UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DESIGN AND ANALYSIS AN C CURVED PHOTOVOLTAIC PANEL

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MASTER OF MANUFACTURING ENGINEERING
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Faculty of Industrial and Manufacturing Technology and Engineering

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A master project submitted
in partial fulfillment of the requirements for the degree of
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DECLARATION

I declare that this master project entitled “Design and Analysis an C Curved Photovoltaic panel” is the result of my own research except as cited in the references. The master project has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :...

Name : Nor Afidah Binti Mhd Saad

Date : 21 July 2024

APPROVAL

I hereby declare that I have read this master project and in my opinion, this master project is sufficient in terms of scope and quality as a partial fulfillment of Master of Manufacturing Engineering (Quality System Engineering)

Signature :..

Supervisor Name : TS Dr. Saifudin Hafiz Bin Yahaya

Date :..

DEDICATION

I extend my heartfelt dedication to my dissertation effort to my beloved family and many friends. I would like to express my profound appreciation to my affectionate parents, Mrs. Hamidah and Mr. Mohd Saad. Even though my father is no longer alive, his memories continue to influence and shape my life. The words of encouragement and insistence on perseverance resonate in my mind.

I express my heartfelt gratitude to my spouse, Mr. Hilkam, who has consistently provided unwavering support and encouragement during the tough times of my master's studies and daily existence. Additionally, assist in the completion of this project and guide how to continue with it, while also providing favorable feedback. I am grateful for your presence in my life.

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ABSTRACT

Solar power is a kind of renewable energy generated by solar panels. Solar panels harness the energy produced by the sun. Several studies are being conducted to explore how solar panels enhance efficiency. It is crucial since increased efficiency would lead to a reduction in power costs. Due to the current rise in electricity tariffs, solar panels have become quite beneficial to us. However, altering the design of a solar panel may also impact its ability to capture solar radiation, increasing its efficiency. Adding a C curved form to the final design may enhance its visual appeal, making it more intriguing. Various techniques may be used to improve the C curved shape of a solar panel to get a better design. The mathematical algorithm may aid in designing a favorable curvature. The equation for calculating the smooth curvature may be derived using the curve bezier function. The Bezier curve function comprises two circles defined by four key points. This research also investigates the methodology for generating the curve of this function using Solidworks. Solidworks is a 3D CAD that offers comprehensive 2D and 3D solutions for product development, including design, engineering, analysis, and tools for product data management. The software is well-recognized for its intuitive interface and has the trust of a large and diverse user community, which includes engineers, designers, students, and professionals. It also provides capabilities for simulations, visualizations, and collaboration. Solidworks is widely used across several industries for product design and development. Two software applications were used to analyze the new design of the C curved photovoltaic panel. First, the simulation expresses use for linear static analysis, and second, the ANSYS Workbench is used for steady-state thermal analysis. Both analyses were used to evaluate performance on the new design C curved panel. The linear static analysis to assess the structural design, such as Von Mises stress, displacement, and strain, and check the minimum safety factor proceed to the second analysis. The thermal analysis focuses only on computing the electrical conversion efficiency using a fluid-solid interface. It is important to note that the simulation concept differs from fluid-structure interaction. However, the research may be expanded to include additional factors that may lead to high temperatures in the future since it is necessary to conduct a thorough thermal management study to enhance the efficiency and lifespan of new solar panels.

REKA BENTUK DAN ANALISIS PANEL FOTOVOLTAIK MELENGKUNG C

ABSTRAK

Kuasa suria adalah sejenis tenaga boleh diperbaharui yang dijana oleh panel solar. Panel solar memanfaatkan tenaga yang dihasilkan oleh matahari. Beberapa kajian sedang dijalankan untuk meneroka bagaimana panel solar meningkatkan kecekapan. Ia adalah penting kerana peningkatan kecekapan akan membawa kepada pengurangan kos kuasa. Disebabkan oleh kenaikan tarif elektrik semasa, panel solar telah menjadi sangat bermanfaat kepada kita. Walau bagaimanapun, mengubah reka bentuk panel solar juga boleh menjejaskan keupayaannya untuk menangkap sinaran suria, meningkatkan kecekapannya. Menambah bentuk C-lengkung pada reka bentuk akhir boleh meningkatkan daya tarikan visualnya, menjadikannya lebih menarik. Pelbagai teknik boleh digunakan untuk menambah baik bentuk C-lengkung panel solar untuk mendapatkan reka bentuk yang lebih baik. Algoritma matematik boleh membantu dalam mereka bentuk kelengkungan yang menguntungkan. Persamaan untuk mengira kelengkungan licin boleh diperoleh menggunakan fungsi lengkung Bezier. Fungsi lengkung Bezier terdiri daripada dua bulatan yang ditakrifkan oleh empat perkara utama. Penyelidikan ini juga menyiasat metodologi untuk menjana lengkung fungsi ini menggunakan Solidworks. Solidworks ialah CAD 3D yang menawarkan penyelesaian 2D dan 3D yang komprehensif untuk pembangunan produk, termasuk reka bentuk, kejuruteraan, analisis dan alatan untuk pengurusan data produk. Perisian ini diiktiraf dengan baik kerana antara muka intuitifnya dan mempunyai kepercayaan komuniti pengguna yang besar dan pelbagai, termasuk jurutera, pereka bentuk, pelajar dan profesional. Ia juga menyediakan keupayaan untuk simulasi, visualisasi dan kerjasama. Solidworks digunakan secara meluas merentasi beberapa industri untuk reka bentuk dan pembangunan produk. Dua aplikasi perisian telah digunakan untuk menganalisis reka bentuk baharu panel fotovoltan lengkung-C. Pertama, simulasi menyatakan penggunaan untuk analisis statik linear, dan kedua, meja kerja ANSYS digunakan untuk analisis haba keadaan mantap. Kedua-dua analisis digunakan untuk menilai prestasi pada reka bentuk baharu panel lengkung-C. Analisis statik linear untuk menilai reka bentuk struktur, seperti tegasan Von Mises, anjakan dan terikan, dan menyemak faktor keselamatan minimum meneruskan ke analisis kedua. Analisis haba hanya tertumpu pada pengiraan kecekapan penukaran elektrik menggunakan antara muka pepejal cecair. Adalah penting untuk ambil perhatian bahawa konsep simulasi berbeza daripada interaksi struktur bendalir. Walau bagaimanapun, penyelidikan mungkin diperluaskan untuk memasukkan faktor tambahan yang mungkin membawa kepada suhu tinggi pada masa hadapan kerana perlu menjalankan kajian pengurusan haba yang menyeluruh untuk meningkatkan kecekapan dan jangka hayat panel solar baharu.

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CHAPTER 1

INTRODUCTION

1.1 Background

Photovoltaic refers to the process of converting light directly into electrical power. The photovoltaic effect creates an electric voltage when radiation interacts with the interface between different substances that often occur in semiconductor materials. This phenomenon commercially serves for power production and as photo sensors. Solar panels are designed to collect sunlight and convert it directly into electricity. They are also used as their foundation.

Photovoltaic (PV) cells, often known as solar cells, are the fundamental components of solar panels and are responsible for converting sunlight into electrical energy. A traditional photovoltaic cell comprises a semiconductor material, often silicon, and is subjected to treatment to produce an electric field. Incorporating dopants into the silicon generates an electric field, which is crucial for the functioning of the photovoltaic cell. Phosphorus is added to one layer to create an abundance of electrons (n-type silicon). At the same time, boron is injected into another layer to form a deficiency of electrons (p-type silicon). The photovoltaic effect occurs when photons from sunshine contact with a photovoltaic (PV) cell, transferring energy to the electrons in the semiconductor material. This energy allows the electrons to separate from their atomic connections. At the junction of the two types of silicon, the electric field drives the unbound electrons in a specific direction, producing an electric current (Rosu et al., 2020).

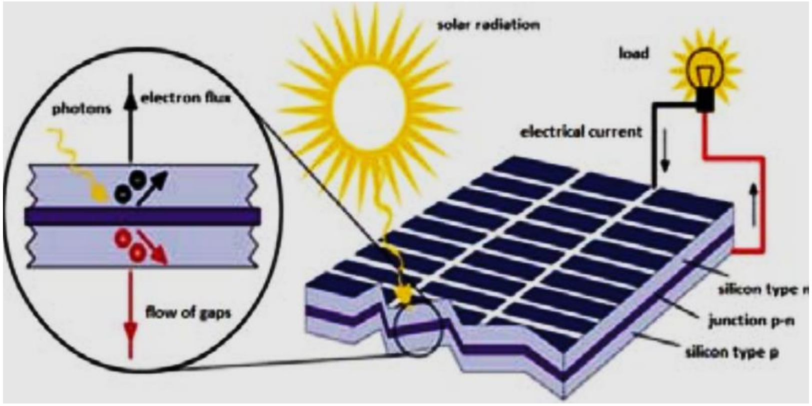

Figure 1:1 Photovoltaic system showed by Rosu et al. (2020)

There are several types of photovoltaic cells. The first was monocrystalline silicon cells. These cells are produced from a solitary silicon crystal, resulting in high efficiency, a characteristic rounded edge, and a uniform appearance. They have a higher cost but also a greater level of efficiency compared to others. The second was polycrystalline silicon cells. These cells are made of several silicon crystals and are less efficient but more affordable than monocrystalline cells. Their form is square, and their surface is decorated with blue speckles. The third was a thin film laying down several thin layers of photovoltaic material on a base to produce solar cells. This material could be amorphous silicon, cadmium telluride, or copper indium gallium selenide. While they provide more flexibility and lower costs, thin film solar cells often exhibit lower efficiency than crystalline silicon cells (Arissetyadhi et al., 2020; Rosu et al., 2020).

The efficiency of photovoltaic (PV) cells is defined as the ratio of the electrical power output to the solar energy input. Most commercial photovoltaic (PV) cells exhibit 15% to 20% efficiencies. However, continuous research and development efforts are being conducted to fabricate cells with enhance deficiencies. Various applications use PV cells, ranging from small scale devices such as calculators and road signs to large scale installations like solar farms. Additionally, they are found in satellites and space missions, serving as the predominant power source. In the field of advancements and research, several ongoing studies in materials science and engineering are focused on developing photovoltaic cells that possess enhanced efficiency, durability, and affordability. Notable advancements include perovskite solar cells, multi-junction cells, and the incorporation of nanotechnology (Deivakumaran et al., 2023; Sato et al., 2021; Swain et al., 2023).

Curved photovoltaic (PV) solar panels are created with curved surfaces. This design diverges from conventional flat solar panels and has distinctive benefits and uses. The curvature of the surface allows for increased light absorption since it provides a more significant and variable surface area that may absorb sunlight from various angles throughout the day. Curved photovoltaic panels enable the creation of solar systems that are both visually appealing and seamlessly incorporated into architectural designs. They are used in architectural projects where conventional flat panels may not be appropriate, such as curving roofs and facades or installing curved PV panels into building design. Moreover, in some designs, the curved form can focus sunlight onto a smaller, more efficient solar cell, thereby decreasing the required quantity of costly solar cell material (Awad et al., 2022; Srinivas et al., 2020; Younas et al.,2022).

The curved PV panels may be tailored to suit precise design requirements and areas, providing a level of adaptability that flat panels may not provide. However, curved PV panels present some difficulties, such as optimizing the curvature for optimum solar exposure throughout the day. This task may be challenging and may require the use of advanced design and planning techniques. Additionally, they might possess a higher level of intricacy and costliness in production and installation. Curved photovoltaic (PV) panels are being used in various unique applications. They are precious when seamlessly integrating with the current architecture or environment is essential. Illustrative instances include the incorporation of technology into the structure of automobiles, communal areas, contemporary architecture, and even portable devices. The curved photovoltaic panels signify a pioneering advancement in solar technology, presenting fresh prospects for design and effectiveness. Nevertheless, they also include a distinct array of difficulties and factors to consider, namely expenses, intricacies in production, and the installation process. With the progress of technology, these obstacles could be resolved, resulting in a broader acceptance of curved PV panels across different uses.

1.2 Problem Statement

The design and implementation of curved solar panels have gained significant attention in recent research by Choi et al. (2019). Demonstrated that the power generated by solar panels was higher when using curved reflectors, leading to increased incident solar power entering the panel (Choi et al., 2019). This finding supports the potential benefits of curved solar panels in enhancing solar power generation. Curved solar panels, characterized by their curved and textured surfaces, have considerable potential for enhanced light absorption and energy conversion compared to conventional flat panels. Nevertheless, several obstacles impede their extensive acceptance and excellent efficiency. Álvarez et al. (2021) conducted a case study fitting analytical models to the behavior of solar panels, providing insights into the photovoltaic performance and behavior of solar panels. This study contributes to understanding the behavior of solar panels, which is crucial for designing efficient curved solar panels. The curved shape of the panel may result in intricate light manipulation, including light scattering and internal reflection. It also reduces the light that reaches the active layer, diminishing the overall conversion efficiency.

Moreover, Guo et al. (2021) highlighted the significance of maximum Power Point tracking (MPPT) in optimizing the performance of photovoltaic systems, especially under partial shading conditions. It is essential as it highlights the need to optimize solar panels' performance, which is crucial for ensuring the effective operation of curved solar panels. Furthermore, Emetere (2020) discussed the damaging effects of harsh solar radiation on the efficiency of solar PV panels, emphasizing the need for spectral filtering to mitigate these effects. Curved solar panels must maintain their efficiency and longevity.

In addition, the study by Kindangen et al. (2021) explored the integration of solar panels as shading devices to lower indoor air temperatures, indicating the multifunctional potential of solar panels beyond power generation. This is significant because it broadens the range of applications for curved solar panels, possibly including additional advantages like shade and temperature adjustment.

On the other hand, optimizing the curvature and surface roughness is essential to achieve a balance between effectively capturing light for efficient absorption and minimizing any undesirable scattering losses. It is crucial to develop alternate substrates that are both flexible and lightweight while also ensuring effective light collection and structural integrity. To achieve mass production and effectively compete with conventional flat panels, the manufacturing methods of C curved panels must be both cost-effective and scalable.

1.3 Objective of the study

i. To design a photovoltaic panel with an C Curved shape using Cubic Bezier Function.
ii. To analyze the C Curved photovoltaic panel using a linear static analysis.
iii. To calculate the C Curved photovoltaic panel efficiency using thermal analysis.
iv. To validate the efficiency of the C Curved photovoltaic panel with the flat photovoltaic panel.

1.4 Scope of Research

The significance of the study focuses on developing the C curved photovoltaic panel using Solidworks, which is employed with the Cubic Bezier Curve methods. Then, the best material will be selected for better efficiency. The study compares these photovoltaic panels with existing panels to validate their electrical conversion efficiency using calculations from the average temperature obtained from thermal analysis using an ANSYS Workbench. The study also highlights the vital role of the cubic Bezier function in ensuring a smooth connection between control points. Additionally, the study evaluates the structural strength, strain, displacement, and safety factor for the linear static analysis. Also, it performs steady-state thermal analysis for validation of electrical conversion efficiency.

1.5 Report Organization

Chapter 1 introduces the background of the study, problem statement, objective, and significance of the study.

Chapter 2 reviews the literature review. This chapter presents research information organized into interconnected disciplines of study necessary for this research. Relevant information from many sources, such as general ideas, essential facts, previous study papers, and journal articles authored by researchers, are used. This chapter provides a comprehensive overview of the research process, starting with the methodological phase and extending to the finalization of the Master Project. It includes the curved solar panels and how to design the curved photovoltaic panel. Furthermore, it also has a method to smooth the curved design and then analyze the curved photovoltaic panel.

Chapter 3 establishes the methodology. This chapter describes the approach to designing the curved solar panel using Solidworks, performing structural analysis using Solidworks Simulation Express, and performing steady-state thermal analysis using the ANSYS Workbench. The temperature obtained from the thermal analysis will be used to calculate electrical conversion efficiency.

Chapter 4 discusses the result obtained with the new design of C Curved photovoltaic panel and the linear static analysis of its structure, such as stress on the new design obtained, the length of displacement, strain, and the factor of safety that are used to check the system's strength relative to the desired load to see if it’s within or beyond the acceptable range. The minimum factor of safety less than one indicates the design has failed.

Chapter 5 recommends future work that can be done to improve this study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Energy efficiency is the practice of minimizing energy use while achieving the same performance or service level. It may be accomplished via several methods, including adopting more efficient technology, enhancing insulation in buildings, and using energy-saving appliances and lights. Energy efficiency reduces energy usage, resulting in cheaper energy bills, less pollution, and the ability to battle climate change. It is commonly acknowledged as a very accessible and economically efficient approach to address environmental problems and reduce energy costs for people and corporations.

The evolution of solar cells may be divided into six distinct phases, starting from 1839 and continuing to the current day. The first operational silicon solar cell was shown in 1954, substantially improving efficiency. Between 1960 and1980, the US government began assisting solar cells, including developing novel device technologies such as Gallium Arsenide cells. From 1980 to 2000, there was a decline in support, although it remained worldwide. Since the year2000, there has been a significant increase in international support and the capacity for installing solar photovoltaic (PV) systems. This growth has been primarily influenced by policies such as Germany's feed-in tariff program and China's expansion of manufacturing capabilities. Concentrator cells and modules with increased efficiency are becoming intriguing prospects for the future (Fraas, 2014).

Solar power is a renewable energy source that has the potential to enhance electricity efficiency greatly. Solar power systems use solar energy to transform sunlight into electricity. This procedure generally uses photovoltaic (PV) cells, frequently seen in solar panels. An essential benefit of solar electricity is its inherent renewability. In contrast to fossil fuels, the energy from the sun is almost endless and accessible daily. Solar power is a viable and enduring option for energy requirements. Moreover, solar power systems are constantly improving their electrical efficiency. Technological advancements have resulted in developing more efficient solar panels capable of converting a more significant proportion of sunlight into electrical energy. Hence, solar power becomes more efficient since it produces an incredible amount of energy from the same amount of the sun. The need to use renewable technology in architecture has prompted novel interpretations and methodologies. The importance of photovoltaic systems has been heightened due to building requirements and international commitments to combat climate change. The existing method slack both aesthetic appeal and technical efficiency (Haghighi, 2022).

In addition, solar electricity reduces dependency on conventional power systems and fossil fuels, thereby reducing the total environmental footprint. Additionally, it has the advantage of decentralized energy generation, which may be particularly advantageous in isolated or rural regions where conventional power infrastructure is scarce or absent.

Various studies have been conducted to hasten technological advancements in solar panel production, focusing on curved dimensions. These studies have demonstrated notable enhancements in electrical efficiency (Kathir et al.,2022; Parthiban et al., 2022; Swain et al., 2023; Venkateshwarlu et al., 2023). Figure 2.1 shows the evolution of research to achieve better cell efficiency. Since 1975, researchers have been looking for a solution for better efficiency. The figure below clearly shows that in the past half-century, there has been a dramatic increase in research reported by NREL (2024) on photovoltaic cells for having good efficiency. There are four groups of semiconductor families and technologies for solar cells: multijunction cells, crystalline silicon cells, thin film technology, emerging photovoltaic, and hybrid tandems, combined by two groups of material solar cells mentioned above. These families have increased the percentage of efficiency solar cells over the years. Therefore, this study contributes significantly to research on good efficiency by developing a new design of a curved shape of photovoltaic panel to enhance efficiency. Green et al. (2023) presents a table comprising the solar cells and modules independently certified to have the highest efficiency as a guideline for another researcher.

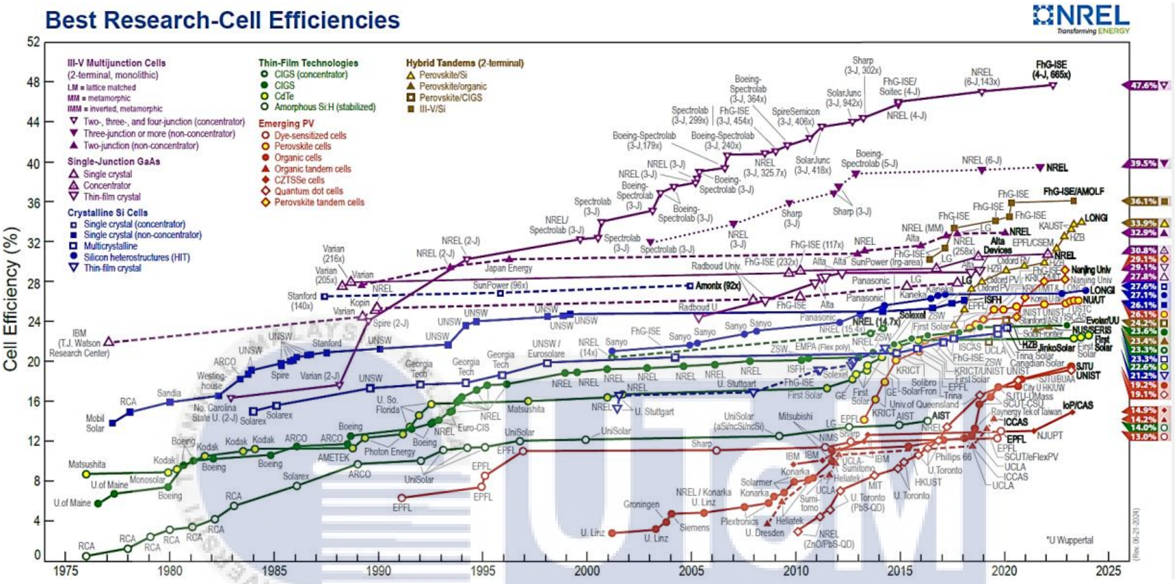

Figure 2:1 Evolution research cell efficiency (NREL, 2024)

2.2 Curved photovoltaic panel

Photovoltaic panels have been proposed to improve the efficiency and adaptability of solar cell installations. By contouring the solar cells to match the curvature of the optical system, the efficiency can be significantly increased, eliminating the need for mechanical tracking systems (Swain et al.,2023). Multi-physics analysis is necessary to consider the mechanical, electrical, and optical aspects of curved solar panels, focusing on the reinforcement layer to ensure the reliability of the solar cells (Espitia-Mesa et al., 2021).

Using curved-type reflectors between solar panel arrays has significantly increased the generated power, making them a promising solution for highly efficient solar power