Combined Thin Film Photovoltaic and Reflective 3D Parabolic Panels for Utility-Scale Solar Dishes

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Abstract

This paper describes innovations which are aimed at "overcoming the implementation lag" in solar energy commercialization within the utility industry. Existing sustainable solar energy technologies have been shown to be "good enough" for electrical utility generation; however, to promote their widespread adoption, they must be made more economical than non-sustainable fossil-fuel generators. New advances in solar thermal concentration for generation by Stirling engine technology, perhaps combined with thin-film photovoltaic (PV) technology, promise to reduce the cost of electrical power generation below that from natural gas powered generators. The solar concentrator is a large parabolic dish made up of a number of mirror panels, as in previous technology. The innovation is that the panels consist of many identical, interlocking, metallic flat-plate reflector elements. This construction provides many advantages. The recent advent of thin-film photovoltaic (PV) technology gives rise to a new "see-through" application — the combination of concentrator and PV technologies. This white paper discusses the possibilities and advantages to be gained through these innovations.

INTRODUCTION

Photovoltaic (PV) electrical generation has become more efficient in recent years, but it still has been unable to move beyond very limited, special purpose usage, and it is only able to capture a relatively small amount on the incident radiation. The cost of silicon solar cells makes the time for recovery of investment too long for utilities to consider their use; it has confined them to applications such as space, localities without convenient utility power, and dedicated conservationists for whom the cost is not the primary consideration. More general acceptance of PV electricity requires better economics.

However, solar power is more than just light — to fully utilize the bountiful solar power readily available, it is necessary consider a wider spectrum of solar energy. Tests have proven that three-dimensional (3D) solar thermal concentrators can provide the high temperatures required for utility and industrial thermal applications. The demonstration in 1984 by Sandia/SES of a 25kW concentrator and Stirling engine generator system was a technical success that opened the way for further large 3D solar concentrator development.

Disappointingly, as successful as the demonstration was, current dish designs for utility-scale applications are still based on its quarter-of-a-century-old technology. Yet there remain many issues of economics, durability, maintenance, weight, transportation, ease of construction, and life cycle cost for utility-scale solar concentrators. For example, although Sandia/SES generated power that was fully acceptable for the electric grid, the costs of maintaining the system led to its abandonment after a relatively short time. Because the mirrors were glass, they were heavy and fragile, requiring a sturdy and heavy structure to support them and hold the parabolic shape as the dish tracked the sun. The silvered mirror surface also was susceptible to degradation or damage, and its reflectivity was only moderate in much of the solar thermal spectrum. "What remains to be demonstrated," noted NREL's Sara Kurtz, who leads the lab's high-efficiency solar research, "is whether solar concentrators – especially their sensitive optics – will prove reliable in the field."

Describing a press conference in Paris by Todd D. Stern, the State Department Special Envoy for Climate Change, the May 27, 2009 *New York Times* "Dot Earth" blog <http://dotearth.blogs.nytimes.com> reported:

> "The United States is proposing to make a seismic change in U.S. policy," he said. "The president is proposing to do that, and Congress as well is in the middle of working on this."
>
> "We're probably the only country that's talking about actual hard mandatory policy all the way out not just to 2020 but 2025, '30, '40, '50, not simply goals," Mr. Stern said.
>
> "We've got a huge problem we're facing," he said. But added that the world has to be realistic as well, avoiding overly ambitious agreements that, while flashy, can't be carried out. "My watchword, throughout all of the time I've been in office, is science and pragmatism," Mr. Stern said. "We need to have an agreement that is

consistent with the science but that is also pragmatic so you can actually get it done."

To meet the presidential goals, utilities, the U.S., and the world needs fields of modular solar power collection systems that are light, efficient, and cost-effective to install, and that have lower maintenance concerns than current systems and greater robustness in harsh environments, such as blowing sand. Solar thermal concentrators combined with thin-film photovoltaics could well be the commanding technology for such solar power applications.

SOLUTION

The solution to the problem stated above is a new generation of 3D solar concentrators that lends itself to utility-scale applications. The proposed Solar Thermal Concentrator (STC) dish is innovative, going beyond the 1984 technology of the Sandia/SES project and overcoming its limitations. A large electric utility system made up of mass-produced 50kW STC modules with an advanced Stirling engine and generator should be able to generate utility-grade electric power at the $0.85 per kWh cost quoted for natural gas fired systems, but with less maintenance and no ongoing fuel costs. The addition of transparent thin-film PV sheets to increase the power generated holds promise of providing an even further cost advantages. The performance improvements that modular electric generation by solar thermal concentrators with Stirling engines and transparent thin-film PV sheets provide will make this new technology a viable and preferred option for electric utilities. A search of over 30,000 patents has shown that the technology described below represents innovations in dish design and reflective coatings.

<u>The Solar Thermal Concentrator</u>:

The principal problem with current solar concentrator dishes is their use of glass mirrors. The new technology to replace curved glass mirrors is a faceted panel of flat-plate reflective mirror elements (see Figure 1). The proprietary connectors joining these identical metallic elements together are adjustable so that the reflection from each element falls within the target area of a Stirling engine.[1] Typically, that target area is eighteen inches across and the individual elements are ten inches square, an optimal size for maintaining full concentration of the sunlight on the target while allowing for some inaccuracy or deflection of the elements. These faceted panels have the advantage that they are

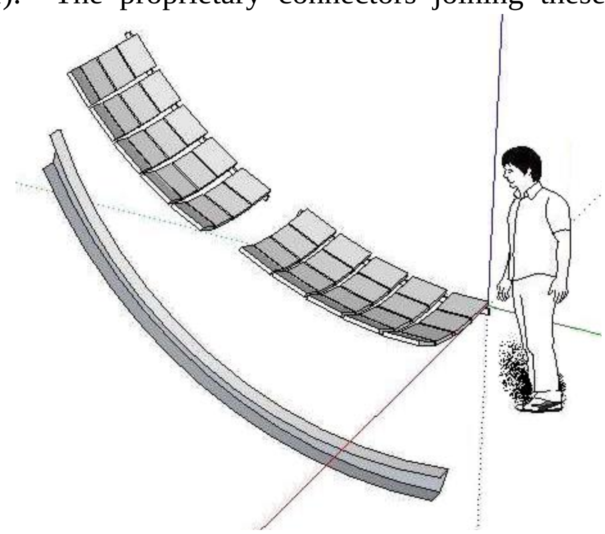

Figure 1. Sketch of faceted mirror panels

[1] The connectors, reflective coatings, and certain other details are proprietary information or the subjects of patents applied for and the property of Genei, Inc.,

more robust, lighter, easier to construct and transport, and lower in cost compared to fragile, heavy, expensive conventional curved glass mirror panels.

Note that the STC itself has a large cost advantage over conventional glass-mirror concentrators because the STC's optimally sized, interlocking mirror elements are light weight and load bearing and so do not require the cost of a heavy metal support structure. Mounting the lighter weight dish on a lighter supporting frame improves this cost advantage further. Moreover, this weight reduction translates into substantial savings in transportation costs to the remote locations that are most suitable for solar power collection fields.

A second new technology is the reflective surface of the mirror elements. There are three different coatings proposed for the elements (see photos in Figure 2).

Figure 2. Photos taken under the same cloudy day conditions

- The "good mirror element" is tough, durable, non-oxidizing, and resists the worst desert erosion. It thus does not need glass protection or layers of abrasion- and UV-protective coatings. Although its thermal reflectivity is somewhat less than glass mirrors, it would be very cost effective for large utility applications, especially factoring in its long lasting and low maintenance characteristics.
- The "better mirror element" has a proprietary one-coat, extra hard, abrasion protective coating over a high-reflectance surface on a metallic substrate. The protective layer has sufficiently high transparency that this element's thermal efficiency surpasses that of glass mirrors.
- The "best mirror element" has a coating that reflects more of far-infrared thermal energy than the other two; the one-coat hard coating protects it also. Unlike first-surface silver, it is resistant to UV and oxidation and thus does not require glass or multilayer coating protections. Independent laboratory measurements show that it is 15 percent higher in efficiency over a wide range of solar energy compared to the "better mirror element," so it is especially well suited to applications where space is limited. In addition, there is a process for recovering and recycling this coating material that makes the life cycle cost lower than conventional glass mirrors, for which silver recovery is uneconomical.

Among these three reflective elements and the solar concentrator dishes built from them are the improvements in economics, durability, maintenance, weight, transportation, ease of construction, and life cycle cost that can satisfy the needs for utility power generation.

Thin-Film Photovoltaic Technology:

A new development in photovoltaic technology promises to make its use on a large scale feasible. Companies such as SunGroupUSA are now producing thin-film photovoltaic (PV) sheets that, although of lower efficiency than monocrystalline silicon cells, are much lower in cost. In addition, SunGroupUSA's PV sheets are transparent enough to suggest new applications. Among these are the use of thin-film photovoltaic panels on windows in buildings with large expanses of glass area, such as greenhouses and high-rise office buildings, to take advantage of thin-film electric generation as well as sunlight utilization (see Figure 3). The thin-film PV sheets from SunGroupUSA are now a well proven technology, having been used for the Beijing Olympics (accepted as meeting both the Olympic Project energy savings and environmental criteria) and in such large building projects as the window curtain walls of the Princess Tower (tallest apartment building in the world) and Gate Tower in Dubai.

Figure 3. Installation of SunGroup thin-film PV panels

Next Step:

The next step is the combination of thin-film photovoltaic technology with thermal solar concentrator technology to obtain the maximum energy from the sun. The discrete-element construction philosophy for the faceted parabolic STC dish assembled from flat reflective elements lends itself well to be fitted with transparent thin-film PV flat sheets for solar power applications. A serious investigation of the combined solar thermal concentrator thin-film PV concept will be required to demonstrate the relative feasibility of the various configurations of the PV sheet on or above the reflective elements and to design and produce a large-scale working prototype of a selected configuration. Only then can utilities be engaged for a demonstration of the full commercialization concept.

To this end, Genei and SunGroupUSA are collaborating with the World Harmony Organization to propose that the U.S. Department of Energy (DoE) fund an examination of the innovative and transformational technology represented by STC combined with thin-film photovoltaics. The first phase will be to perform full thermal and electric generation measurements of five 50"x40" parabolic mirror panels consisting of individual 10"x10" mirror elements with attached thin-film PV sheets as shown in Figure 1. The five 50"x40" parabolic mirror panels will serve to test different mounting or attachment configurations of the thin-film PV sheet on or above the 10"x10" flat mirror elements and to determine which SunGroupUSA thin-film PV sheets, having various degrees of transmittance and electric power output, provide the highest combined efficiency.

The second phase will involve the design, manufacture, and test a large-scale prototype. The purpose of this phase is to validate that the benefits shown by the concept demonstration can be scaled to a full-size 50 kW electric generation module. The third phase will engage manufacturing partners to commercialize the combined solar thermal concentrator and thin-film PV power generation concept in a utility application. This phase should lead to broad acceptance of the concept by the electric utility industry.

Note that the 10”x10” load bearing, interlocking, flat mirror elements with transparent PV sheets and the 3D faceted mirror panels assembled from them can be custom sized for various new or retrofitted solar thermal dish applications. Figure 4 shows how a combined thin-film PV and light-weight metallic mirror panel design could replace glass mirrors in concentrators such as this Sandia/SES electric power generation dish. Shown are the heavy, expensive standard 4'x3' curved glass mirror panels of 1984; each replacement panel would be a 50"x40" faceted mirror, consisting of twenty identical, inexpensive, light-weight, interlocking, optimized, load-bearing, 10"x10" flat mirror elements

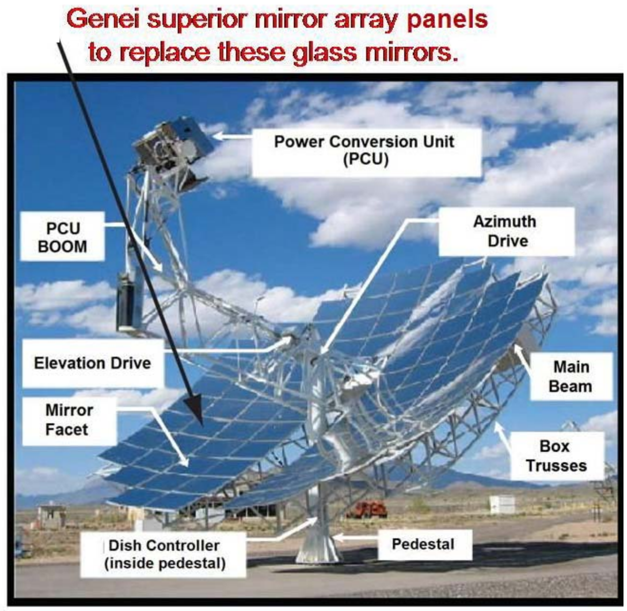

Figure 4. Sandia photo of their STC dish

Cost Advantage of the Concept:

The cost advantage of combined solar concentrator and thin-film PV modules will depend on a number of factors. While sources and costs of most materials are known, labor costs and factors affected by the STC design details are yet to be determined. In addition, there are factors affected by the thin-film PV sheets, including their transmittance, diffusivity, and reflectivity, their mounting or attachment configuration, and the resulting additive power generation capability that the STC/PV design can attain. These factors are the subject of the project’s first phase. However, the cost advantage is expected to be substantial enough to make this system a preferred option for the electric utility industry.

CONCLUSION

The addition of the transparent SunGroupUSA thin-film PV sheets over the reflecting surface of the faceted solar thermal concentrator (STC) dish should substantially increase the power generated per unit area of the dish. Consequently, each STC module could generate more power, or the STC dish size could be decreased. The greater power per unit area will decrease the environmental impact of solar power generation by decreasing the overall size of the field of collectors needed to generate a given number of kilowatts of electricity.

Because the thin-film PV sheets are relatively inexpensive (compared to the cost of conventional PV silicon chips) and the mounting will be simple, the percentage increase in cost of the combined STC/PV dish will be substantially less than the increase in power it is expected to generate. Thus, a large electric utility system made up of mass-produced 50kW STC/PV modules should generate electricity for substantially less than $0.85 per kWh, quoted for natural gas fired systems. But, the STC itself already has a large cost advantage over conventional glass-mirror concentrators because the STC's optimally sized, interlocking mirror elements are low cost, light weight, and load bearing; not only does the lighter weight dish not include a heavy and costly metal support structure, a lighter, less expensive frame can support it. All of this weight reduction, even with the PV sheets added, translates into substantial savings in transportation costs to the remote locations most suitable for solar power collection fields.

The first phase of this project would test several simple configurations for mounting the various thin-film PV sheets on the reflecting elements to determine their highest combined efficiency. Later phases would mature the concept to the point of acceptance as a preferred option by the electric utility industry.

We believe that power generation by the proposed solar thermal concentrator and Stirling engine combined with transparent PV thin films is the most scientifically testable and pragmatic technology for advancing the "seismic change in U.S. policy" the president has proposed. Moreover, it will create a large job market for solar power manufacturers and help dispel the current financial crisis.

ADDITIONAL INFORMATION

There is additional information on the Genei Website <www.genei.us>.

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