SOLAR PANELS SUPPORT SYSTEMS IN TROPICAL COUNTRIES: AN INEXPENSIVE APPROACH

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ABSTRACT

This paper presents a new design concept for an inexpensive solar panel support system on top of flat roof building in tropical region. The design aims to reduce cost of such system while mitigating the unique challenges in tropical region such as typhoon, security and dust by introducing a foldable design concept with self-cleaning system and protection against theft. The system also includes a basic mechanical single-axis sun tracking mechanism to improve the performance of the circuit while minimizing the overhead in terms of cost and power consumption. We discuss the benefits of our design and how it meets the challenges in tropical regions.

Keywords: *Solar panels, support systems, tropical countries, and tropical regions*

1 INTRODUCTION

The amount of energy the sun supplies to Earth is several thousand times more than the current consumption by humans (Haugan, G.-T. 2013). If this energy can be captured, the energy problem which has been a major road block to many human developments around the world would be solved. The sun provides two forms of energy, heat and light, which can be converted to electricity for further transportation and usage. These two forms of energy can be harnessed by two primary methods of cultivation using concentrating solar power (CSP) or photovoltaics (PV). CSP system is an indirect method of solar energy cultivation. The system concentrates solar thermal energy (heat) onto a medium which is used as a source of energy by an electrical power generator. A classical CSP system uses mirror to concentrate solar thermal energy onto water which generates steam and drive a turbine to generate electricity. PV system, on the other hand, generates electricity directly via photoelectric effect. Solar power has been around for a long time. However, the lack of economic feasibility has prevented its wide adoption of this power source. The recent astronomical increase of gas prices at the turn of the 20th century has played a significant role in the rising dominance of solar power (U.S. Regular All Formulation 2013). The tripling of gas prices in the decade after the turn of the century provided an incentive for the research and development of solar power system. Furthermore, the advancement of electronics manufacturing process also reduced the cost of PV systems significantly. The price per watt of a silicon based PV has reduced from over $77 per watt (PVX spot market price 2013) to less than $0.50 per watt (Why Africa is missing 2013) between the 80's and now. The other key major contribution to the rising dominance of solar power is the change in climate. Climate change brought about the perceptive of the public that renewable energy, such as solar power, is a requirement for sustainable development in the future. It also introduced a new market for carbon trading which is a result of an international legislation (Kyoto Protocol) to limit the increase of greenhouse gases, such as CO2, which thought to be the primary factor for the climate change. This new market further provides renewable energy system, such as solar power, an additional benefit.

2 CHALLENGES

While solar energy sector remains vibrant in developed countries, such as the USA and Germany, countries located in the tropical or sub-tropical region which would most benefit from the development of solar energy do not fare as well. Africa has seen a reduced adoption in solar power due to the poor infrastructure (Why Africa is missing 2013). People are more hesitant to invest in a solar power system due to its poor image, which is a result of the lack of grid connectivity, and therefore reliability. In developed countries, homes and power plants are generally connected to the grid and reliability is not an issue. In fact, grid connected system can also potentially provide an additional source of income for homes where power utilization is low. It also provides an additional incentive for development firms to build a solar plant.

While grid connectivity is certainly an issue, this problem does not necessarily apply to urban areas in tropical countries. The huge initial investment cost is definitely one of the primary problems which affect the adoption of solar power system. The return on investment of solar panel, without government incentives, is often in the range of 10+ years. People are more inclined to invest their money on other methods that would provide a higher rate of return. The risk associated with the solar power system is also quite high compare to other investment method. This is because the system must be placed in an open area which can be subjected to theft and other natural elements. In fact, theft is probably the primary concern that people in the tropical region consider before deploying such an expensive system. While the problem is not limited to the tropical region, lower income will certainly exacerbate the problem. While these incidents may be relatively isolated and a solar array may be covered under home insurance policy, that won't recompense for the trauma of being a victim of theft. Furthermore, being stolen from may also increase your insurance premiums. There are some methods shown in tropical countries to minimize the risk of theft or frustrate a criminal's efforts without causing grievous bodily harm to offenders: Installing movement detector lights on roofs; using anti-theft fixtures; chaining the panels together with locks and heavy gauge nylon coated wire; affixing a security cable and locking from the panels to below roof level to the roof trusses.

The force of nature is also another concern that one must consider before deploying a solar panel system. Tropical cyclone is one such problem that does not present in a more developed nation, which is not normally located in the tropical region. Tropical cyclone can generate an air velocity of over 120 km/h which can easily topple or damage the panels and its support structures. There have been several literatures that study the effect of such occurrences, and how to mitigate them by using various support systems. For the structure design, two basic analyses for the supporting system were applied (Mihailidis, Panagiotidis & Agouridas 2009): detailing frame design and loading calculation including the aerodynamic forces and self-weights. For the aerodynamic force analysis, the geometric shapes of the frame system and the environments affect the aerodynamic loads. Researches considered the solar panel placed on various environments. For example, the solar panel placed on a flat roof leads conical vertex on the corner of the building (Văsieş, AXINTE & TELEMAN E 2012); and how the uplift force damages the solar water heater during typhoons (Chung, Chang & Liu 2008; Chung, Chang & Chou 2011; Chang, Hsu, Wang & Tyan 2012). These studies identified two important results. First, the corner panels are considered the critical ones which experience the largest fluctuating resultant forces. Second, application of wind guide plates or parapets may reduce wind load and result in uniformity of pressure distributions. Hence, engineers may create designs as strong as the aerodynamic load required. However, these support systems are designed to be fixed on buildings or grounds.

Sand and dust are another problem which is often overlooked in the tropical region. Tropical regions have warmer climate than the temperate zone which results in sand and dust being lifted higher. These particles can cover the panels and consequently reduce the efficiency of the whole system. This problem can be even worse near agricultural areas, such as sugarcane plantation areas, where fields are often burned to reduce workload and enrich the soil. The soot cloud can travel over a large area and cause a huge burden for the people who have solar power in terms of maintenance as the panels need to be kept clean in order to generate electricity. Moisture and temperature are also another problem which uniquely applies to the tropical region. High moisture and temperature can affect the efficiency of the panels (Ettah, Udoimuk, Obiefuna & Opara 2012; Hanif, Ramzan, Rahman, Khan, Amin, & Aamir 2012). As a result, panels used in the tropical region must have higher protection against moisture than those aimed for temperate regions due to higher humidity. They must also have a more efficient heat-sink or certain mechanism to reduce the temperature of the panels in order to maintain optimum operating efficiency.

Obtaining an affordable sun tracking module is also a challenge. Research has shown that sun tracking mechanism can significantly increase the efficiency of solar PV panels. The amount of energy gain depends mainly on two factors. One is the geographical location of the where the PV solar panel is installed. Factors like climate changes and temperature variations as well as latitude and longitude coordinates affect the amount of sun radiation the PV panel can receive. For example, sun tracking in temperate latitude like United States and Europe can increase gain by up to 50% in comparison to a fixed system (Huld, Cebecauer, Suri & Dunlop 2010; Neville 1978). In tropical regions, while the gain is not as much as those found in temperate regions, the reported gain remains as high as 30% in areas such as Tunisia (Maatallah, Alimi & Nassrallah 2011), Taiwan (Chang 2009), and Malaysia (Samsudin & 2008).

The other factor that affects the energy gain in a PV solar panel system is the tracking system and the way it operates. Both single-axis and dual-axis tracking systems have shown gain over fixed inclined surfaced panels. Dual-axis tracking systems in tropical regions have shown radiation gain of up to 130% over fixed tilt systems (Helwa, Bahgat, El Shafee & El Shenaway 2000). Single-axis trackers can rotate horizontally or vertically and are comparable to the amount of gain obtained by dual-axis trackers as reported by (Huld, Cebecauer, Suri & Dunlop 2010; Chang 2009).

While the benefit of a sun tracking system is obvious, it is not normally installed due to cost. This is because the cost of developing the control module for sun tracking is quite high, especially the ones for dual-axis tracking due to non-linear dynamics. The cost for weather-proofed sensors, motors and microcontrollers can be expensive as well. As a result, the price of a tracking system can be as high as twice the cost of a solar PV panel (Wattsun AZ-225 2013) which can easily triple the price of the whole solar power system.

3 PROPOSED MODELS

Developing a solar panel system in tropical regions require different considerations from the ones used in temperate regions. One needs to consider various factors and find the right balance between cost, return on investment, and risk. This section presents a design concept that took the aforementioned challenges into consideration and presents a relatively inexpensive solution as compared to a traditional system.

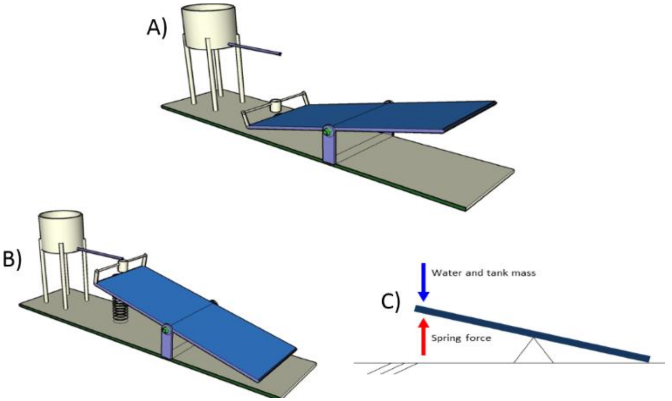

Figure 1: Design Concept of Solar PV System

The proposed system is shown above in Figure 1. It is composed of two symmetric frames housing multiple PV frames designed for buildings that have flat rooftop, which are very common in tropical regions. The design is capable of rotating around a single-axis to track the sun, like a see-saw. The tracking mechanism, which we expect to improve the performance and offset the reduced efficiency of the panels due to heat, is based entirely on a mechanical mechanism. One side of the panel is attached by a water bucket which provides a downward force, shown in Figure 1-A. The downward force is supplied via the water provided by the water tank, which is commonly found on flat rooftops. Underneath the panel on the same side as the water bucket, a spring is installed to provide an upward force, shown in Figure 1-B.

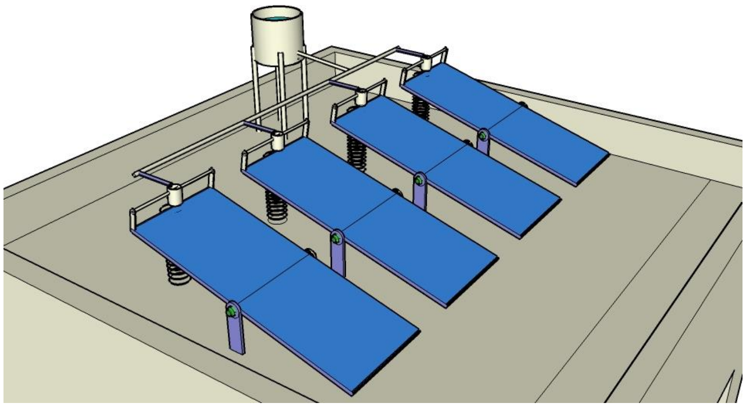

Figure 2: Multiple Solar PV Systems on a Rooftop

We envisioned the system to operate in the following manners: In the beginning of the day, as the sun rises, the bucket is filled with water and the panel is in the position shown in Figure 1-A. A small hole at the bottom of the water bucket leaks water throughout the day. This slowly reduces the downward force and allows the frame to tip to the other side due to the force of spring. At the end of the day, as the sun sets, the frame is in position shown in Figure 1-B with the bucket touching a lever attached to the end of the pipe, which in turn is connected to the water tank. This triggers the water trap to open and allows the water to fill the bucket making the frame moves back to position shown in Figure 1-A. The position of the panels at any given time is determined by the oppositely acting forces of the water and the spring, as shown in Figure 1-C. The idea can be easily extended to multiple frames with minimum overhead as shown in Figure 2 by attaching more pipes to the main water outlet from the water tank. Figure 3-A and 3-B show how the system fills the bucket with water. When the bucket touches the lever, it opens the water trap which prevents the water from falling from the pipe. The trap closes slowly, allowing for the bucket to be filled completely before it closes back. The excess water falls on the panel itself, allowing it to clean the surface from dust or soot that can decrease the efficiency of the panel, as shown in Figure 3-C. It must be noted that the trap should be slightly bigger than the pipe to allow the water to flow backward, toward the bucket.

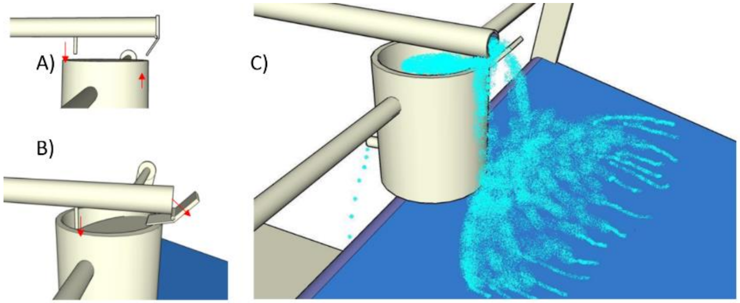

Figure 3: The Water Filling Mechanism

Furthermore, the proposed design is protected against windstorm and typhoon via a simple locking mechanism, shown in Figure 4-A and 4-B. The locking mechanism is a simple metal rod, shown in red. In a normal operating condition, the rod is locked in the center, between both support frames making both sides work together as a single unit. During a windstorm or a typhoon, the rod is slid to one side allowing both ends of the frame to touch the ground, as shown in Figure 4-B.

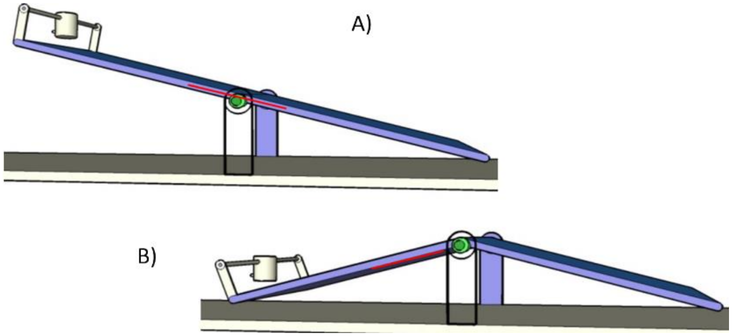

Figure 4: Locking Mechanism to Prevent a Windstorm or Typhoon

The mechanism is designed to prevent the turbulence created by wind getting underneath the panel to topple the system, and possibly break the unit. Obviously, one must protect the side of the panel from letting the wind getting underneath as well. This can be done by either covering the sides during the windstorm or by having multiple panels next to each other from one side of the roof to the other end of the roof, as shown in Figure 5.

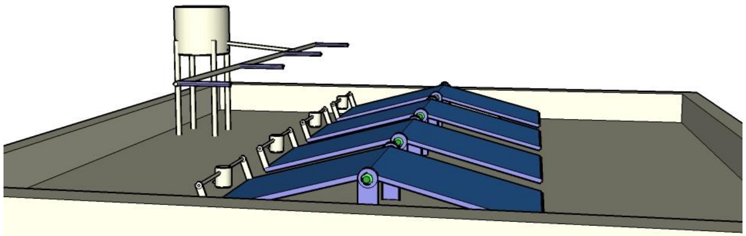

Figure 5: Multiple Solar PV Systems during Windstorm or Typhoon

Finally, due to high cost of the PV panels, the system should be protected against theft. This can be easily done using anti-theft nuts and bolts, which requires special tools, to secure the panels to the frame. This makes any attempt to forcefully unassemble the panel without proper tools result in destroying the panels, making them useless.

4 IV. Calculations and Discussions

The tracking mechanism is dependent on the water leaking from the bottom of the bucket. This requires a calculation to assure that the position of the panel is consistent with the azimuthal angle of the sun in the sky in order to maximize the solar power conversion of the system. As a result, the time it takes for the water to drain must be carefully calculated.

Since water drains from a bucket, we expect the flow to be at maximum after the bucket is filled with water, and the rate will gradually decrease as the water level decreases. Let h(t) be the height and volume of water in a bucket at time t. If water leaks through a hole with area a at the bottom of the bucket, then Torricelli's Law (Liu, Merati, Woodiga, Davis, Leong, Johnson & Chen 2008) states that

$$\frac{A\mathrm{d}h(t)}{\mathrm{d}t} = a\sqrt{2gh(t)}$$

Where A is the area of the cross section of the cylindrical tank (the bucket in our case), and a is the area of the circular hole (at the bottom of the bucket). Solve this equation to find the relation of height of water at time t, where the tank is full at time t = 0. Then

$$\mathrm{t} = \frac{A}{a}\sqrt{\frac{2h}{g}}$$

By calculating the time required for the water to drain from the pot. The amount of water in the bucket is know at any given time and the position of the sun in the sky is also known for any given time hence, the area of the circular hole can be adjusted so that the weight shift in the bucket which causes the panel to change its position will be in proportion to the sun's position in the sky.

To illustrate the mechanism more, let us consider an example of a system installed in a region where the sun rise is at 6:00 am and the sun set is at 6:00 pm. At sunset, the bucket is filled with water and the panel is in the position shown in Figure 1-A. The rate at which water is draining from the bucket should be calculated so that the amount of water in the bucket will make it heavy enough to maintain its position for 12 more hours until sun rise. By that time, the amount of force caused by the bucket and water should be equal to the force caused by the spring underneath the panel making further water leakage give the upper hand to the spring force causing the panel to start rotating. The panel keeps moving for another 12 hours until sunset where the bucket reaches the tip of the pipe and gets filled with water and the pattern keeps on repeating.

It should be noticed that there are few things that needs to be considered with this mechanism. One is that the amount of water has to be precisely calculated so that the panel can track the sun efficiently. Another is that water cannot be drained by any source other than the assigned hole. Also, the area of the circular hole should be adjusted every 3 months to adjust to seasonal changes in the position of the sun in the sky for a given time.

Surely there are other factors that can affect the system and its functionality, but these factors will not be clear until a field test is conducted to see how it would perform in real life and evaluate how many challenges were solved and whether our goals were met.

5 CONCLUSION

An affordable mechanical single-axis sun tracking support system is proposed. The design addresses unique challenges associated with tropical regions, including dust particles, security and typhoon. The proposed system is very affordable as compared to commercial products. The unit is simple to understand and install on any flat rooftops that contain a water tank. The equation that will determine how the tracking system tracks the sun is also provided. The system remains to be tested to determine the reliability and the functionality in practice. The efficiency of the unit as compared to a fixed-mount unit should be investigated as well. Nevertheless, our proposed design concept should be viable and significantly affordable to other commercial products. Countries from tropical regions can benefit from this design.

REFERENCES

Haugan, G.-T.(2013), "Solar Power" in Sustainable Program Management, Auerbach, 2013, pp. 235-48. (Haugan 2013)

U.S. Energy Information Administration. (2013), "U.S. Regular All Formulation Retail Gasoline Prices", available at: http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=pet&s=emm_epmr_pte_nus_dpg&f=a (accessed 25 November 2013).

Solar Server. (2013), "PVX spot market price index solar PV modules", available at: http://www.solarserver.com/service/pvx-spot-market-price-index-solar-pv-modules.html (accessed 25 November 2013).

Hankins, M. (2013), "Why Africa is Missing the Solar Power Boat" available at: http://www.renewableenergyworld.com/rea/news/article/2013/04/why-africa-is-missing-the-solar-electricity-boat (accessed 18 November 2013).

Mihailidis, A., Panagiotidis, K, and Agouridas, A. (2009) "Analysis of solar panel support structures," in 3rd ANSA & uETA International Confrernce, Halkidiki, 2009.

Văsieș, G. , AXINTE, E., and TELEMAN E.-C. (2012), "Numerical simulation of wind action on solar panel placed on flat roofs with and without parapet," Buletinul Institutulupi Politehnic Din Iași, Vol. LVIII(LXII), pp. 139-155.

Chung, K., Chang, K., and Liu, Y. (2008), "Reduction of wind uplift of a solar collector model," Journal of Wind Engineering and Industrial Aerodynamics, Vol. 96, pp. 1294-1306.

Chung, K.-M., Chang, K.-C., and Chou, C.-C. (2011), "Wind loads on residential and large-scale solar collector models," Journal of Wind Engineering and Industrial Aerodynamics, Vol. 99, pp. 59-64.

Chang, K.-C., Hsu, U.-K., Wang, W.-C., Tyan, R.-H. (2012), "Flow visualization and wind uplift analysis of a suspended solar water heater," Procedia Engineering, Vol. 31, pp. 3-8.

Ettah, E.B., Udoimuk, A.B., Obiefuna, J.N., Opara, F.E. (2012), "The Effect of Relative Humidity on the Efficiency of Solar Panels in Calabar, Nigera," Universal Journal of Management and Social Sciences, Vol. 2, No. 3, pp. 8-11.

Hanif, M., Ramzan, M., Rahman, M., Khan, M., Amin, M., Aamir, M. (2012), "Studying Power Output of PV Solar Panels at Different Temperatures and Tilt Angles," ISESCO Journal of Science and Technology, Vol. 8, No. 14, pp. 9-12.

Huld, T., Cebecauer, T., Suri, M., Dunlop E. D. (2010) "Analysis of one-axis tracking strategies for PV systems in Europe," Progress in Photovoltaics: Research and Applications, Vol. 18, Issue 3, pp. 183-194.

Neville, R. C. (1978), "Solar energy collector orientation and tracking mode," Solar Energy, Vol. 20, Issue 1, pp. 7-11.

Maatallah, T., Alimi, S. E. Nassrallah, S. B. (2011), "Performance modeling and investigation of fixed, single and dual-axis tracking photovoltaic panel in Monastir city, Tunisia," Renewable and Sustainable Energy Reviews, Vol. 15, No. 8, pp. 4053-4066.

Chang, T. P. (2009), "The gain of single-axis tracked panel according to extraterrestrial radiation," Applied Energy, Vol. 86, No. 7, pp. 1074-1079.

Samsudin, K., Noor, A.M., Rahman, A.R.A. (2008), " Evaluation of Genetic Algorithm based Solar Tracking System for Photovoltaic Panels" in International Conference on Sustainable Energy Technologies, Singapore, 2008.

Helwa, N.H., Bahgat, A.B.G., El Shafee, A.M.R., El Shenaway E.T. (2000), "Maximum Collectable Solar Energy by Different Solar Tracking Systems," Energy Sources, Vol. 22, No. 1, pp. 23-24.

Chang, T.P. (2009), "Output energy of a photovoltaic module mounted on a single-axis tracking system," Applied Energy, Vol. 86, No. 10, pp. 2071-2078.

Civicsolar. (2013), "Wattsun AZ-225 Dual Axis Tracker 225 sq-ft" available at: http://www.civicsolar.com/product/wattsun-az-225 (accessed 18 Novermber 2013).

Liu, T.-S., Merati, P., Woodiga, S.A., Davis, C., Leong, C.H., Johnson, J., Chen, K.H. (2008), "Drainage and filling in cylindrical and rectangular containers" Journal of Automobile Engineering, Vol. 222, No. 4, pp. 565-577.