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GOLDEN RATIO APPLIED IN THE ORIENTATION OF SOLAR CELLS IN A GOLDEN SPIRAL SOLAR PANEL

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ABSTRACT

One of the most recurring sequences in nature is the Fibonacci sequence. As the sequence was explored, it was found out that this sequence led to the golden ratio. This study tried to apply the concept of Fibonacci and Golden Ratio to maximize efficiency of solar panels and thus, providing solutions to one of the world's most serious problems, the lack of energy source. It aimed to design a golden spiral solar panel; and measure and compare the voltage and current produced, and the power generated by both flat-oriented solar panel and the golden spiral solar panel. Results showed that the golden spiral solar panel produced more voltage and current, and generated more power by 10.74%, 14.85%, and 26.13%, respectively. Independent sample t-test resulted to high significant difference between the outputs of two panels in terms of the three basic electrical quantities in favor of the golden spiral solar panel.

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INTRODUCTION

Fibonacci sequence is one of the most interesting, mind-boggling concepts in the field of mathematics. This term which is simply an expression of the sum of two consecutive terms in order to get the next term, has been found on various life points and mathematical concepts. As the sequence was explored, it turned out that those terms within the sequence generated values that ultimately lead to a unique number – the Golden Ratio. Defined by a non-repeating real number (1.618…), the Golden Ratio has been branded by mathematicians as the divine or ideal proportion. It was said that, if the proportion is applied to any form, then the product will turn out pleasing to the eye. Infrastructures like the Taj Mahal, the painting Mona Lisa, and the spirals of the nautilus shell are all conforming to the Golden Ratio. At the recent times, one of the obstacles mankind is currently facing is the search for the most efficient source of energy. Humans have since clamored for it and have already tried different ways to harness energy.

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Of all the conventional energy sources present as of today, one of the cleanest yet efficient energies can be found from the sun. That is why humans have tried so hard to maximize the most abundant, yet least maximized form of energy in the whole planet – Solar Energy. Solar panels are already on circulation and can now be found virtually everywhere. The problem is that, not all can really avail, for the efficiency comes with a hefty price. Because of this, only those who have much investment can fully maximize this source of energy. There are many factors to consider in rendering a cost-and-energy-efficient mechanism. By experimenting with patterns found in nature, and integrating mathematics, possibilities in generating renewable source of energy are evident. Recent studies have been conducted in using Fibonacci and Golden Ratio concepts in constructing solar trees to produce more efficient solar panel arrays. The study of Ybo, Maisog and Bodabila (2017), which is one of the latest studies related to the concept, used Fibonacci sequence and golden ratio in the arrangement of the leaves in the trees, in arranging the solar panels. Their study showed that the solar panels arranged in this manner can generate approximately 7.77% more energy than the usual flat oriented array of solar panels. By trying to understand the relationships of all these elements, this research used the Fibonacci and Golden Ratio concept to produce a new design of solar panel that is more efficient.

The study intended to apply the Fibonacci terms and the Golden Ratio, in a design of the solar panel. Specifically, it aimed to

- Design a solar panel conforming with the Golden Spiral;
- Measure the voltage and current produced; and power generated of both the golden spiral solar panel and the flat-oriented solar panel; and
- Compare the voltage and current produced; and power generated of both the golden spiral solar panel and the flat-oriented solar panel.

MATERIALS AND METHODS

In constructing the prototype model, the researchers used the following; (1) 60 polycrystalline silicon photovoltaic cells of the same dimensions (1.53x0.75 in), 30 for the prototype model and 30 for the flat oriented; (2) copper wire; (3) iron plane bar for the frame of the prototype (4) glue sticks; (5) matches; (6) 2'5''x1'plywood for the base; (7) Solder tools for constructing circuits; (8) voltmeter for measuring the voltage of the system; (9) glass boxes to enclose the prototypes for protection from any debris or human interference.

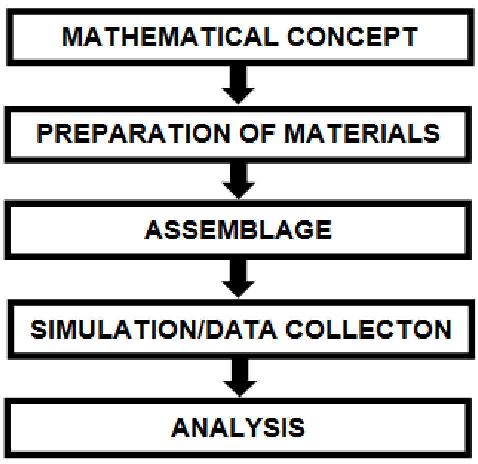

Figure 1. Flow chart of the Research Design of the study

Mathematical Concept

The golden ratio, oftentimes referred as the golden proportion, divine proportion, or golden rule, is a mathematical wonder, which is believed to imbue aestheticism to any form it is applied. Buildings like Taj Mahal, The Parthenon, and even paintings like Mona Lisa, as well as organic forms like the sunflower and the nautilus shell, are said to be aesthetically pleasing to the eye, for all of them conform to the ratio. At some point, the researchers reached a certain level of curiosity, that compelled them to contemplate about their significance beyond what meets the eye. Facts are yet to be divulged, as to whether the golden ratio has a certain purpose on the natural order.

Preparation of Materials

Due to the scarcity of materials, the researchers maximized what are available at hand. Materials and equipment used for the prototype construction were gathered. Sixty pieces of 1.52x0.7in Polycrystalline Silicon solar panel cells, copper wires, glue sticks, popsicle sticks, plyboard, glass, digital multimeter, soldering rods and iron, are among the materials utilized.

Assemblage

The base was crafted in the likeness of the golden rectangle, which also served as the foundation of the prototype. For the spiral prototype, Fibonacci sequence was incorporated as the consistent increment for the elevation, with mainly 5 pillars, each measuring 2, 2, 4, 6, and 10 (inches), consequentially. An iron rod was then coiled from bottom to top, with its path aligned with the golden rectangle base, lying tangent to each pillar. Popsicle sticks were then glued in the spiral to create a surface to accommodate the solar cells. Solar cells were then carefully soldered and linked with copper wires, per adaptation of the methods stated in the Simulation Study of Multi-wire front Contact Grids for Silicon Solar Cell (Fiegna and Nicolai, 2015) as basis. For the flat prototype, the solar cells were also soldered and linked with copper wires and was placed in a plyboard. Both designs were then enclosed with a glass box, to inhibit damage caused by debris, weather disturbances, and human or even animal interference. Two (2) sets of 15 solar cells were connected in series and were then connected in a parallel manner.

Simulation/Data Collection

The voltage, current, and power of the two systems were monitored every hour for approximately 7 school days and were recorded. Weather was recorded, in a variation of sunny, partially cloudy, and cloudy. Collection was inevitably halted during extreme or unfavorable weather conditions like rain.

Analysis

The data generated by the simulation was analyzed to evaluate efficiency. Voltage, current, and power were the dependent variables, and the designs as independent variables. Independent sample t-test was used for statistical analysis, through the SPSS software.

RESULTS AND DISCUSSION

This section presents the results and discussion of the study. It is arranged according to how the objectives were set in this investigation.

Design of the Prototype Golden Spiral Solar Panel

Two models were made for the purpose of comparison; one being the typical flat-oriented, the dominant design in the commercial market; and one conforming to the golden ratio, the experimental design. The design has the base which follows the golden rectangle with posts that serve as elevations also following the Fibonacci sequence all in inches. According to Mafimidiwo (2016), "the mathematical work of 'Leonardo of Pisa', popularly known as Fibonacci, played a major role in utilizing the native advantage of the abundant intake of sunlight energy." Figure 2 shows the design of the base of the golden spiral panel. The dimensions of the base follow the Fibonacci sequence which start from the smallest square to the largest square with lengths $1\text{ in}, 1\text{ in}, 2\text{ in}, 3\text{ in},$ and 5 in

respectively. The total area of the rectangle produced is 40 in^2. A spiral is then made connecting the edges of a square as shown.

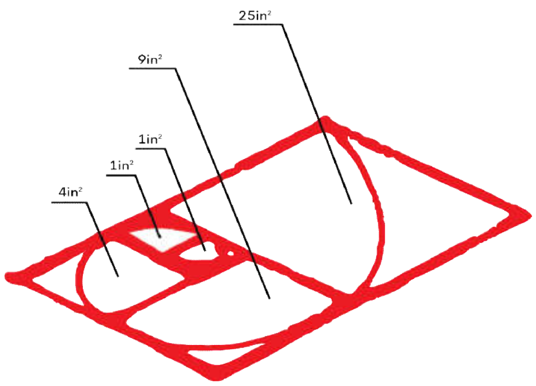

Figure 2. Base of golden spiral solar panel

The lengths of elevation of the panel also follow the Fibonacci sequence multiplied by 2 starting from $2\ in, 2\ in, 4\ in, 6\ in,\ and\ 10\ in$. A pillar is added in a specific edge of a square within the golden rectangle base starting from the edge of the biggest square to serve as the elevations. This design is complemented by Grigas (2013), where in the study, Fibonacci said to have revealed through his analytical numbers that, in the case of a leaf, it grows vertically upwards the stem in the direction of the sun, which was fashioned to absorb more sunlight energy. Figure 3 shows the attachment of pillars that would serve as elevation in specific edges.

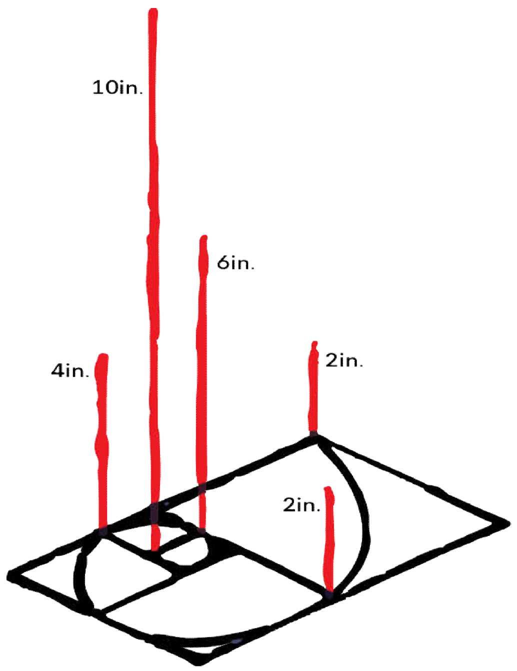

Figure 3. Base with posts for elevation

A spiral is then stretched from the tip conforming to the spiral in the base. The spiral runs along from the pillars with the highest length to the lowest post. Based on the study of Gharghi, Bai, Stevens, and Sivoththaman (2006), there is a significant advantage of a vertically rotating Fibonacci solar panel in tracking the sun for a higher efficiency. Thus, the spiral was introduced to the design. Figure 4 shows the spiral along the posts.

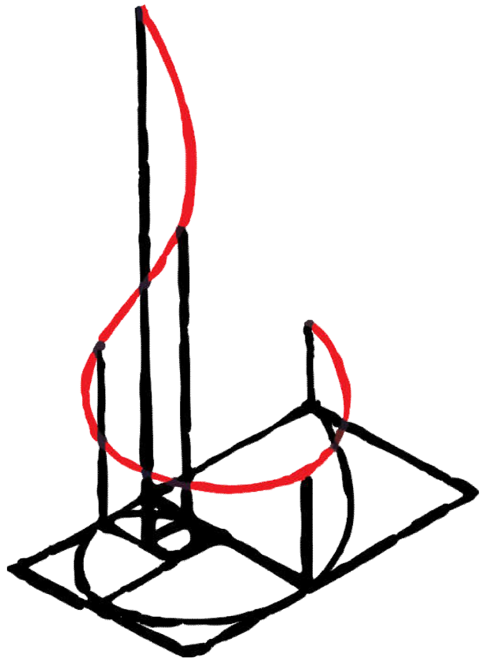

Figure 4. Attachment of spiral along the posts

Popsicle sticks glued to the spiral along the posts serve as the platform of the solar cells. Due to the curvature induced by the spiral, an angle gradient is produced. Figure 5 shows the design of the golden spiral panel with platform. Two sets of 15 solar cells connected in series are connected in parallel with each other. The solar cells placed on the platform with the circuit conform on its elevation and shape.

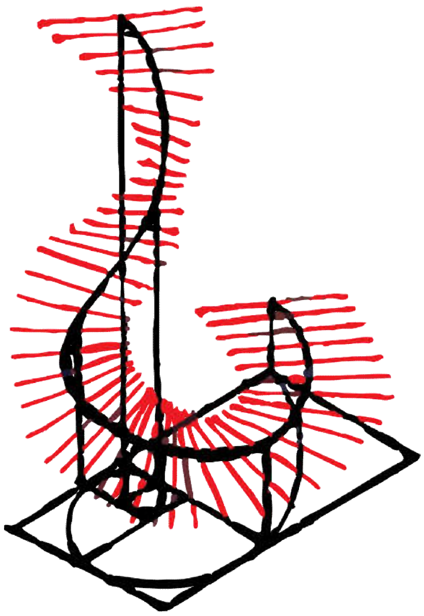

Figure 5. Attachment of platform

The actual prototype in Figure 6 mainly conformed to the golden spiral, with the surface constructed with popsicle sticks, to accommodate the cells. The design, which was also conformed to the Golden spiral, was strategically crafted to maximize solar energy in different time frames throughout the day, with its dynamic angle gradient. This was supported by Suto and Yachi (2011), citing Fibonacci numbers to increase height will increase the amount of energy stored. The spine of the spiral underneath the surface is aligned to the golden spiral situated at the base.

Figure 6. Actual prototype

Measurement of voltage and current produced, and power generated of both designs

Figure 7 shows the trend of voltage and current produced, and power generated of flat-oriented solar panel collected for 30 hours while Figure 8 shows the values of these three quantities for the golden spiral solar panel.

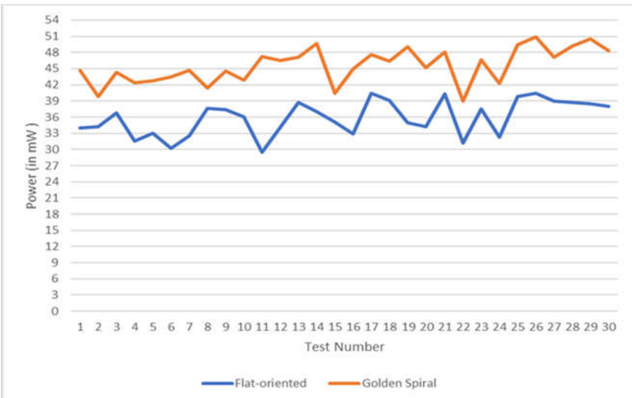

Figure 7. Power generated by the flat-oriented solar panel and golden spiral panel

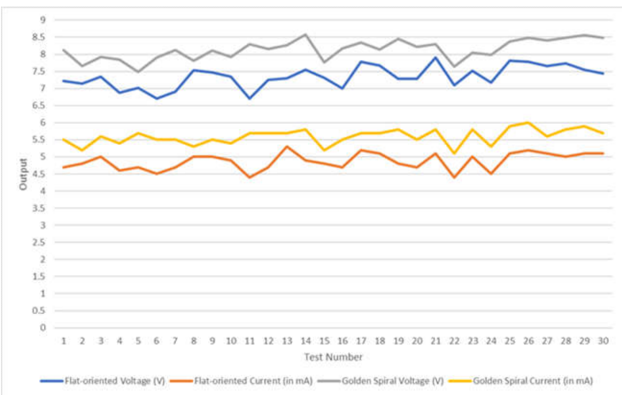

Figure 8. Voltage and current produced and power generated of golden spiral solar panel

The voltage produced by the flat-oriented panel ranged from 6.71V – 7.81V while for the golden spiral panel, the values ranged from 7.49V – 8.57V. The data on current, measured in milliamps ($x10^3$) collected for 30 hours of both the flat-oriented and golden spiral design. The current produced by the flat-oriented panel ranged from 4.4mA – 5.3mA while for the golden spiral panel, the values ranged from 5.2mA – 6.0m A. Power is solved through the formula $P = IV$, where the product of the current and voltage of the same test number or hour serves as the power generated in the given hour. The data on power, measured in milliwatt ($x10^{-3}$) collected for 30 hours produced by the flat-oriented panel ranged from 29.52mW – 40.45mW while for the golden spiral panel, the values ranged from 38.96mW – 50.50mW. The records were in all-time high during strike noon, for the flat and spiral solar panels; while the lows are typically in the early morning and late afternoon hours. It was projected that the dimensionality produced by the spirals would yield significant records during the measurement. This was supported by Mafimidiwo (2016), citing the mathematical work of Leonardo of Pisa as a vital element in utilizing the nature advantage of the abundant intake of sunlight energy. The height was also observed as another major element, supported by Suto and Yachi (2011), stating that using the Fibonacci numbers lead to a more effective solar radiation conversion into optimized output solar energy.

Comparison of voltage and current produced, and power generated of both designs

Table 1 shows the result of Independent Sample t-test for voltage, current, and power. There is a highly significant difference between the voltage produced by the two panels, with $t = -9.885$ and $p<0.05$; current produced by the two panels as with $t = -11.777$ and $p<0.05$; and the power generated by the two panels as shown in table 1, with $t = -10.68$ and $p<0.05$. The voltage generated by the golden spiral panel is greater than that of the flat-oriented panel by 10.74% with means of 8.13V and 7.35V respectively. The current produced by the golden spiral panel is greater than that of the flat-oriented panel by 14.85% with means of 5.89mA and 4.87mA respectively. The current generated by the golden spiral panel is greater than that of the flat-oriented panel by 26.13% with means of 45.32mW and 35.93mW respectively. All of the outputs coincide with the golden spiral solar panel being more efficient compared to the flat-oriented solar panel. These results are supported by the study of Ybo *et al.* (2017) which showed that solar panels arranged in a solar tree which conforms in the golden proportion of leaves in a tree is more efficient than solar panels arranged in a flat manner. This study used solar cells instead of panels arranged in a golden proportion manner, also generates more output in terms of voltage, current, and power. These results are strengthened by the view of a mathematician and a philosopher, Adolf Zeising who while studying the natural world stated that, the Golden Ratio is operating as a universal law. This states that everything that follows the golden ratio is aesthetically appealing, ensures harmony and balance, and generates more efficiency as cited in the study of Akhtaruzzaman and Shafie on 2011. Furthermore, per Murmson (2018), exposure to sunlight was a significant factor that determines the amount of power generated. The design concept of the spiral solar panels further maximized its capacity. Due to the angle gradients of the prototype, it managed to store energy more efficiently, even in different time frames during the day. Unlike the

Table 1. Independent Sample t-test for Voltage, Current, and Power

Independent Samples Test							
Levene's Test for Equality of Variances				t-test for Equality of Means			
		F	Sig.	Mean	T	df	Sig. (2-tailed)
Voltage	Flat	0.223	0.639	7.3463	-9.885	58	0.00
	Spiral			8.1350	-9.885	57.464	0.00
Power	Flat	0.014	0.905	35.9280	-10.680	58	0.00
	Spiral			45.3173	-10.680	57.921	0.00
Current	Flat	0.592	0.445	4.8700	-11.777	58	0.00
	Spiral			5.5933	-11.777	57.568	0.00

conventional flat solar panel, whose latitude and angle are uniform, the vertical occupation of the spiral panel maximized an even smaller area, thus drastically increasing the density of sunlight stored per square inch. This is even justified, per findings of Suzumoto and Yachil (2011) and Suto and Yachi (2011), citing that the amount of generated power increases with relative increases in solar altitude or height. Thus, complementing the acquired results, in relation to the findings that a Fibonacci photovoltaic module is expected to yield more power per installation area than a conventional plane module. Reception of reflected light from the other cells maximize power generation, thus double daily energy density, as supported by Yahyavi, Vaziri, and Vadhun (2010).

Summary, conclusion and recommendation

Two solar panels were made; one flat-oriented, the typical solar panel; and one golden spiral panel. The design of the golden spiral panel was made possible through the use of golden rectangle and golden spiral. The data collected from the flat-oriented solar panel in terms of voltage and current produced show that the values range from 6.71V – 7.81 and 4.4mA – 5.3mA respectively. The power generated ranges from 29.52mW – 40.45mW. For the golden spiral solar panel, it produced voltage which ranges from 7.49V – 8.57V5. Current produced ranges from 2mA – 6.0mA and power generated ranges from 38.96mW - 50.50mW. The means of these three quantities are 7.35V, 4.87mA, and 35.93mW in the flat-oriented solar panel while, 8.13V, 5.89mA, and 45.32mW are the means for the golden spiral solar panel. Thus, the output of the golden spiral in terms of the three quantities is higher than that of the flat-oriented solar panel. The Independent Sample T-Test shows that there is a significant difference between the voltage and current produced, and the power generated between the flat-oriented solar panel and the golden spiral solar panel. The golden spiral panel produces 10.74% more voltage, 14.85% more current, and 26.13% more power than that of the flat-oriented panel. With the voltage, current, and power being significantly different and the golden spiral panel is higher in all three quantities, it can be concluded that the said solar panel is more efficient than the flat-oriented one The following are recommended for further study and investigation. For the materials, the researchers recommend to use a different variation of solar cells. Standard tabbing wire for solar panels is highly suggested for the linkages, and future studies are advised to use quality-wise and budget-friendly materials for the frame. Creation of design variations is also recommended. It is suggested for the conduct of the study to be extended for at least a month, and in full days, for more variation of data and results. Data loggers can also be installed to the future studies for more rigid and convenient collection. Weather conditions can also be assessed independently, as to provide more concrete analysis in relation to the acquired parameters. Investigate for the optimal maximum tilt and angles for the solar cells and the solar panel designs.

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