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**DEVELOPMENT OF A RETRACTABLE PV ARRAY
FOR EASY RETROFITTING OF EXISTING HOMES**

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ABSTRACT

The cost of retrofitting PV onto existing homes is high due to the challenge of custom designing small systems to fit existing roofs. The roofs may not have the necessary solar orientation or exposure and may be cluttered with obstacles such as vents and chimneys, etc. This paper presents a concept for a retractable pre-packaged PV system that could be installed over patios, decks, parking areas, roofs, or any suitable space around existing homes. It will be big enough to meet residential power needs, in a lightweight tensile saddle structure that retracts at high wind speed (20 to 30 mph). A system has been designed and a prototype built (without PV material) for evaluation.

1. INTRODUCTION

1.1 Why a Retractable PV Array for Homes

There are over 50 million existing homes in the United States that could potentially produce more than 100 gigawatts of distributed photovoltaic (PV) power to supplement the 800 gigawatts of grid generating capacity. The benefits would be enormous: power matching the grid's peak needs, reduction in greenhouse gases, power for recharging plug-in hybrid vehicles (thus reducing foreign oil demand), greater grid reliability, and other vehicle-to-grid benefits, and much more. However, PV systems installed on existing homes are often done by do-it-yourselfers or inexperienced electricians who cut corners to cut costs or out of ignorance of the special needs of DC components. These systems often do not meet the National Electric code,

may be unsafe, and may not provide the performance or life expected. John Wiles lists some of the more prominent problems in Sandia Report SAND 2005-0342.

- Improper ampacity of conductors.
- Improper types of conductors.
- Improper or unsafe wiring methods.
- Lack of, or improper overcurrent protection on conductors.
- Inadequate number and placement of disconnects.
- Improper application of listed equipment.
- Use of non-listed components when listed components are available.
- Improper system grounding.
- Lack of, or improper equipment grounding.
- Use of underrated hardware or components.
- Use of AC components (fuses and switches) in DC applications.

Despite these problems, distributed photovoltaic power has great promise in alleviating peak power loads on utility grid systems. The integration of new thin film PV technologies into building materials, such as roofs and windows, should significantly increase the cost effectiveness of photovoltaic power, especially in new construction. But the most promising area for distributed PV power is on existing homes. Unfortunately, the balance-of-system costs for these systems remain high due to the challenges of adapting to existing structures. New BIPV (Building Integrated Photovoltaics) in roofs and windows will not alleviate these costs much, due to the design and installation difficulties associated with the replacement of built-in home products.

In addition, existing roofs and windows may not have the necessary solar orientation and exposure, and roofs may be cluttered with obstacles, such as HVAC units, vents, chimneys, etc. Moreover, the replacement of existing roofs and windows, which have 20 to 30 years of remaining useful life, would be hard to justify. Finally, as John Wiles points out above, the DC components and wiring needs of PV systems are foreign to a populace so used to alternating current.

These problems add to the complexity and balance-of-system cost of retrofitting PV onto existing structures. For PV to successfully tap this huge distributed market, the engineering and installation of retrofit PV systems must become less complicated and costly, and the installed systems must be less prone to safety and reliability problems, especially for small residential applications.

What is needed is a BIPV product with all proper DC wiring and components pre-installed, which could easily and economically be retrofitted onto existing homes. This could solve the above problems and enable the rapid growth of distributed PV power, greatly benefiting customers and utilities. However, such a pre-packaged system of any significant size would be difficult to achieve using rigid crystalline silicon PV modules.

1.2 A Pre-Packaged, Retractable, Flexible, Thin Film PV Array with Integrated DC Components and Wiring

Some thin film PV technologies have the potential to be fabricated onto flexible substrates, allowing them to be rolled up. Such materials could be integrated into a retractable system that could provide both shade and PV power. This is a new form of BIPV that combines an entire photovoltaic array with a lightweight shade structure that could be easily retrofitted over patios or parking areas. Such a system goes beyond most BIPV products; it could be manufactured with DC wiring and components integrated, eliminating junction boxes, intra-array wiring, and more. At least ten U.S. companies are working on or making thin film PV products that potentially could be adapted: Nanosolar, Miasole, DayStar Technologies, Uni-Solar, Iowa Thin Film (now PowerFilm Solar), Global Solar, ISET, Konarka, First Solar and Ascent.

Perhaps the most compelling advantage of a retractable thin film PV array is the potential cost savings of the resulting lightweight materials and structures. The reason for this assertion is as follows:

All permanent structures must be designed to withstand the maximum wind speed expected in a 50-year period. Figure 1 shows a U.S. map denoting maximum wind speeds utilized for building purposes. In most parts of the U.S.,



this maximum is 90 mph (40 meters per second), with parts of the Gulf and East Coasts as high as 150 mph (67 meters per second).

Fig. 1: Maximum 50-year Wind Speeds in the United States Based on International Building Code Data.

Most of the time, the wind speed is far below the maximum. Figure 2 shows the percent of time the wind exceeds various wind speeds for a typical region that has a maximum wind speed of 90 mph (40 mps). Note that the wind reaches 1/3 of maximum speed, 30 mph (13 meters per second), less than 5% of the time.

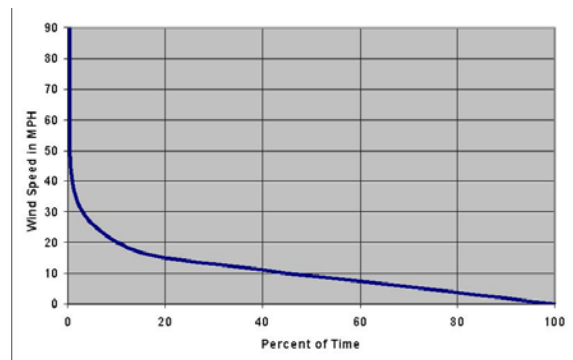


Fig. 2: Graph of Percent of Time the Wind Exceeds Various Wind Speeds for Typical Region with Maximum Wind Speed of 90 mph (40 meters per second).

Consequently, a PV system designed to automatically retract when winds exceed 25 mph (11 mps) would typically lose no more than 10% of available solar power. Note that the wind load force is proportional to the square of the wind speed: if the wind speed at retraction were 28% of the maximum speed, the wind load force would be less than 10% of the maximum load. Therefore, the retractable PV system, along with structure supporting it, could be

designed to withstand 10% to 20% of maximum wind load, compared to 100% for a permanent structure. This has great potential for reducing the cost of materials and structures, and the cost of PV power.

The combination of a lightweight shade structure with a retractable system that can deploy flexible thin film PV material, DC wiring, and components is an innovative concept. But there are numerous technical hurdles that stand in the way of making this concept a reality. It is not a matter of just adding PV cells to a retractable shade awning. If the technical challenges can be solved, it would provide a new cost-effective method of deploying PV arrays on existing homes.

2. TECHNICAL CHALLENGES AND TECHNICAL APPROACH

The proposed retractable PV system could be made light enough that it could be pre-packaged and UL (Underwriters Laboratories) listed, just as retractable shade systems are today. But PV cannot simply be added to the popular, articulated arm retracting shade awnings. The problems in doing this include the following:

- The extended awning fabric sags, forming a catenary curve that tends to flap and flutter in even moderate 10 to 15 mph winds. The fluttering of the awning fabric could damage PV cells, printed metallic wiring, ribbon wiring, and connectors.
- Such systems generally must be retracted when wind speeds reach 15 to 20 mph, and thus the solar power would be lost during sunny, moderately windy days.
- These systems require power to retract, whereas a retractable PV system should be capable of automatic failsafe retraction without power. The articulated arms on the shade awnings are spring-loaded, providing a small, but constant, tension on the lightweight awning material. Although they can be provided with wind detection for automatic retraction, power must be available to retract against the spring-loaded arms. A power outage would present a safety and reliability problem for a retractable PV system that is integrated into these awnings. Because power outages when storms are approaching are not unusual, such systems could remain extended and be subject to damage by high wind.
- These systems have no provision for wiring the PV modules or the rotating roll.
- Wrapping around the small 3-inch aluminum roll diameter, which is traditionally used, could damage the solar cells, wires, connectors, and laminations.

Therefore, if flexible PV modules and wiring are to be provided on a retractable awning-type structure, a new approach must be taken.

Non-retractable lightweight tensile structures solve the flutter problem by tensioning the fabric in the down, as well as the up direction to stabilize it. The simplest approach uses a 4-point saddle-shape structure (see Figure 3). Any three points define a triangular plane. A 4-point saddle places the fourth point far enough out of plane to stabilize the catenary curve in the fabric. A 4-point saddle can be achieved with rigid beams at the edges, or catenary edge shapes, but 4 points are the absolute minimum number of anchor points for a tensile structure.

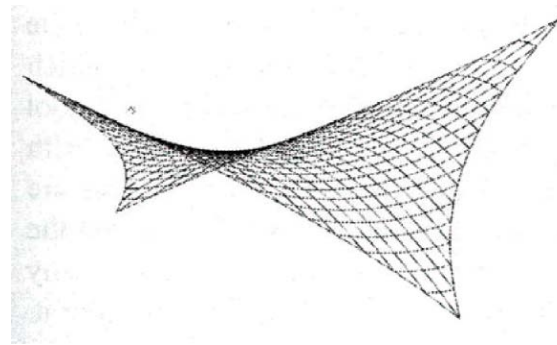


Fig. 3: Typical Permanent 4-point Saddle Tensile Structure.

Permanent 4-point tensile structures must have a significant saddle to provide stability against the expected 50-year maximum wind speeds. Such structures are not well suited for PV because a significant saddle would, in turn, cause significant variation in the solar intensity across the PV array. Such variations can adversely affect efficiency of PV cells that are series-connected. (PV cells are wired in series to achieve the required system voltage; cells in the series that are subject to less solar intensity can affect the efficiency of the entire module or array.) In addition, permanent tensile structures tend to be expensive because they must be engineered for high wind loads.

The challenge is to develop a cost-effective retractable structure that has sufficiently high wind tolerance and resistance to flutter, yet is suitable for attaching or integrating a flexible, thin film PV array with DC wiring and components. Our proposed approach is to provide a pre-packaged PV system, big enough to meet residential power needs, in a lightweight tensile saddle structure that retracts at high wind speeds (20 to 30 mph). The saddle shape for our system will be gentle enough to minimize the

efficiency problems described above. The reduced saddle will be feasible because the system will not have to withstand the maximum wind loads required of permanent structures. To successfully accommodate a PV system, the structure must be designed with an optimum saddle shape – enough to minimize damaging flutter, but not so much as to degrade PV efficiency. A retractable saddle shape is an innovative idea even for non-PV shade structures. In fact, retractable tensile structures of any type are rare, and none developed so far are suitable for PV. The combination of a retractable lightweight 4-point saddle tensile structure with a PV array and wiring is a very innovative concept.

Therefore, the primary goal is to devise a retractable, saddle-shape tensile structure that can remain extended more than 90% of the daytime without PV damage due to wind stress or fatiguing flutter, and that will safely and reliably retract without PV damage when wind speeds exceed the threshold speed or cause excessive flutter. The secondary goal is to achieve this result with a simple, cost-effective system that could accommodate the DC wiring and components, and potentially could be UL listed.

3. SOLAR IN MY BACK YARD

NIMBY, “Not In My Back Yard”, applies to all the established ways of generating electricity except PV (unless perhaps you have acres of back yard breezy enough for a wind turbine). SIMBY, “Solar In My Back Yard”, could be the answer to retrofitting PV in millions of homes. A system could deploy PV over back yard lawn or garden areas, without blocking the solar spectrum required for growing flowers, ornamentals, vegetables, etc. The photosynthesis process allows plants to absorb the carbon in CO₂ and emit oxygen that we need to breathe. Figure 4 shows that plants use only a narrow part of the solar spectrum that reaches the earth’s surface.

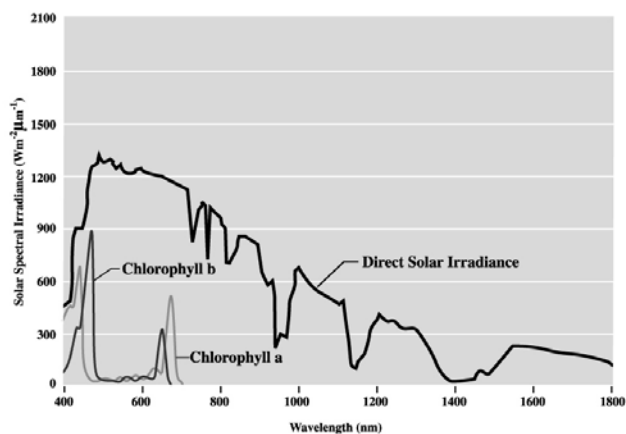


Fig. 4: Chlorophyll is vital for photosynthesis, the process by which plants convert sunlight to biomass. Here the

primary spectral absorption bands of chlorophyll are compared with the total solar spectral irradiance that reaches the earth’s surface.

A thin film PV material that is designed to convert the non-photosynthesis wavelengths of solar radiation to electricity and will pass through the photosynthesis wavelengths, could allow your back yard to bloom and generate all the electricity you need; photosynthesis and photovoltaics working together. It could remain retracted on rainy days for natural watering and it could remain extended on cold clear nights to hold the day’s heat in and help protect against frost damage.

4. CONCLUSION

If photovoltaic power is to provide a meaningful part of the world’s energy needs, it must be able to be deployed cost-effectively. A retractable, flexible thin film PV system, which can be automatically extended when the sun is bright enough and automatically retracted at night, (or when the winds are too high, or on rainy days, or snowy days, etc.), would be an effective solution.

We expect the residential systems to range in size from about 10-feet x 10-feet to 20-feet x 20-feet and perhaps as large as 24-feet x 24-feet. (Note: they can be made rectangular or paired together to best fit available space and power needs). At a PV efficiency of just 10%, these systems could produce peak power from about 1 to 6 KW, an ideal range to meet home power needs. A single 20-foot x 20-foot sized system (400 square feet) would produce about 4 KW peak power, enough to supply most of the electric energy for an average size home. This configuration would be a large enough system to shade two cars or a large patio.

A larger commercial retractable PV system up to 40-feet by 40-feet and larger could potentially be constructed. A single 40-foot x 40-foot array could shade 8 cars and generate 16 KW of peak power for the grid and/or recharging plug-in hybrid electric vehicles, reducing foreign oil dependence and greenhouse gas emissions. These systems could be ganged together to cover commercial roofs or large parking areas. Successful development of these systems could drive the future development of PV materials to optimize PV cells, substrates, encapsulation, and wiring that would meet the needs of the retractable system.

Additional benefits would include:

- Ease of installation and retrofit – A UL-listed PV array simplifies installation on existing residential structures, greatly reducing the installation time of

PV systems. And it can be easily oriented for best solar exposure.

- Improved safety – If the DC wiring and components are factory assembled and UL certified, it will ensure Code compliance with the latest NEC standards. In addition, when retracted, the PV modules can be sufficiently covered to eliminate shock hazards during installation and maintenance.
- Reduced balance-of-system cost – The system could provide the lowest installed PV cost per watt with high production automated manufacturing. Further savings could be achieved by not having to design for snow loads – the system could be automatically retracted when it snows.
- Hurricane survival – When retracted, the system can easily be capable of withstanding hurricane force winds without damage.
- Emergency power – In storm ravaged areas, the retracted system could be extended for immediate backup power generation.
- Shade value – In addition to generating power, it could shade patios or parking areas, or it could shade roofs and west-facing walls to lower air conditioning costs.
- Plant growth value - PV could generate electricity without blocking the sun's energy needed for photosynthesis.

In summary, the development of a UL-listed retractable PV array could reduce balance-of-system costs and greatly expand the installation of PV on and around existing homes, providing distributed power for the grid peak power needs.

4.1 Status of the Retractable PV Project

A retractable saddle-shaped system suitable for PV has been designed and a crude prototype built to test its functionality (Figure 5). Most of the testing so far has been focused on perfecting the automatic tensioning and retraction system. There is interest in partnering to develop suitable PV materials and the manufacturing process of this exciting new BIPV product.



Fig. 5: Photo of Prototype Test Structure.