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A STUDY OF RENEWABLE SOLAR ENERGY SOURCES, REGARDING A COMPARISON BETWEEN THE PHOTOVOLTAIC (PV) SYSTEM AND CONCENTRATED SOLAR POWER (CSP) SYSTEM

Md. Saeed Ibne Mahbub and Md. Shahidul Alam

Department of EEE, International Islamic University Chittagong, Chittagong, Bangladesh.

ABSTRACT

Solar Irradiation reaching earth's surface within one hour is sufficient to fulfill the power demand of whole world for one year, we are using small portion. Available solar power technologies are two: Photovoltaic (PV), Concentrated Solar Plant (CSP). PV uses Photovoltaic Cell made by semiconductor responding to Solar Irradiation to generate Electrical Power and it takes one Sun flux, multiplied Sun flux in Concentrated PV system, works under the principle of Photovoltaic Effect with 19% efficiency.CSP system uses different kinds of reflector to take multiple Sun flux, works with the principle of Thermodynamics using coupled Alternator with Heat Engine or Steam Turbine to convert the heat to electricity, with (20-40) % efficiency. Next century's world will go through fuel crisis, renewable and sustainable energy sources should come to operation. This paper is focusing to find a conclusion regarding which available solar power system could be the best solution for the world.

Keywords: Photovoltaic (PV) System, Concentrated Photovoltaic System, Concentrated Solar Plant (CSP) System, Solar Irradiation, Solar Tower, Parabolic Trough, Parabolic Dish, Fresnel, Stirling Engine, Reflector.

1. INTRODUCTION

Sun is the singular source of renewable energy, proved the largest resource in the world. The average solar irradiance (DNI) reaching the earth surface is 1360.8 watts per meter square [1]. Total world is using only a few of the solar power available on the earth surface that means most of the solar power available on earth is totally being unused. Present world is in search of dependable, available and green power source as today's concern is not to produce power only at present but also for future with same reliability and keeping environment safe. There are two available solar power plant systems those are 1.Photovoltaic (PV) 2. Concentrated Solar Plant (CSP).

As solar is the best solution to meet the power and energy crisis of today's world. A proper study is needed to make the decision about the best available solar power system with less power loss, much efficiency ,more implementation option, easy to set up, low cost per unit, back up during unavailability of sun. Our suggestion is to adopt CSP to cope with today's power and energy crisis as well as of future.

2. SOLAR IRRADIANCE

The energy carried by sunrays on a given area measured as W/m^2 per area is termed as solar irradiance.

Sun intensity of radiation on its surface is approximately 6.33×10^7 W/m^2. Radiation spreads away as distance squared, by the time of its earth travel (1.496×10^{11} m or 1 AU is the average earth-sun distance) the energy falling on 1 m^2 of earth surface radiantly is reduced to 1367 W [2].

As the orbit of the earth is slightly elliptical in shape, the intensity of solar radiation reached to the outside of the earth's atmosphere changes with the square of the distance between earth and sun. Solar irradiance available at earth varies by ±3.4 percent with the highest irradiance occurring at the perihelion (earth closest to the sun) and the minimum at the aphelion. (Earth furthest to the sun). This variation is calculated by the equation:

$$I_o = I_{sc}\left[1 + 0.034\ \cos\left(\frac{360N}{365.25}\right)\right] \quad (\text{W/m}^2)$$

Where I_o the extraterrestrial solar irradiance outside the earth's atmosphere and N is is the number of day.

The extraterrestrial solar irradiance falling on a surface parallel to the ground is,

$$I_{o,h} = I_o \cos\theta_x \ \ (\mathrm{W/m^2})$$

Where I_o is the extraterrestrial solar irradiance, and θ_z, the angle between the two surfaces, which is the solar zenith angle.

The daily extraterrestrial solar radiation on a horizontal surface $H_{o,h}$ is calculated by the equation:

$$H_{o,h} = \int_{sunrise}^{sunset} I_{o,h}\ dt \ \ (\mathrm{J/m^2})$$

Where time *t* is in seconds and evaluated from sunrise to sunset.

The daily extraterrestrial solar irradiation falling on a parallel surface.

$$H_{o,h} = \frac{86{,}400\ I_o}{\pi}(\omega_s \sin\emptyset \sin\delta + \cos\emptyset \sin\omega_s) \quad (\mathrm{J/m^2})$$

The angles$\emptyset$ and δstands for latitude and declination are deω_s is The hour angle of sunset, the constant 86,400 has the implied units of "seconds", the units of the extraterrestrial solar irradiance, I_o must be watts per square meter ($\mathrm{W/m^2}$)

2.1Methodology of calculation:

2.1.1) Pyranometer:

The instrument used for measuring the global horizontal solar irradiance is called pyranometer. When a pyranometer is horizontally oriented, the direct normal solar irradiance is given by the cosine of the angle of incidence, which is termed as the solar zenith angle $\theta_z$the global horizontal solar irradiance is given by the equation

$$I_{t,h} = I_{b,n} \cos\theta_s + I_{d,h} \quad (\mathrm{W/m^2})$$

Where $I_{b,n}$ is the direct normal irradiance coming from the sun, $I_{d,h}$is the diffuse radiation falling on a horizontal surface.

To measure the direct normal irradiance easily an instrument is used named normal incidence pyrheliometer or NIP.

A ratio used to normalize the present location-specific solar radiation is the clearness index $\overline{K_T}$ the ratio of global horizontal solar radiation at the location to the extraterrestrial horizontal solar radiation above that site

$$\overline{K_T} = \frac{H_{t,h}}{H_{o,h}}$$

2.1.2) A Simple Half-Sine Model:

A simple analytical model of calculating clear-day solar irradiance needed to calculate the data required for solar energy system design. The only data needed is the times of sunrise, sunset, and the peak, noontime solar irradiance level.

$$I = I_{noon} \sin\left[\frac{180*(t-t_{sunrise})}{t_{sunset}-t_{sunrise}}\right] \quad (\mathrm{W/m^2})$$

[2]

3. SOLAR POWER SYSTEM

System developed to harness the solar power for producing electrical power by using the available solar energy. Solar Power System (SPS) takes solar irradiance as input to give electricity as output. SPS is the most available renewable power system with the implementation opportunity all over the world. As sun is the largest resource of renewable energy, this system is more convenient than other renewable power system. This system is applicable for both grid connected and standalone system. It gives more range of output power from KW to MW scale. Available solar power systems on the earth are:

4. PHOTOVOLTAIC (PV) SYSTEM

Photovoltaic system is a combination of photovoltaic cell. A semiconductor unit works under the principle of photovoltaic effect. Photovoltaic Effect refers to the fact that when a semiconductor material is energized by the photon energy the outer most electron of an atom is energized and jumps to the conduction band, this electron poses electricity if it finds a close circuit. Photovoltaic cells are made by semiconductors, which are highly sensitive to solar irradiance. When photovoltaic cells are exposed to the sunlight the electron of the outer most shell of the semiconductors are energized and produces a flow of current to the outer circuit.

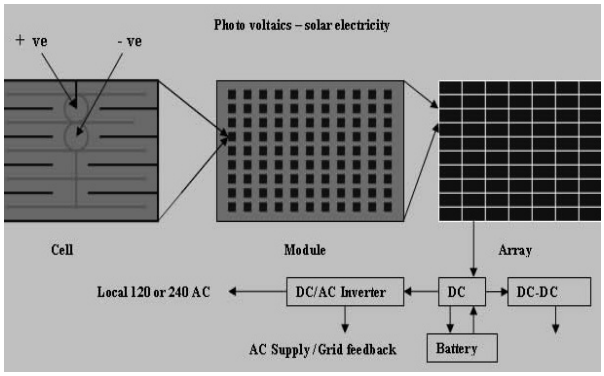

Fig 1. Photovoltaic System

Array:

Photovoltaic cells are arranged together to create an arrangement of photovoltaic cells to produce multiple electricity than photovoltaic cells.

Module:

Combination of multiple arrays for producing electricity in large scale.

PV system takes Solar Flux as input and gives Direct Current (DC) electricity as output. It uses dc batteries for storage purpose. It uses Alternating Current (AC) to Direct Current (DC) converter to feed AC loads.

Two set up of PV system are available:

1) PV system:

This system uses the flux of 1 natural sun to convert directly to the DC electricity. The PV module is exposed directly to the sun light.

2) Concentrated PV system:

A special type of PV system uses multiple sun flux in a concentrated form to produce dc electricity from sun irradiance. A reflection unit turns as concentrator is exposed to the sunlight. The PV module is set at the center of the concentrator, focused by the concentrator rather than the sun.

As it uses multiple solar intensity concentrated PV system is efficient than normal v system. This system includes the application of solid-state technology & nanotechnology.

5. CONCENTRATED SOLAR POWER(CSP) SYSTEM

A power system works under the principle of thermodynamics using sun as the heat source, the working fluid of the system is heated by the sun flux multiplied by the reflection unit namely concentrator. This system is like other thermal power plant, the difference is this system uses different concentrators to energize the sun flux to increase the temperature to 450℃ to 1000℃ [3]. The temperature then used to create steam for rotating the steam turbine or to run the heat engine to produce mechanical torque to generate the electricity from the coupled alternator.CSP system includes mechanical technology.

The CSP system is a system applicable for future electricity expansion. Researches and experiments are being done to increase the efficiency and reduce the initial cost. The different systems are needed to adopt different features to fix the job.

5.1 SOLAR TOWER

This system includes concentrators and a tower at the focal point of the concentrators. the solar irradiance is reflected by the concentrators and centered at the focal point of the tower thus the temperature is rise from 450-650 ℃. The reflection unit turned as heliostat, a large array of adjustable flat glasses. Different concentrators surrounding the tower are used to increase the intensity of normal sun light. Heliostat includes flat silver coated glasses to make the concentrator cheaper. Heliostat multiplies the sun flux to several times. The concentrated solar power is focused to the receiver of the tower. The tower works as the power conversion unit, including water pipes, water is supplied to the pipes and the water turns into steam using the heat of the receiver. The working fluid of the system is water. Previous system used water as only working fluid. Present system includes liquid metal sodium in general or molted salt as intermediary fluid. Intermediary fluid takes the direct heat from the receiver and transfers the heat to the water to generate steam; by using intermediary fluid a fixed range of temperature exposed to the water could be maintained. The generated steam is delivered to the steam turbine for creating mechanical torque. The alternator connected to the steam turbine produces electricity in AC form. The solar tower system takes solar power and gives three-phase AC electric power. The system backed by molten salt as heat storing element gives back up during cloudy day and night.

This system is still going under development. The experiments and researches are being done to increase the efficiency and reduce the initial cost.

By implementing multiple towers rather than 1 tower with same heliostat field and feeding same turbine increases the efficiency of each tower (up to 5% increase in efficiency), low tower provides reduced cost (the cost less by 25%). Super heat steam tower with temperature up to 540℃ can make the efficiency higher (28%), air receiver giving operating temperature ranging between (500-800)℃ gives an increase in the efficiency by 13%, solar fuels deriving solar and chemical reaction increase the temperature (ranging from 900℃ to 1500℃) with an efficiency improved to (37%) in case of solar tower [4]. This system is much more applicable for large power plants where huge land area is available. Such system is the best option for implementing at desert area.

5.2 PARABOLIC TROUGH

A renewable power system that uses a sequence of parabolic curved reflector with a pipe situated at the reflecting center of the reflection unit. The working fluid is used as synthetic oil or liquid gas. The pipe containing the working fluid, made by anti-reflective material and surrounded by glasses is situated at the focal line of the reflector. The reflector is made by silver-coated glass curved as a parabolic trough. The concentrator to heat the pipe as 460℃ concentrates the natural solar heat. The overall system is made up by combining all the reflective units and a unit pipeline travelling through the whole system. The working fluid is heated much more than normal temperature used as to transfer the heat generated by the concentrator to the water for generating steam. The generated steam is used to rotate the steam turbine. An alternator is connected to the turbine for generating three-phase AC electricity. Parabolic trough system provides thermal storage with molted salt for generating electricity when the sunlight is unattainable.

The efficiency of the parabolic trough could be increased and the initial cost could be decreased by using various latest technologies by using thin glass mirror results in higher efficiency and low cost(reduces 25% initial costs). With front surface aluminized reflector makes the system cheaper (reduces initial cost up to 45%) but it reduces the reflectivity less than 90%. All polymeric based reflectors provides the cheapest reflectors material (2/3rd. lower cost than other reflectors) and with an increased reflectivity up to 97% [4].

Parabolic trough is applicable for large scale power plants. It also requires large area but less than required for solar tower.

5.3 PARABOLIC DISH

A unique thermal power plant with a fully parabolic reflection unit and a power conversion unit at the focal point. Segmented glasses with silver coating usually make the reflection unit, there are also available reflection unit using thin polymer film called stretched membrane as reflector. Present system is using stretched membrane with glued mirror. The sun flux reaching the concentrator is energized and then focused to the receiver of Power Conversion Unit (PCU). The receiver is made by thin pipes with working fluid inside. Now hybrid

receiver is applicable for using other heat sources in case of unavailability of sunlight. For heating the hybrid

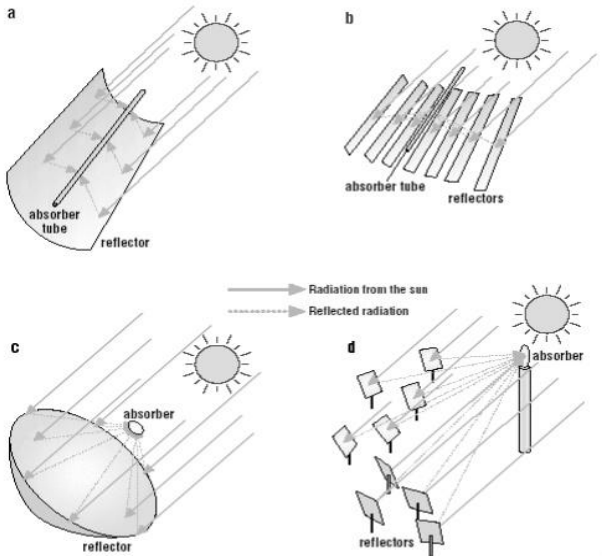

Fig 2. a. Parabolic Trough, b. Fresnel, c. Parabolic Dish, d. Solar Tower

receiver artificially bio gas or bio fuel gives the scopes of implementation for making the system solely renewable and sustainable. Three types of working fluid are available for different conditions. Helium is used in case of low cost system as no intermediary heat transferring fluid is used .Liquid metal generally sodium is used where the fixed range of temperature is needed to transfer the heat of the receiver to the engine. Hybrid receiver containing system uses air as working fluid all through the system. This system contains power conversion unit including a special type of heat engine works under the Carnot cycle with alternating compression and expansion of working fluid, named as Stirling engine after its inventor S. J. Stiring. The difference between the system engine and other Stirling engine is that in normal condition the system engine takes solar direct normal irradiance as input to give mechanical torque or rotation as output. There is an embedded alternator at the power conversion unit to generate three phase AC electricity from the mechanical rotation produced by the heat engine.

This system gives various implementation scopes with a range of KW to MW. As this system is available at KW ranges, it gives the opportunity for home power system installation like home photovoltaic system. This is also useful for large-scale power production replacing other conventional power plant as the hybrid system is backed by fuel source residential consumers has the ability to use the system as diesel generator when sun light is unattainable. The grid connected home parabolic dish system includes the attributes of giving additional power to the grid during daytime and taking power from the grid during night.

Although this system is the most efficient CSP system it is undergoing through development to make the system more cost effective. By using new support structure and producing the required material at low cost region the cost could be reduced (up to 20%). Alternative material using along with iron and leveraging the components from large scale supply chain and assuring supply from low labor cost region the reduction at initial cost is possible (up to 35%). According to the manufacturer of the Stirling engine the cost of the engine will be reduced up to 20% by 2015[4].

The system contains electrification opportunity for both the stand-alone system and grid-connected system. Hence the industries could use this system for being independent on power production. The areas available at the multistoried building's roof top of the mega cities could be used to enable an interconnected power generation system by implementing a unit of parabolic dish system at each building.

5.4 FRESNEL

A green power system includes flat reflectors made by Fresnel lenses with a pipe containing working fluid at the concentration line of the reflectors; the pipe is connected to the steam turbine to produce mechanical torque and electricity from the coupled generator. The Fresnel system includes both the characteristics of the solar tower and parabolic trough. The difference with solar tower is that the tower is replaced by a simple pipe where as it is different from the parabolic trough as it uses Fresnel reflectors which are flat in shape and the pipe is distant from the reflection unit.

This system gives MW range electrification scope. This system uses thermal storage of molted salt to make the system applicable during cloudy day and night. Fresnel lenses are cheaper than mirror. Thus the system is cost effective than parabolic trough and solar tower. This system requires large land areas for setting up. The Fresnel system is using the design of flat mirror to build the concentration unit. This system enables simpler installation and easy production than other CSP system. The land available below the plant could be used for other purposes providing high land per KW.

This system is cheaper than other CSP system still giving the option to make the system more advanced. The cost could be reduced (up to 10%) with the improvement in structure. The use of superheat steam as working fluid increase the efficiency (up to 18%).[4]

6. COMPARISON BETWEEN PHOTOVOLTAIC AND CONCENTRATED SOLAR POWER SYSTEM

Photovoltaic system is less efficient than concentrated solar power system. The efficiency of PV is 19%[5] and of concentrated PV system is 21%[6]. The efficiency of parabolic trough is 20%[6] , parabolic dish is 40%[6] and Fresnel is 27%[6] the CSP system is using solar power more efficiently than PV system thus it is more convenient to use CSP system for reducing the overall cost.

Photovoltaic system is still in R&D phase. To make the power system more advanced it is necessary to change the major portion of the existing photovoltaic system. Concentrated solar power is much more similar to the conventional power plant using solar heat rather than burning fuel or coal or gas and the most efficient

heat engine (in case of parabolic dish). Implementing and financing for CSP system is much more secured than implementing or financing.

The PV system is a solid state and nano technological system. This system includes microelectronic principle. There is no such option to repair the system in case of any damage. The CSP system is mechanical system with the various options of repairing. As it is very much like other thermal power plant; so no specialized person is needed for repairing purpose.

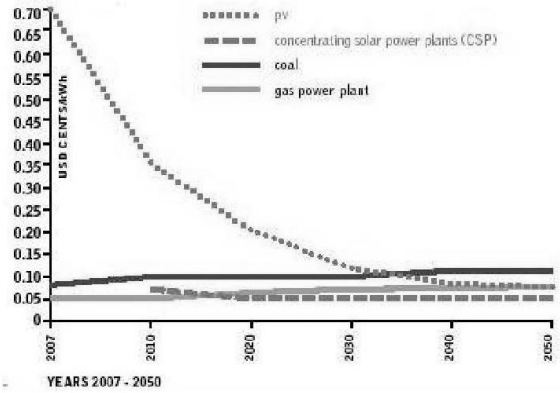

Fig 3. The graph of years versus cost/unit for different power system.

Cost per unit of CSP is less and stable over the year than other power plant system.

The existing PV system gives no option of repairing if the photovoltaic module is damaged due to any fault condition. The whole PV module is needed to replace in such case. This system is much more costly in case of secondary installation. Whereas CSP system gives repairing options; as like as other conventional thermal plant. The secondary installation is also cheaper than PV system as reflection unit need not to be changed.

When the life cycle of PV system is over it is needed to replace the most costly part of the system, which is the PV module. Where as in case of CSP system by repairing or replacing only the power conversion unit the whole system could be up to dated.

The PV system is generating DC electricity. The conversion is needed to feed the most common AC loads. CSP system gives output as three-phase AC electricity. Without providing any conversion process the electrification of both the stand alone and grid connected system could be done.

The PV system provides only dc storage without giving any chances to use the system as base power plant in case of grid connection. PV system could be implemented only as picking power plant. CSP system provides thermal storage and fuel back up for necessary condition. The only renewable power system available with necessary back up could be implemented, as base power plant is CSP.

Interconnection with grid is done by using DC to DC converter, DC to AC converter in case of PV system. Thus the equipment needed for grid connection causes power loss. Using STATCOM and FACTS devices the grid interconnections are done in case of CSP system with less power loss. The grid interconnection of CSP system is easier, cost effective and provides less power loss than PV system.

In case of load variation there is no such technology for controlling the output of the PV system efficiently. The CSP system is a thermal power plant with only difference of using solar heat mainly rather than fuel. As CSP is basically a steam power plant(except parabolic dish system) the electrical output could easily be changed by changing the flow rate of steam in such conditions.

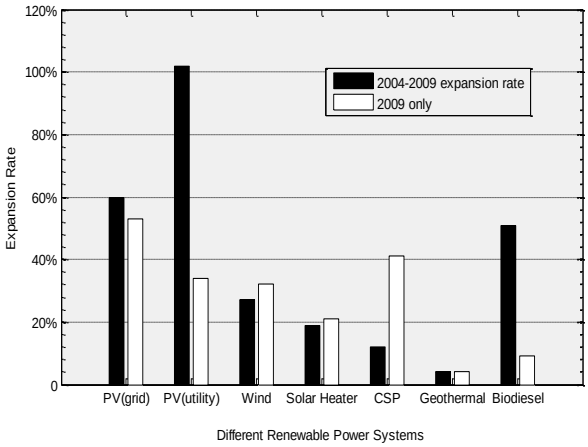

Fig 4. The graph of different power systems versus expansion of the system from the year of 2004- 2009 and 2009 only.

The expansion of PV system is much more than CSP in the year of 2004 – 2009 but when only 2009 year has taken into account the expansion of CSP is greater than PV and it will expand more than PV in future.

The world is now needed an unique and universal green power system. The PV system could be applicable only for developed countries that are much ahead in microelectronic technology. The under developed and developing countries have to be fully dependent to the developed countries for importing PV system and te3chnology. Whereas CSP system is a mechanical system; including the equipment available all over the world. the exception is the stirling engine used at the parabolic dish system, the developing countries could also produce this engine by setting up the industry like other engine industries.

The other thermal power plants could be turned into solar thermal power plant only by replacing the heat generation unit by the concentration unit. CSP is the only system (except parabolic dish) providing this facility of changing conventional power plant into renewable power plant. The PV system does not give such scope for using available infrastructure of the previous conventional system.

Recommendation for the future advancement:

Function / Technologies	Solar collection	Thermal generation	Storage
1.Parabolic Trough	• Mirror size reduction and enhanced accuracy is needed • Optimized support structure design will reduce the implementation cost.	• Advanced receiver characteristics will increase the efficiency •Use of alternative working fluid will boost the efficiency • Higher operating Temperature is required.	•Alternative storage reservoir designs and storage medium compositions will decrease the initial cost and will increase the efficiency.
2. Solar Tower	• Field configuration and heliostat size optimization is required • Optimized tracking system will reduce the **cost**	•By using alternative working fluid advanced efficiency will be gained. • Higher operating Temperature is required. • Improved cycle technology will boost the efficiency.	•Alternative storage reservoir designs and storage medium compositions will decrease the initial cost and will increase the efficiency.
3. Parabolic Dish	• Optimized support structure design will make the system cost effective • Optimized mirror sizes for various solar resources will reduce the cost		• Storage development is needed to use the solar energy more efficiently
4. Fresnel	• Automatic mirror assembly is needed • Optimized mirrors will make the system more cost effective.	•Advancement in receiver characteristics will increase the efficiency •Higher operating Temperature could results in improved efficiency	• Storage development is required
5. Photovoltaic	Use of low cost Semiconductor is needed. •Optimized module Size will reduce the cost.	Not applicable	Advanced converter & battery.

7. CONCLUSIONS

Solar is the best option for world to produce green, sustainable energy for now and future as solar is more abundant and free source with abate carbon emission. CSP is much better option than PV as being compact, easy to handle, much more efficient.CSP system is inexhaustible, immediately available and applicable for all over the world. This is proven and highly reliable system saving carbon (CO2) emissions at low cost[8]. It gives huge nationwide implementation opportunity as it makes the country independent on fuel reducing dependency to the imported fuels ,saves scarce & most valuable natural resources, improves the diversity of energy supply, creates the scope for local investment ,local jobs to develop the local economy. CSP is the system the world should apply to solve the power problem and energy crisis of present and as well as for future.

8. REFERENCES

1. Kopp, Greg and Lean, Judith L, 2011,A new lower value of total value of solar irradiance : Evidence and climate significance.
2. Stine, William B. and Gey, Michael, 2001, Power from the sun.
3. Dr. Richter, Christoph and Teske Sven and Nebrera Jose A., 2009,"Concentrating Solar Power, Global Outlook 09, Why Renewable Energy is Hot",
4. Kearney A. T., 2010, Solar Thermal Electricity 2025, clean electricity on demand, attractive STE cost stabilizes energy production.
5. SolarEnergyNews,www.brighterenergy.org/9715/news/solar/sunpower-offers-solar-modules-Boasting-19-efficiency/
6. Stine, W. B. and R. P. Driver, 1994, A compendium of Solar Dish/ Stirling Technology.
7. West, C.D., 1986, Principles and Application of Stirling Engine.
8. Walker, G., 1980, Stirling Engine.

9.NOMENCLATURE

Symbol	Meaning	Unit
I	Irradiance	(W/m^2)
H	Total daily Irradiance	(J/m^2)
θ, ϑ	Angle	(radian)
δ	Declination	(radian)
φ	Latitude	(radian)
K	Clearness index	
T	Time	s

10. MAILING ADDRESS

Md. Saeed Ibne Mahbub
Department of EEE,
International Islamic University Chittagong,
154/A, College Road, Chittagong-4203, Bangladesh.
E-mail : saeed.ibne.mahbub@gmail.com