non Conventional Energy Resources",S.K., Kataria& Sons,2012.
[4] Müller-Steinhagen, H &Trieb, Franz. "Concentrating solar power- A review of the technology". Ingenia, pp.43-50, 2004.
[5] F. Trieb and G. Knies, "A Renewable Energy and Development Partnership EU-ME-NA for Large Scale Solar Thermal Power & Desalination in the Middle East and in North Africa." DLR, Stuttgart Germany, 2004.
[6] Solanki Chetan Singh. "Solar Photovoltaics- Fundamentals, Technologies and Applications", PHI Learning Private Limited, 2012.
[7] Kesari J. P., Sharma P. B., "Empowering India with Solar Energy Technology: A Roadmap at International Conference on Climate Change and Sustainable management of rural Resources", ITM University Gwalior, 5th to 7th February 2012.
[8] Kesari J. P., Krishen, Sharma P. B., "Solar Power is a Panacea for Changing Rural India-The role of CSP under IndoJapan Collaboration", Proceedings of 2nd International Symposium –collaborative research project of CSP for India and Japan, Tokyo Institute of Technology, Tokyo, Japan, 25 April 2012.
[9] Tyagi A. .P, Dir. Gen., "Report on Solar Radiant energy Over India-2009", Chapter-5, Ministry of Earth Sciences,