TECHNICAL VIABILITY OF HOLOGRAPHIC FILM ON SOLAR PANELS FOR OPTIMAL POWER GENERATION

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ABSTRACT
In this paper, holographic film as a static solar tracker for a PV module has been studied. The technical viability of using holographic film over solar plate and its benefits over motor driven conventional tracking system has been investigated. The design aspect of such system designated as HPC solar concentrator and its layout design has been reflected. The working principle of holographic film over solar module has been explained. A comparative study of system in terms of its parameters like cost, size, flexibility, power concentration, efficiency etc have been discussed and analysed. The results and outcome of system reveal that such system show a promising aspect to meet the home energy demand of users in rural society.

KEYWORDS: *HPC: holographic concentrator, PV: Photovoltaic, kWh: Kilowatt hour etc.*

I. INTRODUCTION

Holography is a technique that allows the light scattered from an object to be recorded and later reconstructed so that when an imaging system (a camera or an eye) is placed in the reconstructed beam, an image of the object will be seen even when the object is no longer present. The technique of holography can also be used to store, retrieve, and process information optically. Dennis Gabor is considered the Father of Holography and Holographic Technologies [1]. The first practical optical holograms that recorded 3D objects were made in 1962 by Yuri Denisyuk in the Soviet Union [2] and by Emmett Leith and Juris Upatnieks at University of Michigan, USA. [3]. Advancement in photochemical processing techniques to produce high-quality display holograms were achieved by Nicholas J. Phillips [4]. The new holographic film developed for HP Concentrator [5] when used with solar cell delivered increased power at much reduced size thus eliminating the necessity for large number of solar array. This increased the solar cell efficiency roughly by 40% obviates reduction in cost of power generation. The holographic film is shown in Figure 1(a) & (b).

Fig 1(a) Holographic (HPC) Film (left) (b)1 Giga watt HPC (5.9 million m2) film HPC Film(right)

The lower cost of the energy produced, coupled with the fact that the HPC solar panels are cheaper to make because they use 60% less silicon consequently means that those who decide to use them will

not only be helping the environment, but they will also save huge amount of money with this new technology. The HPC panels can be used vertically as well as horizontally. This means that in the future, windows in buildings or farm houses could be made from the solar panels. The advantages of this are really quite extraordinary. Just imagine a huge high rise building being designed to use the HPC from the start. The building would be able to create its own power. The significance of this is that buildings create roughly 30% of the world's greenhouse gases because of the amount of fossil-fuels they use to generate electricity. The new technology replaces unsighted (usually will not be noticed as being used as window panels) concentrators with sleek flat panels laminated with holograms. The system needs 25 to 85 percent less silicon than a crystalline silicon panel for equivalent power. Further, the photovoltaic material needs not to cover the entire surface of a solar panel. A typical HPC concentrator is shown in Figure 1(b).
In this paper, the working principle of holography has been explained. The design of HPC concentrator of solar plate has been computed and the outcome has been shown. The performance parameters of such system have been analysed.

II. HOW HOLOGRAPHY WORKS

A detailed theoretical account of how holography works is provided by Hariharan [6] . Two holograms next to the PV cell as shown in Fig.2 concentrate light onto the cell due to total internal reflection.

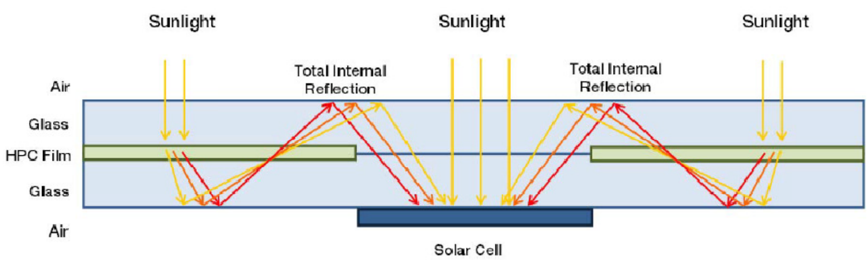

Fig. 2 : Working principle of Holography

III. HOLOGRAPHIC FILM AND SOLAR CELL PERFORMANCE

Worldwide, solar energy output has gone up in recent years, particularly in Europe, China and the U.S. The total output from all solar installations worldwide, however, still remains around seven giga-watts, only a tiny fraction of the world's energy requirement. High material and manufacturing costs, low solar module efficiency and a worldwide shortage of refined silicon have all limited the scale of solar-power development required to effectively compete against coal and liquid fossil fuels. A number of approaches are being explored to improve the cost per kilowatt of solar power, primarily by improving the efficiency of the solar modules, or by concentrating greater amounts of solar energy onto the cells. The Holographic Planar Concentrator (HPC) is one solution that achieves both of these goals.

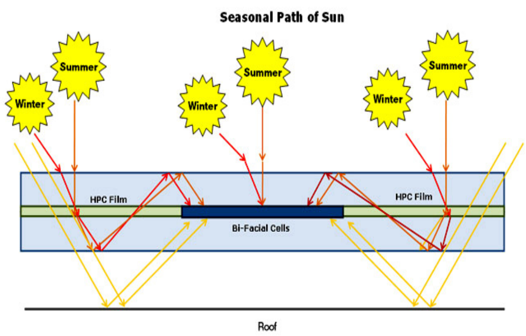

Fig.3 : Bifacial HPC solar module of solar plate

An HPC is built up from several layers of gelatine-on-PET films. In each film holographic optical elements are imprinted using diode-pumped, solid state lasers. The holographic stack diffracts wavelengths that are usable by the solar cells while allowing unusable wavelengths to pass through, unabsorbed. The usable energy is guided via total internal reflection at the glass/air interface to strings of solar cells, resulting in up to a 3X concentration of energy per unit area of photovoltaic material. Fig.3 shows a bi-facial module based on this design. Because of the HPC film, this module uses 50% less PV material than a traditional, fully populated module. The reduction in expensive silicon greatly lowers the module's material cost and also results in manufacturing savings through reduced assembly and processing requirements.

IV. DESIGN ASPECT AND LAYOUT OF HPC SOLAR MODULES

The following parameters are to be considered to design HPC solar module :

- PV Sizing
- PV to Hologram Ratio
- Technology of PV cell and their Conversion Efficiency
- Hologram Stacks Design

The design of HPC solar module is based on harvesting of solar energy. The PV size depend on the load energy requirement of users to be considered. Hologram to PV ratio is the width of two holograms divided by the width of a PV cell. Two holograms are used in this calculation because the two holograms next to the PV cell both concentrate light onto the cell. The data from these modules not only shows the performance of the module but also allows us to predict the performance of modules with different layouts. The layout design of a solar module and practical HPC module has been shown in Fig. 4(b) and 4(a).

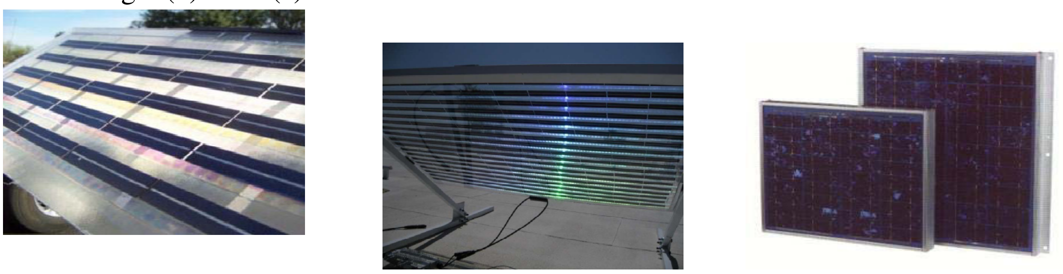

Fig 4: (a) HPC solar stack layout design (Left and Middle) (b) Standard solar module (Right)

A) Design : HPC PV module Sizing

Based on energy balance equation, the empirical formula has been used to compute the optimal size of HPC PV module for demand based load energy requirement at user end as stated below. For energy balance condition [13],

PV stored energy (Wh) = Load Energy(Wh) * S.F (1)

i.e P_{PV} (Wp) * Sun hour * Area of equalization = P_{TL} (Wh) * S.F (2)

Where,

- P_{PV} (Wp) is the required peak power of PV power delivered at noon @STP
- Area equalization factor = 0.5 (approx)
- Sun hour = 6.2hr (total duration during day time in a day) for adopted area
- P_{TL} is total load energy in watt- hours (i.e Total load power over a period of 24 hours in a day assuming hourly load power (P_L) as constant.)

  $$\text{i.e } P_{TL}(\text{Wh}) = \sum_{0h}^{24} (P_L) \quad [\text{Watt-Hours}] \qquad (3)$$

- Safety Factor (S.F)= 1.5 for cloudy weather/low insolation (sun radiation)

From equation (2) and equation (3), considering the PV to Holographic ratio for optimum output :

The optimal number of HPC PV module = (PV to Holographic Ratio x P_{PV} (Wp) / Standard (75Wp or dual 2x36Wp) PV Module (4)

Where,
PV to Holographic ratio can be considered as 0.5 or even less.
The prototype design modules are tested in two different layouts. In the first test, the module was kept normal to the sun where as in the second test, the module is to be mounted in a standard configuration for a fixed solar module on a flat roof facing north - south at an angle 45 degree. The type of PV cell is equally important from efficiency point of view. The holograms are described by bandwidth and diffraction efficiency. The bandwidth is the range of wavelengths that are concentrated onto the cell by the hologram. The diffraction efficiency is the average efficiency over the bandwidth.

B) Benefits : The Bi-facial HPC solar module designed for a typical requirement of home power supply may offer the benefit with the following expected outcome as follows :

- Power production : 20% - 40% per kWp
- PV cell material : 50% - 70% less
- Cooler operating temperature : 10 degree lower
- Non-subsidized market value : $ 0.07/ watt as expected by 2012
- Power generation (watt) : 140 watt during sun hour period
- Size (m2) : 1.0
- Cost : $ 84
- Energy yield (kWh/yr) : High (20% - 50%)
- Manufacturing cost : $0.95/ watt
- Sale Price : $1.25

V. HARDWARE SIMULATION OF HPC CONCENTRATOR

Traditional solar tracking system (Fig.5) based on motor driven unit, are bulky and unattractive. It require huge space also, if installed on roof/ground space. A novel HPC concentrator comprises of HPC film on solar module has been simulated with conventional solar plate system added with lenses and mirror etc and aligned in horizontal plane. The simulated static system thus reduces the size of solar module, concentrate solar radiation from both sides and thus does not require to rotate the solar plate of system. Fig.5 shows component of both conventional dynamic system and non conventional HPC static tracking system which have been considered in this study.

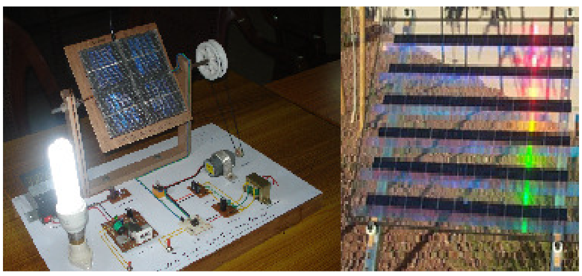

Fig.5 : Solar Tracking System (a) Traditional motor driven (b) HPC Solar Concentrator

VI. PERFORMANCE ANALYSIS PARAMETERS OF HPC CONCENTRATOR : CASE STUDY

A) ***Energy Conversion Efficiency*** **:** Prism Solar Technologies, Inc. USA [4] has developed a unique proprietary holographic planar concentrator (HPC) [7] for use in photovoltaic (PV) module applications. The company manufactures a transparent holographic film that collects sunlight, selects the most useful portions of the spectrum, and focuses that light onto adjacent solar cells. In this technology - 50% of solar cells, the most expensive component of a PV module are replaced with inexpensive holographic film, which lowers the module cost per watt. Thus the result of an HPC module produces 25% more energy (kWh) over a year's time compared to a conventional module resulting in a substantial increase in revenue.

B) *Plant Size* : A prism solar system can be sized smaller and produce the same amount of energy e.g. a 200mW conventional solar plant will produce the same amount of energy in kWh as a 150mW prism solar plant. Increasing the energy yield offers numerous advantages on the system level by reducing the number of peak watts needed to produce a given amount of energy in kWh. The more kWh generated per peak watt means an effective low cost-of-energy through reduced capital expenditure including fewer interconnections and a smaller inverter size and a reduction in operation and maintenance costs for the system. Prism solar modules are also unique due to high performance in diffuse light or cloudy (low radiation)conditions.

C) *Power Generation* : Prism solar has a potential to generate a few hundred watt to one giga-watt with solar module using HPC film by manufacturers worldwide. Currently, most major PV module manufacturers remain in a "commodity" module market with little product differentiation. This provides a significant opportunity for prism solar to offer greater margins and unique benefits enabling to achieve the increased kilowatt harvesting made possible by prism's technology. (Fig. 6)

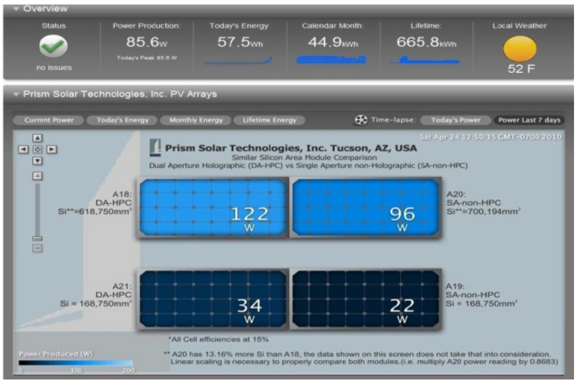

Fig 6: Power generation by HPC at different temperature

D) *Performance Test:* Field tests of the holographic concentrator system are reported by W. Gowrishankar[8]. The performance ratio greater than 1 was observed during the period under investigation. The field tests include comparison of dynamic tracking of solar plate with other flat plate non-tracking PV systems at the same test yard. Predicted yields in terms of Power and Energy are also compared with the data acquired during test.

E) *Concentration of Power:* Holographic concentrators incorporated into PV modules were used to build a 1600W grid-tied PV system at the Tucson Electric Power solar test yard. Holograms in concentrating photovoltaic (CPV) modules diffract light to increase irradiance on PV cells within each module. No tracking is needed for low concentration ratios, and the holographic elements are significantly less expensive than the PV cells. Additional advantages include bi-facial acceptance of light, reduced operating temperature, and increased cell efficiency. These benefits are expected to result in higher energy yields (kWh) per unit cost (Fig 7).

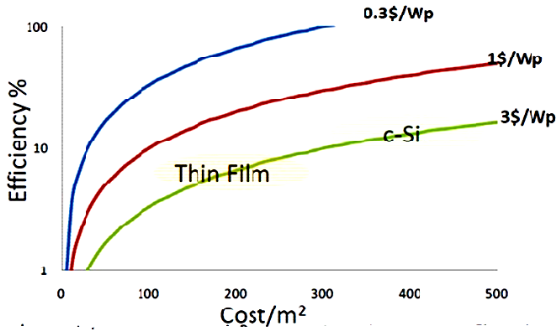

Fig.7 : Cost reduction with increase in efficiency

In their ability to concentrate light, holograms are not as powerful as conventional concentrators. They can multiply the amount of light falling on the cells only by as much as a factor of 10, whereas lens-based systems can increase light by a factor of 100, and some even up to 1,000 [7].

F) ***Cost effectiveness*** : The cost may be reduced and electrical properties improved by utilizing thinner solar cells. Light trapping makes it possible to reduce wafer thickness without compromising optical absorption in a silicon solar cell. In this study, a comprehensive comparison of the light-trapping properties of various bi-periodic structures with a square lattice have been presented. The geometries that have investigated by manufacturer are cylinders, cones, inverted pyramids, dimples (half-spheres), and three more advanced structures, which we have called the roof mosaic, rose, and zigzag structure. Through simulations performed with a 20 µm thick Si cell, the geometry of each structure for light trapping have been optimized . Investigated the performance at an oblique angle of incidence, and computed efficiencies for the different diffraction orders for the optimized structures. This has been reported that the lattice periods that give optimal light trapping are comparable for all structures, but that the light-trapping ability varies considerably between the structures. A far-field analysis reveals that the superior light-trapping structures exhibit a lower symmetry in their diffraction patterns. The best result is obtained for the zigzag structure with a simulated photo-generated current J_{ph} of 37.3 mA/cm^2, a light-trapping efficiency comparable to that of Lambertian light-trapping is noticed [9].

The main limitation of solar power right now is cost, because the crystalline silicon used to make most solar (PV) cells is very expensive. One approach to overcoming this cost factor is to concentrate light from the sun using mirrors or lenses, thereby reducing the total area of silicon needed to produce a given amount of electricity. But traditional light concentrators are bulky and unattractive - less than ideal for use on suburban rooftops.

G) ***Flexibility*** *:* Next, there's the installation cost; as you may notice that in a household PV system, quite a bit of hardware is needed. As of 2009, a residential solar panel setup averaged somewhere between $8 and $10 per watt to install. [Source: National Renewable Energy Laboratory]. It is imperative that the larger the system, the less it typically costs per watt. It is also important to remember that many solar power systems don't completely cover the electricity load cent percent of the time. Chances are, you will still have a power bill, although it will certainly be lower than if there were no solar panels in place.

H) ***Temperature Compatibility :*** High temperatures can cause solar cells to operate at lower efficiency and produce less energy. HPC film keeps the solar plate cooler and give benefits like:

- HPC Film allows wavelengths that cannot be converted by the PV cells to pass through the module rather than being absorbed as heat.
- With HPC Film, the cells operate closer to their ideal temperature.

- HPC modules operate approximately 10 degree C cooler and thus increases the efficiency.

I) Power

HPC can produce more power than the ordinary concentrators. A typical output power as obtained during investigation is shown in Fig .8

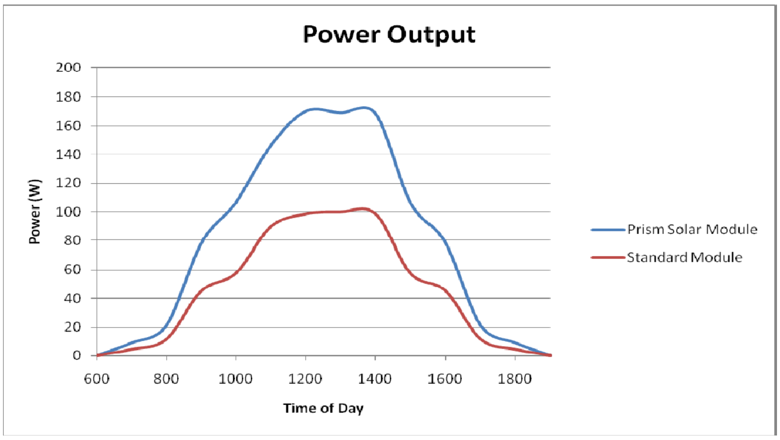

Fig.8 : Power generation with/without HPC

Fig.8 shows the power produced throughout the day Power output of a 100W standard module and the same module with HPC is measured. This data was taken on January 26th 2009. All data was taken when the sun was not blocked by clouds.

J) ***Energy:*** Greater amount of energy is also produced with the use of HPC. Fig.9 shows amount of energy produced during the day for this module as compared to a standard module. The peak power increase of typical module is 55%; however, the total power produced in one day is 60% greater due to the greater efficiency at low light levels.

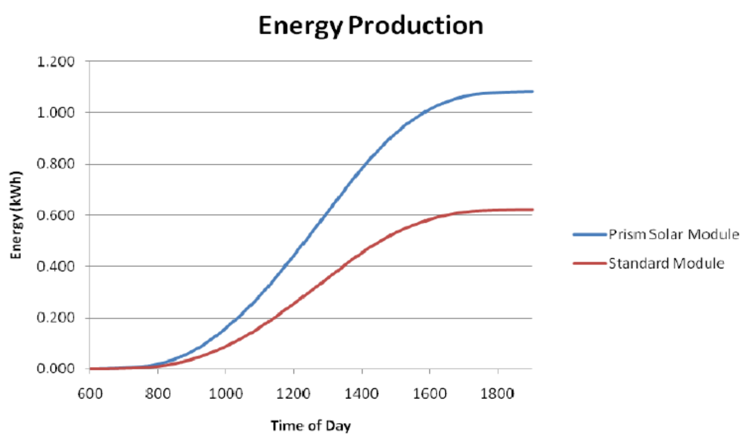

Fig 9: Comparative study of energy produced by prism solar module (i.e HPC solar plate) and standard Module solar plate in a day

VII. Discussion

The future for HPC solar module looks incredibly bright. The HPC solar panels can be used vertically as well as horizontally. This means that in the future, windows in buildings could be made from the solar panels. The advantages of this are really quite extraordinary. Just imagine a huge high rise building being designed to use the HPC solar module from the start. The building would be able to create its own power. The significance of this is that buildings create roughly 30% of the world's greenhouse gases because of the amount of fossil-fuels they use to generate electricity.
Hopefully one day, technologies like the HPC solar module will help us to eliminate the need for fossil-fuels, and will help us to create the greener environment. The future of holographic film implementation in solar panels for power generation in India is yet to be initiated in the rural society. The Government has not paid due interest towards this field. The implementation of this project in India largely depends on self-production of holographic films in our country on a large scale. This technology has become possible in a developed country like China because they can produce these films on their own so that when these plates are implemented in solar cells, the cost increases negligibly. This technology has also been adopted in a few more countries like USA & UK whilst the method used in USA relies heavily on large-scale development of this technology so that the overall cost decreases, whereas in UK, these have been more or less implemented in conservatories. Despite the sticker price, there are several potential ways to defray the cost of a PV system for both residents and corporations willing to upgrade and go solar [10,11,12]. These can come in the form of tax incentives, state subsidies, utility company rebates and other financing opportunities. Plus, depending on how large the solar panel setup is and how well it performs it could help pay it off faster by creating the occasional surplus of power. Finally, it is also important to factor in home value estimates. Installing a PV system is expected to add thousands of dollars to the value of a home.
To implement this holographic theory in India, a large-scale planned production or self-production is compulsory. That is, the future of this tremendous concept is not far away in India too. The design aspect of PV sizing and feasibility study of implementation of HPC PV system has been discussed by authors as reported in his paper [13].

VIII. Conclusion

In the proposed scheme, the use of HPC plate on solar module has been explained. The test results carried out by organisation or individuals as reflected by different authors in their papers in the past show a promising aspect of such PV system. From the result, it has also been revealed that HPC increases solar cell efficiency by 40-50%, reduces the size by 50%. The green electricity generated by the proposed system can be used in the remote areas where grid availability is either very poor or not available. As discussed in this study, the implementation of system will reduce the level of hazarders gases i.e CO_2, SO_2 etc emitted from fossil fuel in conventional system and thus keep the environment clean and green. The intelligent system will reduce the electricity bill of home and create employment opportunity for potential youth specially in villages. The literacy rate is expected to increase by a factor of 40% - 50% and the economic status of villagers in India will certainly increase.

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Biography

S.N. Singh had completed doctoral PhD degree at the Department of Electrical Engineering, National Institute of Technology Jamshedpur (India). He obtained B.Tech degree in Electronics and communication engineering from BIT Mesra, Ranchi - Jharkhand (India) (A Deemed University) in 1979/80. Presently his area of interest is *solar energy conversion technology.* He had published more than 45 papers in National and International journals based on his research work. He had remained *Head of Department of Electronics and Communication Engineering for* two terms and presently heading Govt of India sponsored VLSI SMDP-II Project.

Rakesh Kumar had completed M.Sc. Engineering Degree in Power Electronics from the Department of Electrical Engineering of National Institute of Technology Jamshedpur (India) in the year 2003. He obtained his B.E degree in Electronics & Communication Engineering from RIT Islampur –Maharastra (India). Presently he is working as Associate Professor in the Department of Electronics & Communication of R.V.S College of Engineering & Technology, Jamshedpur. His field of Specialization is in Power Electronics and Industrial control. He has completed several projects on Holography and allied field.

Preeti Saw is pursuing her B.Tech degree in Electronics and Communication Engineering from R.V.S College of Engineering & Technology, Jamshedpur(India). She has keen interest in doing innovative research project on solar power conversion technology. She had published one paper in International journal. Presently she is doing project **o**n ‘*Technical viability of holographic film on solar panels for power generation’* She is also investigating and carrying out the impact study of solar electricity on socio economic development of rural tribal sectors in the Jharkhand state of India.