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Modeling and Applications of a Solar Dish Stirling Engine in the Perspective of Bangladesh

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Abstract- Background: Energy is the most essential thing to ensure sustainable development and the forward ongoing approach of human civilization. For over the last three decades, the consumption of energy has doubled to the rate it was back in the last century. In our country, the scenario is even worse. In spite of being a promising country the economic development was not achieved the way it was expected just because of the lack of reliable energy source and the proper distribution of its necessary for industrialization. The amount of the total stored natural gas in the country is inadequate and tends to exhaust by the next decade. So, it is high time to find a reliable alternative source for the flawless supply of energy in this densely populated country. This paper focuses on a way to get rid of this prevalent power crisis by utilizing this solar energy using the parabolic dish solar Stirling engine which consists of a concentrator that focuses the incident solar rays to a definite point where a Stirling engine will be located to harness the heat energy and convert it to a mechanical output to be further changed to electricity with the aid of a generator coupled to it. As the fossil fuels will definitely move away soon or later, all the nations of the Earth have become concerned to find the alternatives of fossil fuel, especially a renewable source of energy so that it will never exhaust and therefore a constant assurance of the energy might be found.

Keywords: *solar dish; sterling engine; solar energy; parabolic concentrator.*

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MODELINGANDAPPLICATIONSOFASOLARDISHSTIRLINGENGINEINTHEPERSPECTIVEOFBANGLADESH

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Modeling and Applications of a Solar Dish Stirling Engine in the Perspective of Bangladesh

Shashwata Chakraborty

Abstract- Background: Energy is the most essential thing to ensure sustainable development and the forward ongoing approach of human civilization. For over the last three decades, the consumption of energy has doubled to the rate it was back in the last century. In our country, the scenario is even worse. In spite of being a promising country the economic development was not achieved the way it was expected just because of the lack of reliable energy source and the proper distribution of its necessary for industrialization. The amount of the total stored natural gas in the country is inadequate and tends to exhaust by the next decade. So, it is high time to find a reliable alternative source for the flawless supply of energy in this densely populated country. This paper focuses on a way to get rid of this prevalent power crisis by utilizing this solar energy using the parabolic dish solar Stirling engine which consists of a concentrator that focuses the incident solar rays to a definite point where a Stirling engine will be located to harness the heat energy and convert it to a mechanical output to be further changed to electricity with the aid of a generator coupled to it. As the fossil fuels will definitely move away soon or later, all the nations of the Earth have become concerned to find the alternatives of fossil fuel, especially a renewable source of energy so that it will never exhaust and therefore a constant assurance of the energy might be found.

Materials and Methods: Dish concentrating solar power (CSP) systems use paraboloidal mirrors which track the sun and concentrate solar energy into a recipient where it is absorbed and transferred to a heat engine/generator or else into a heat transfer fluid that is transmitted to a ground-based plant. Dish concentrators have the highest optical efficiencies, the highest concentration ratios and the highest overall conversion efficiencies of all the CSP technologies. If dish Stirling systems are installed in clusters, applications up to 10 MW can be obtained. To recognize the basic working principle and the element of a solar dish Stirling engine is of substantial importance. A dish system consists of the following elements:

(a) A Parabolic Concentrator,
(b) Tracking system,
(c) Heat Exchanger,
(d) Engine with generator and
(e) Control unit

Results: The average annual power density of the incident solar radiation is generally in the range of 100–300 W/m2. Thus, with a solar PV efficiency of 10%, an area of 3–10 km2 is required to establish an average electricity production of 100 MW, which is approximately 10% of a large coal or nuclear power plant. Being different from other energy conversion technologies, solar energy technologies cause neither noise, nor pollution; Therefore, they are often installed near consumers to cut off construction costs. As a result, we can sustain a great advantage of installing it just in places where there is just enough open land to receive enough radiations from the sun.

Keywords: solar dish; sterling engine; solar energy; parabolic concentrator.

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I. Introduction

Finding out sustainable energy sources has been a prime concern throughout the world ever since the price hike in the fuel market during the post Second World War period. Since then, extensive researches have been carried out finding different scopes of utilizing renewable energy sources and developing numerous advanced energy conversion technologies, which has resulted in a number of modern and innovative ideas of finding the alternatives of fossil fuel. [1-10]. As per many researchers, the most reliable source has been the sun till now, and tremendous efforts have been made to harness this energy as this never exhaust till the world ends. Much improved and innovative schemes and mechanisms have been proposed in the last decades to produce electricity and efficiently generating it into the grid in less toiling means [11-15]. As a developing nation, the toughest challenge of Bangladesh is to touch the energy demand and thus to become supreme in power generation. It is projected that the primary energy consumption may be raised up to 37% between 2013 and 2035 [16]. Bangladesh is the 9th most densely populated country of the Earth [17]. 1203 people live in per square kilometer in this country, according to the latest statistical report by the World Bank in 2013. It is one of the least urbanized countries in the world in which 72.24% of people reside in the countryside. It is really clear that the future economic growth and economic evolution of the land will become a big challenge as she has to confront the rapid energy demand by overwhelming deficiency and additional constraints. However, with its 160 million people, Bangladesh could not ensure yet 100% accessibility of power supply [18]. Merely 20% people are now grid-connected [15] and only 42% people are associated with electricity [19] with the vast majority being deprived of a power supply. Per capita electricity use is only 146.5 kWh here in Bangladesh, whereas in India is480.5 kWh and in Pakistan is 456.2 kWh [20]. The current literature indicates that for the developed countries, the average

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per capita electricity consumption is 8009.5 kWh but for the developing countries consumption is 1169 kWh. In addition, for any high-income country, the average per capita electricity consumption is 9789 kWh and for any low-income country, it is 392.4 kWh [20]. Then from all the points, the land has been confronting a severe power crisis for about a tenner. Known reserves (e.g., Natural gas and coal) of commercial primary energy sources in Bangladesh are limited in comparison to the development needs of the country [21]. Power generation in the country is almost entirely dependent on fossil fuels, mainly natural gas, that accounted for 81.4% of the total installed electricity generation capacity (5248 MW) in 2006 [22]. The government of Bangladesh has declared that it aims to provide electricity for all by the year 2020, although at present there is high-unsatisfied demand for energy and is growing by more than 8% annually [23]. Demand supply gaps and load shedding have increased constantly. During the year 2012 the total electricity generation was 35,118 million-kilowatt hours (kWh) out of which 27,795 million kWh was generated from 151 billion cubic feet (BCF) of natural gas [24]. Moreover, in recent years, quick rental power plants have been established to minimize the immediate power shortage, and it simply raised the price of electricity. Also, Various numerical models have been developed to improve the performance of a solar dish by using the pre-heat method [25, 26]. Improved pyrolysis system can also increase the efficiency of the solar dish Stirling engine [27].

However, if combined heating from solar and charcoal firings is provided, it will be more efficient [28, 29].

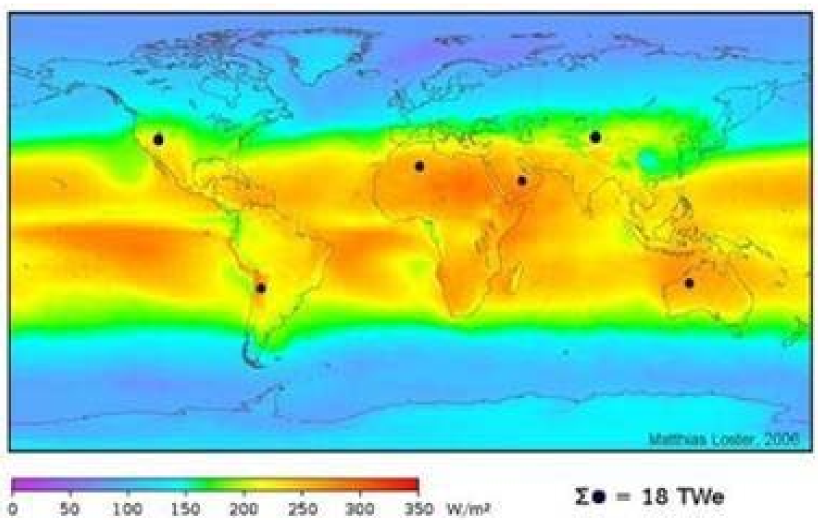

Figure 1: The Solar Irradiation throughout the World

At peak season during summer, the country experiences a severe power crisis that clearly impedances the overall progress of the country with a surprising net deficit of average 1500 megawatt (MW) [26]. Granting to the Energy and Power report of September 2015, at present total 30% of the fuels are imported from abroad for meeting the energy crisis. If this goes on, for meeting the demand of the country by 2030, we have to import 92% of the fuels from outside that will cause a gigantic sum of cost per annum of 17 billion US$. [30]. Thus, in this crucial situation, the only means of survival for Bangladesh is to detect an alternative and reliable power source based on renewable energy.Withal, the geographical location and the climatic pattern might pave the only path out of this giant task of solving the energy crisis, if applied in good order. From all the points of view, the most common source of energy that might provide a solution to this mammoth to take task is the solar energy, according to the opinion of the specialists. The geographical location and the climatic condition of Bangladesh is very favorable for the installment of power plants that can harness renewable energies like solar power. Bangladesh is located between $23^0 34'$ N and $26^0 38'$ N latitude and $88^0 01'$ E and $92^0 41'$ E longitudes and the climate are tropical; the very location makes the Bangladesh good recipient of solar energy [31].Bangladesh has a total area of 1.49E+ 11 m2 and an average 5 kWh/m2of solar radiation goes down on this land over 300 days per annum [32]. Figure 1 clearly demonstrates that Bangladesh got, on average around 200-250 W/m² of sunlight [33].Based on the availability of renewable energy sources, specific conditions, and the technology level in Bangladesh, many renewable energy sources for which commercial technologies exist for power generation has been experimented. Unlike the other renewable sources, this solar energy is also a dilute form of energy, and then the effectiveness and acceptance of a particular solar energy converting system solely depend on the efficiency of the mechanism in harnessing the power, side by side the minimal sum of losses during converting the harnessed

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energy into usable power or more specifically, the electricity. In Bangladesh people are usually well represented with the solar photovoltaic system or the solar PV, solar cooker and so along. This report aims at introducing a safer and a newer concept that already has been shown to be a successful one in many other lands. It is more usually known as Solar Parabolic Concentrator with Stirling Engine.

II. Methodology

The Solar Dish Stirling System: Dish concentrating solar power (CSP) systems use paraboloidal mirrors which track the sun and concentrate solar energy into a recipient where it is absorbed and transferred to a heat engine/generator or else into a heat transfer fluid that is transmitted to a ground-based plant. Dish concentrators have the highest optical efficiencies, the highest concentration ratios and the highest overall conversion efficiencies of all the CSP technologies. If dish Stirling systems are installed in clusters, applications up to 10 MW can be obtained. Above this range, other solar thermal systems may be economical or more effective. Dish Stirling systems have demonstrated the highest efficiency of any solar power generation system by converting nearly 30% of direct normal incident (DNI) solar radiation into electricity after accounting for parasitic power losses [34]. These high-performance solar power systems have been in development for more than two decades, having the principal focus in recent years on reducing the capital and operating costs of systems. Dish Stirling systems currently cost about US$10, 000 per kW installed; major cost reduction will take place with bulk production and further development of the schemes. Significant progress has been formed to improve reliability, thereby shortening the operating and maintenance (O&M) costs of the schemes. As capital costs drop to about US$3, 000 per kW, promising market opportunities appear to be developing in green power and distributed generation markets in the southwest United States, India, the Mediterranean area, southern Europe and Africa [35]. Thus, we can be sure of the availability of this technology here in Bangladesh.

Basic Principles and components: To recognize the basic working principle and the element of a solar dish Stirling engine is of substantial importance. A dish system consists of the following elements:

(a) A Parabolic Concentrator,
(b) Tracking system,
(c) Heat Exchanger,
(d) Engine with generator and
(e) Control unit

a) *Parabolic Concentrator*

The parabolic reflector functions due to the geometric properties of the paraboloidal shape: any incoming light beam that is parallel to the bloc of the saucer will be meditated to a key point, or "focus". So parabolic reflectors can be employed to gather and concentrate energy entering the reflector at a particular angle. In comparison to spherical reflectors, which suffer from a spherical aberration that becomes stronger as the ratio of the beam diameter to the focal distance becomes larger, parabolic reflectors can be made to accommodate beams of any width. This advantage of the parabolic geometry has made it popular and reliable over the spherical concentrator.

The concentrator tracks the sun bi-axially, i.e. In the Zenith and Azimuth direction in such a manner that the optical axis of the concentrator always points to the sun. The solar radiation is concentrated by the parabolic concentrator onto the solar receiver which is located close to the focal point of the parabola. The receiver catches the high temperature thermal energy into a fluid that is either the working fluid for a receiver-mounted engine cycle, or is used to carry the energy to ground-based processes. Normally, highly reflective fabrics are used along the reflector. It might be metalized glass or plastic, thin mirrors, aluminum foils or simply could be the mirrors we use every day in our homes. It might be made fused to a one single reflector surface or can be composed of an accumulation of many smaller reflecting unit parts. Also, the highly reflective properly, they should also suffer the stress as they will be turned out throughout the daytime. [15] Making the concentrator with many smaller segments might be a better approximation for the ground that it will cut costs as we can replace only a portion of it when needs to be substituted. Another important advantage of the mirrors is that they remain almost 100% intact for over the decade just through simple maintenance of cleaning and washing. The only thing that might reduce the reflective efficiency of these glasses are the scratches.

For wide-surface concentrators, the entire concentrator surface is shaped parabolically by a molding operation. With many dish concentrators, the reflector is made up of facets mounted on a standing structure. There is a considerable variety of facet designs that have been used.

The concentrators play 2 important roles. Firstly, concentrating the total incident radiation. And secondly, convert this incident light energy as heat energy for a recipient. From the concept of the geometry and theoretical calculations, all the rays are to be centered in one individual spot. But in practical application, this is unimaginable because of the fact that no surface having 100% smoothness, so some flaws are obvious. And secondly, there are always some dispersion or irregularities. Third and most importantly, the sun is not a point source and thus the light beams are not fully parallel. That is why rather than centering the light to a point, it is rather focused on a really small area compared to the entire area of the concentrator. But it is

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obvious that the flux is maximum at the central zone, and tends to decrease near the edge. The concentrators have a variety of sizes starting from an area of 20m2 or a diameter of less than 1meter to 25meter. The larger the diameter the more the capacity to converge the sunlight, the more the quantity of flux. And based on the concentration ratio it varies from 1500 to 4000.

b) Tracking System

The ways to move the concentrator around the sun associates two ways. The foremost one is Azimuth-elevation tracking that lets the dish turn out in a plane parallel to the earth's surface. The other one is polar-equatorial tracking method in which the dish rotates about an axis parallel to the earth's axis of revolution. The other axis of revolution or the declination axis is perpendicular to the polar axis. The tracking system is governed by the electric motors with gearbox units, as well as hydraulic system is also examined [7].

c) Solar Heat Exchanger (Receiver)

As the proposed engine type is the Stirling engine, the receivers should be employed in a way that will help functioning the Stirling engine properly. As a fact two methods are employed in transferring the concentrated energy to the working gas while using the Stirling engine, The first type receiver, small tubes carrying the working fluid of the Stirling engine, are directly exposed by keeping with the place of direct concentrated solar flux. As in this type of receiver, the tubes carrying the fluid gets illuminated from the radiation, it has been named as Directly Illuminated Tube Receiver (DIR).

In the other instance, the receiver transfers the energy flux through an intermediate liquid metal. The liquid metal vaporizes on acceptance of the heat flux and then condenses on the tubes containing the working gas of the engine. As the vapor comes back as liquid through condensation, this particular type of receiver is likewise called a heat pipe receiver. Again, various study shows that, use of Aluminum as the receiver material results in much better efficiency and the higher temperature difference than that of copper [7].

d) The Stirling Engine with Generator

Brayton engine and Stirling engine are two different types of engines used specifically for this purpose. Stirling engines are preferred for these systems because of their favorable properties like high efficiencies (thermal to- mechanical efficiencies in excess of 40% have been reported to be found), high power density (40–70 kW/liter for solar engines), and potential for long-term, low-maintenance operation. Dish Stirling systems are modular, i.e., each system is a self-contained power generator, allowing their assembly into plants ranging a great deal of variance in size from a few kilowatts to tens of megawatts.

e) The operation of Stirling Engine

Thermal energy provided by concentrating solar radiation can be transformed into electrical energy using a Stirling engine coupled to a generator. Stirling engines are internal combustion engines and thus they use a closed thermodynamic process; i.e., always the same working gas is used within the working cycle. As because of the working fluid being different, diverse sources could be applied as the external supplier of energy, including the solar heat energy in contrast to Otto or Diesel engines where the working fluid is the fuel itself, i.e., petroleum gas or oil. That is why Stirling motors are also suited for solar operation. The basic principle of a Stirling engine is based on the cyclic compression and expansion of gas at different temperature levels to create a net conversion of heat energy to mechanical work. One of the greatest advantages found in such type of engine is that it works on comparatively lower temperature than the rest of the available technologies. And as because it is an external combustion engine, that means a definite working fluid remains throughout the system. Referable to the low thermal inertia, a dish Stirling System reacts very quickly to changes in solar thermal input. Hence steady state operation is achieved within a few minutes after system start.

f) Extraction and Supply of the Harnessed Energy

The generator coupled to the Stirling engine converts the mechanical energy to electrical energy which then can be used individually or can be provided through a dedicated grid system.

g) Solar Home System (SHS)

The system with a larger concentrator and a more powerful engine can be used for supplying electricity in 2-5 houses depending on the size. With appropriate sunlight conditions, the system has proven to be competitive for remote household applications. Such system will run good for the remote zones, marshlands and small islands of Bangladesh like the Saint Martin, Bandarbans, Rangamati and the remotest parts of the Srimongol and the rest of Sylhet where the national grid electricity supply has not reached yet. Installing it on a mass scale might turn the houses to be self-dependent on the field of the daily electricity supply.

h) The Grid System

Variety of grid interactive systems are being tested in countries where extensive utility grid lines are available. A series of these units can be connected and synchronized to the grid using an appropriate power conditioning sub-arrangement that converts the DC energy to alternating current (AC) energy synchronized to the grid energy [36]. Thus, no additional energy storage is necessary. The grid itself is the storage medium for this kind of grid- interactive system, which

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delivers energy to the grid as long as enough sunshine is available out there.

III. Result & Discussion

a) Technical potential of Solar Dish Stirling System

Schematic comparison with the available Solar PV Technology

The average annual power density of the incident solar radiation is generally in the range of 100–300 W/m2. Thus, with a solar PV efficiency of 10%, an area of 3–10 km2 is required to establish an average electricity production of 100 MW, which is approximately 10% of a large coal or nuclear power plant [42]. Being different from other energy conversion technologies, solar energy technologies cause neither noise, nor pollution; Therefore, they are often installed near consumers to cut off construction costs. As a result, we can sustain a great advantage of installing it just in places where there is just enough open land to receive enough radiations from the sun. Thus, identification of suitable locations for the application of solar energy is practically the search for suitable rooftops and unused ground. A study suggested that 6.8% (10,000 km2) of Bangladesh's total land are necessary for power generation through the operation of solar PV to meet electricity demand of 3000 kWh/capita/year [37]. Another study found that total household roof area is about 4670 km2 [39] which is roughly 3.2% of total land area of the country. In urban area (Dhaka city) 7.86% of total land are suitable for electricity generations through solar PV systems. [38]. Looking at the grid availability, only 1.7% of the land in Bangladesh is assumed technically suitable for generating electricity from solar PV [38]. The capacity of grid- connected solar PV is found out using the annual mean value of solar radiation (200 W/m2) and a 10% efficiency of the solar PV system. Thus, the technical potential of grid-connected solar PV in the perspective of Bangladesh is calculated as about 50,174 MW. Whereas the potential market for grid-connected PV systems is in the highly populated urban and electrified areas, the potential market for SHSs is households without access to the national grid network, especially those in remote and hilly areas. Agreeing to a survey report, a market of SHSs of approximately 0.5 million households, expected of reaching 4 million in the future is envisioned in Bangladesh [40]. If an average standard 50-Wp solar panel is considered for each household [41], the technical total capacity will be equivalent to 200 MW.

Now, seeing a crude estimation of the cost of the Dish Stirling CSP, it is even far more efficient than that of the Solar PV systems. Granting to the information provided by Ripasso Energy, they have minimized the usage of land at a great extent, which means we have to cover even lesser land than that of all the present popular photovoltaic (PV) technology along with an increased efficiency of concentration to about 95% spectral reflectivity. It results in a stunning ratio of usage of only an area of 2 hectares of land for one megawatt of energy production [43]. When arrives to the term of Stirling Engine, the same 100 MW electricity output could be found utilizing only 2 km2 of land. Besides, some innovative thinking might result in the minimal usage of land as for using a floating platform or building the modules individually on the rooftops which has been discussed later. From the previously mentioned estimation, for meeting the demand of this same 3000 kWh/capita electricity demand every year, if we consider that a Stirling Engine of the Ripasso Energy remains active for 10 hours daily, it will produce at least 10,000 kWh of energy using every 2 hector of land space. Which means, it will be needed to provide only a land space of 2630 km2 of land compared to the 10000 km2 needed for the solar PV system. It is only 1.78% of the total land area of Bangladesh. And it will apparently use no space if it is possible to utilize just half of the rooftops throughout the country.

Some other advantages are that, when a PV module gets damaged, it will be highly costly to replace it. But if the concentrator damages, it will same as be replacing a household mirror. It uses no toxic materials, whereas though PV panels are eco-friendly, their manufacturing causes huge environmental hazards as they use toxic and expensive materials like Bismuth Telluride.

b) Further Proposition for Modification

Bangladesh is rich in shallow water bodies and the marshlands which remain under water almost the entire year. The haor, baor, canals, large reservoirs are seen almost everywhere in Bangladesh. Whatever might be their source of water, but they usually have no current flow or tide and ebb. These stagnant water bodies might be a useful solution to the problem of the landmass necessary for establishing the solar dish Stirling engine modules. For this purpose, only a small modification of the entire setup could be of great help. Building one or two of these structures on the floating platforms and letting them float near the banks and edges of the water bodies will serve two purposes. Such a setup has been illustrated in the following figure.

It will not only be a source of the required land area, but at the same time it will be a reliable solution to the household power crisis of these regions as because the grid connections are still out of reach to these remote areas. That is, some of these families and villages will be self-dependent in their power supply. As a result, the government will have a one less task to solve regarding the prevailing power crisis.

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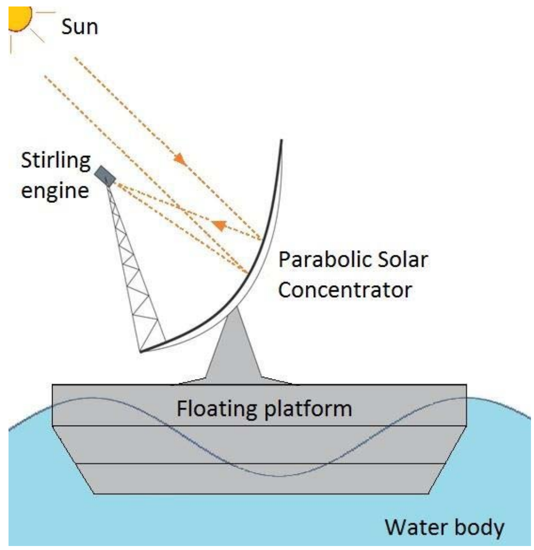

Figure 3: Establishing the Solar Dish Stirling System on a floating Platform in Still Water Body

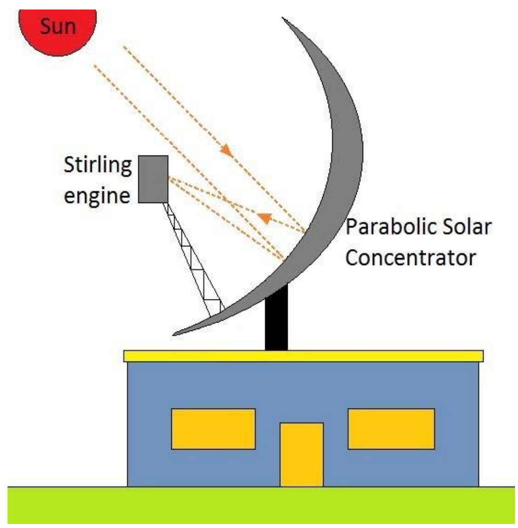

Figure 4: Establishing a Solar Dish Stirling System on a roof top

Nowadays, along with the people getting employed, the villages are developing economically. And it is reflected on the gesture of the homes. Newer houses are built using the modern materials like steel rod, cement which have a good strength and load bearing capacity. So, a highly reinforced rooftop is enough for setting up this system that will help solving the problem related to the place of installation. Being analogous to the dish antenna or mobile tower, the base of the system takes a lot lesser space than that of the disk. So, it will be indeed an excellent idea to set the module on the ceiling or rooftop of the house rather than on the ground to save space.

IV. Conclusion

Among all types of the available solar power harnessing system, this has been proved to be more promising and eco-friendlier. The installed cost might be higher because of the less acquaintance among the people. However, mass scale production might be a solution to this, and further research will surely bring some fruitful result to make it both more efficient and cost effective. When the world has been looking for an alternative source of energy, we should not lag behind as because soon or later, even after paying adequate money, these fossil fuels will not be available. So, in order to avoid this inevitable situation, it is high time to plan carefully for solving these energy related problems in a simple but sustainable mean. Solar powered plants are beyond doubt will lead the world energy source one day. But the earlier introduction to these technologies not only ensures the cost savings of the nation, but also will help to save the environment from the disasters caused by the GHGs, all types of exhaust gases, and side by side the nuclear hazards. The sun is the cleanest source of renewable energy. As all the data and methodology has been described here are now in use, so these technologies are easily available and if

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necessarycare is taken, the modules can easily be produced in our country. Initially the installation cost is high, though it is far minimized by the effective use of it as the modules are robust in design and they are usually built in a way to last for more than two decades with the fully functional conditions [44]. It needs the least maintenance. Simply the regular cleaning of the mirror surfaces can keep it in the original state when it was installed. Lastly, if all things work out and the Government helps to introduce this efficient technology in our country, the long-dreamt self-dependence in the field of energy will soon come true.

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