Developing Passive Solar Tracking Photovoltaic Cells

Solar Power and Current Energy Systems

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Introduction to the Energy Systems and the Air We Breathe

For over 100 years the world has been in an energy crisis, and has recently encountered the addition of the threat of global warming, "Global temperatures are already higher than they have ever been in at least the past millennium, and the increase is accelerating even faster than scientists had predicted." (Goel, 2012, p. 1). Humanity is in quite the dilemma: To increase electricity around the world while also decreasing their greenhouse emissions (CO2). The implementation of solar power is one of humanity's best solutions (Qazi, 2019, p. 63848). The history of solar power goes back to ancient times, as Jones (2012) reveals in the following:

> Passive solar energy has been used as a form of light and heat since early mankind… the ancient Greeks designed their homes to capture the sun's heat during the winter. Later, the Romans improved on solar architecture by covering south-facing windows with... mica or glass, preventing the escape of solar heat captured during the day. (p. 2)

Using the sun for energy is nothing new, but huge innovations in solar power technology have come along since the Space Race with photovoltaic cells.

Even with a lot of attention and innovation in the field of photovoltaic cells (PV), the percentage of global energy that uses solar power has remained meek. Solar energy potential remains vastly untapped, even with Islam (2018) pointing out, "europe can be met by harvesting from only 0.4% of the Sahara desert….by using only 2% of the earth's total land surface" (p. 3). For my group's Net-Zero Residential Home Design Initiative (Net-Zero Home) technical project, the project takes on the challenge of moving forward with the small innovations of solar power technology that can help broaden the usage of solar power, by designing and building a passive solar tracker that is desirable for the domestic market. In conjunction with the technical project, I have chosen to further investigate why solar power makes up so little of the global energy production (Islam, p.3 2018). The prospectus aims to break down the problem domain of incorporating solar power into pre-existing energy systems through the lens of active network theory (ANT) and social technical systems (STS). The technical project intends to design a passive solar tracker that promotes the sustainability of solar energy by this innovation.

Innovation of Solar Power Though the Development of a Passive Solar Tracker

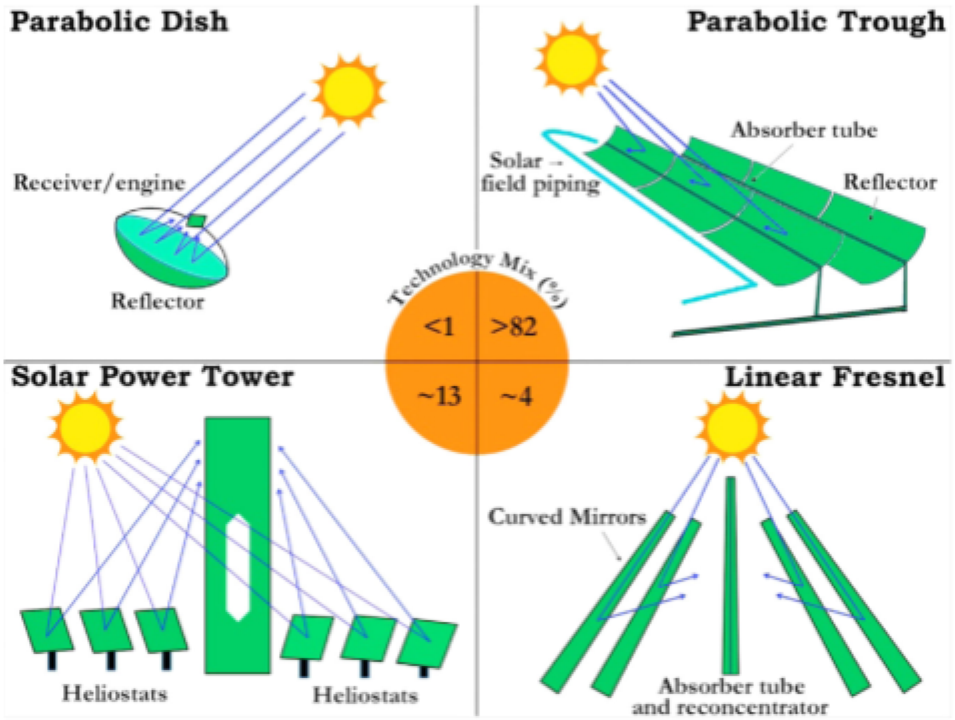
To discuss this prospectus topic on Passive Solar Tracking, first the functionality of Photovoltaic Cells needs to be explained, "The solar industry was re-invented through the development of the photovoltaic cell (hereafter PV). PV cells convert solar radiation directly into electricity. When photons of sunlight strike the cell, electrons are knocked free from silicon atoms and are drawn off by a grid of metal conductors, yielding a flow of direct current." (Jones, 2012, p. 12). PV cells, or what is commonly called solar panels, provide the best current form of solar energy production on small scale systems. For this project, the technical group members are looking on how to increase the efficiency of PV systems using solar tracking, as Chowdhury (2018) mentions as one way to increase PV effectiveness:

> In general, there are three ways to increase the efficiency of photovoltaic systems... The first method is to increase the efficiency of power generation of the solar cells, the second is related to the efficiency of the control algorithms for the energy conversion, and the third approach is to adopt a tracking system to achieve maximum solar energy. (p. 1)

While PV is the most widely adopted form of solar energy, PV is not always the most efficient. Concentrating solar power (CSP) is the best large-scale solar generation, being able to be constructed in deserts and wastelands that would normally be desolate (Hou, 2009, p. 3-4). There are many designs for CSP systems; CSP designs use large arrays of mirrors focused on a fluid tank that is heated to run a turbine, as shown in figure 1 below.

Figure 1

The four common types of Concentrated Solar Power (CSP) energy systems.

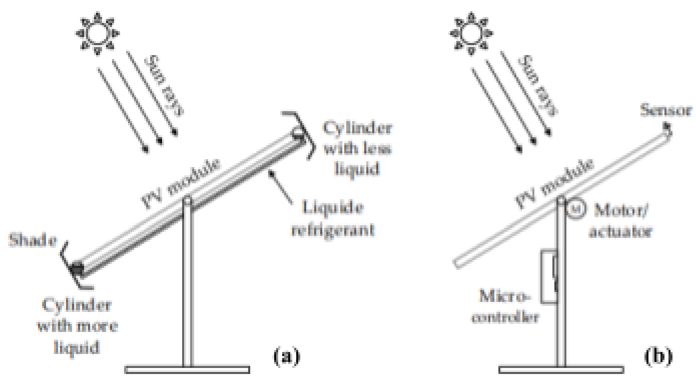


Note: Illustrates the four most common CSP systems, that use mirrors to concentrate solar radiation to generate energy through steam turbines. Figure from "A comprehensive review of state-of-the-art concentrating solar power (CSP) technologies: Current status and research trends" (Islam, 2018, p. 990).

The focus for the project is on the smaller scale solar power system, that can be used by any household. To design the passive solar tracking system we must understand and test different forms of solar tracking alongside the passive, to get a gauge of the efficiency. Our approach builds on other research and active tracker prototypes, like Chowdhury's (2018) project on, "A Low-Cost Closed-Loop Solar Tracking System Based on the Sun Position Algorithm". The issues of coming up with a design lie in the compactness of the design and the level of accuracy that is needed to obtain a high degree of efficiency. An active solar tracker uses either a clock and algorithm that predicts the position of the sun in the sky based on the time and day of the year, or the tracker uses feedback from photoresistors to locate the sun in the sky in real-time. Using solar trackers allows for more daily energy collection than an equivalent station PV system would, “single-axis and dual-axis photovoltaic tracking systems, with appropriate control systems, the electrical energy can increase from 22–56%, compared to fixed PV systems.” (Seme, 2020, p. 19). Building off of active solar tracker designs, a passive solar tracking system needs little to no electronic or human input to run once deployed; the passive tracker uses pressurized fluids/gas or highly thermal sensitive metals (bimetallic strips) to operate (figure 2).

Figure 2

Examples of Passive vs. Active Solar Tracker Rigs

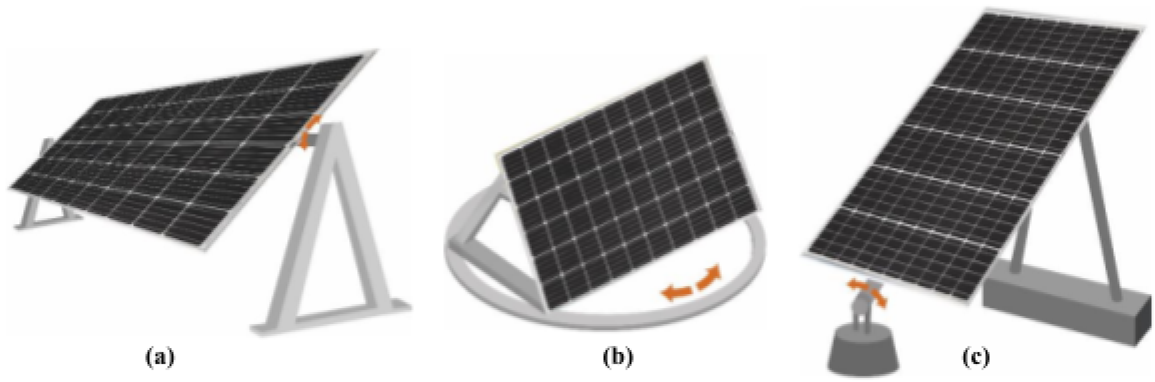


Note: An example of a passive and a active solar tracking rig: (a) is a passive tracker that uses thermal sensitive fluids, (b) is a type of active tracker using a sensor with microelectronics. Image sourced from “Solar Photovoltaic Tracking Systems for Electricity Generation: A Review” (Seme, 2020, p.7).

The goal is to have a system that tracks the sun but doesn't need any electronic input or manual setting/resetting to operate at a similar efficiency to the active trackers and follows one of the three styles shown by Seme (p. 9) in figure 3.

Figure 3

Single Axis Solar Tracker Rotation Methods



Note: The image contains 3 types of solar one axis trackers: (a) shows a Horizontal single-axis tracking system (HSAT), (b) is a Vertical single-axis tracking system (VSAT) tracking east to west, while (c) is a tilted single-axis tracking system (TSAT). Image sourced from "Solar Photovoltaic Tracking Systems for Electricity Generation: A Review" (Seme, 2020, p.9).

The outcome should be a design that can be used both domestically in first world countries but also for developing countries that do not have much familiarity with renewable energy or even electricity in many cases.

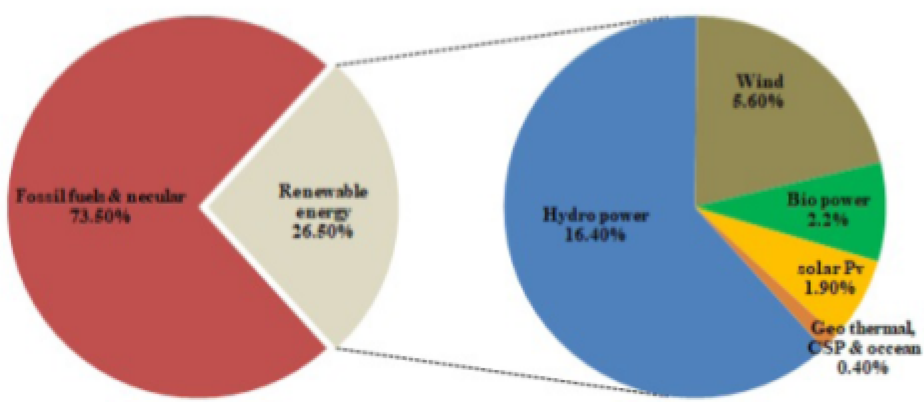
The solar tracking project is a small part of a long term project, Net-Zero Home, with a mission to upgrade an existing home to be more energy efficient and environmentally friendly. The Net-Zero Home will in turn greatly contribute to the application of first world homeowners, as well as developing countries and their energy needs (Adenle, 2020, p. 7). In many studies on renewable energy in developing places, like Africa, the most promising source of renewable energy is solar power; it brings not only electricity, but education and food to families (GPT, 2020). Engineers are further building on the field of renewable energy by developing a more compact, simplified, and efficient design that could help save the air we breathe.

The Issues of Introducing Solar Power Into Current Energy Systems

By the year 2050, the International Energy Agency (IEA, 2021) has set a goal in which 42 countries pledged to meet an energy CO_2 emission of zero. This goal was set to minimize the effects of global warming by eliminating the continual output of greenhouse gases into the atmosphere, like CO_2, that drive the earth to retain a larger amount of thermal energy from the sun. The prediction by the IEA is that the world can keep the change in global temperature (since the industrial revolution) to a max of 1.5 degrees Celsius, if a majority of the industrialized countries can achieve an energy network that produces zero-emissions. The IEA looks onto solar power to carry the torch to meet this dream. Qazi's review on sustainable energy in figure 4, estimates that only 27% of global electricity production is renewable energy and that only 2% of that renewable energy is from solar power (p. 63841, 2019).

Figure 4

Estimated Share of Global Electricity Production



Note: This is an estimate from a review of over 42 papers renewable energy studies by "Towards Sustainable Energy: A Systematic Review of Renewable Energy Sources, Technologies, and Public Opinions" (Qazi, 2019, p.63841).

To fully understand the STS that encompasses the problem domain, the lack of solar power integration in energy grids, we must analyze the negatives that solar power faces when being integrated into a pre-existing framework of complex actors. For the 2050 zero-emission goal, to be achieved the problem domain needs to be understood, by breaking down the issues into four main sub-domains: Economics, Technology, Geography, and Policies. If solar power is not adopted by the entire world, then the CO2 emissions will continue to rise, for it is much easier to produce CO2 than it is to get rid of it. Goel (2012) supports this by concluding, “Humanity may have only a narrow window of time left…to begin the long process of stabilizing greenhouse gas concentrations.” (p. 5).

The first issue of solar power when being implemented into an already established power network is the technical issue of solar power's lack of high-quality electricity. Solar power is not consistent as its output changes wildly depending on the time of day and the weather. An energy market with fluctuating changes in electricity quality gives a very unstable financial investment for power companies. This is especially evident in poor countries that already have a poor energy market, as supported by Kumar (2019), “In short, access to solar energy does not replace existing traditional energy use but operates somewhat intermittently alongside these alternative forms “(p. 172). On other technical limitations with the lack of an obvious clean energy storage method for electricity, with solar power being unusable and certain times of day, this means that for a fully independent solar power network to be functional advancements in energy storage are needed.

When analyzing the economic actors, solar power requires an increased upfront cost to implement (compared to traditional energy sources), and many energy grids have to replace existing non-renewable power, “Renewable energy technologies show low operational costs and extensive lifetimes, in trade of high investment costs.”(Haas, 2018, p. 403). Furthermore, solar power is not studied or manufactured globally. For example, India has to ship PV panels overseas and pay the foreign country a premium to import them (Behuria, 2020, p.8). Countries with less industrial and technical involvement in solar energy have too many difficulties adopting them.

While the major problem with replacing traditional power systems with solar extends from economics, it also has to address the political policies. Without government intervention, solar power infrastructure will not succeed (Nguyen & Kakinaka, 2019, p. 1055). Policies need to be made that incentivize companies to invest in solar power, as well as the negative current policies need to be suppressed. A company will not invest in a system unless they have a good reason to believe they will profit from it. Governments need to adopt policies like tax breaks, funding, and regulations that push for renewable electricity networks.

The geological problem domain arises with the location of where power is needed. CSP systems can be set up in deserts and open land that gets a lot of sunlight, a lot of lands that are not used for any productive applications can be reserved for CSP plants in many countries like the US (Shum, 2017, p. 462), as well as China, “China has abundant solar energy and largely available wasteland especially in the West and the North. The condition is very suitable to construct CSP plants" (Hou, 2009, p. 4). CSP systems demand the usage of large swaths of land that is unused/populated, this makes the CSP system more practical in certain countries. The last big point on geography is that potential energy production from the sun is positively influenced by locations of higher altitude and lower latitude, where more direct radiation is received from the sun. To efficiently integrate solar power into existing energy networks, this STS deliverable strives to find a better understanding of the four main STS/ANT actors discussed.

Conclusion

The deliverables for the technical project will be an innovative passive solar tracker that will use PV to collect solar energy from the roof of a small house owned by the University of Virginia. This solar tracker should provide significant improvements in the efficiency and domestic appeal of solar power. The STS deliverable is the recognition of the problems that encompass the integration of solar power into pre-existing energy systems, with the focus on the geological, economical, technological, and political actors in the problem domain. The problem domain of the STS shows the missing actors that are in play, making the goal of a fully carbon-neutral world more achievable. To attempt tackling an obstacle the problem needs to be clearly and accurately analyzed.

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