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Adaptive solar panel - overview and conceptual design

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Abstract. Renewable energy should reach its maximum usage capacity, around 20%, by 2025, as laid out by the Malaysian government to achieve the seventh Sustainable Development Goals (SDG): Affordable and clean energy. Many actions have been implemented to support the idea, including the development of solar energy panels in large photovoltaic installation. However, the installations require a wide area of land, and the efficiency offered is limited due to their fixed position. The efficiency of solar panels in absorbing the light from the sun is important to increase the energy supply. Several designs of the adaptive solar panel were developed by researchers, but the installation costs are high due to the components used. Commonly used actuators to move the solar panels are motor (DC motor, stepper motor, servo motor) that actuate according to the signals from photosensor, programming logic control (PLC), or microcontroller. Herein, the development of an Adaptive Solar Panel (ASP) is studied. SMA with high recoverability when it is strained is introduced as an actuator that capable of generating large actuation when heated to move the solar panel. In discovering the potential of SMA wire, a modern environmental-friendly design with six layers of solar panels with a rotational support system was designed in this study. In future work, the SMA wire actuation will be evaluated by computational simulation method using LS-Dyna. **Keywords:** Actuator, shape memory alloy, solar panel.

1. Introduction

The current energy sources for Malaysia's power generation are natural gas and coal. Only 2% of the total power generation is produced from renewable energy sources [1]. Thus, an ambitious target has been set by the Malaysian Government to utilize the renewable energy up to 20% by 2025. Due to our major dependence on fossil fuels, an alternative renewable energy source that is locally available is required to replace the depleting fossil fuels. Hence, utilizing solar energy as one of renewable energy sources is good for the environment as it is non-polluting. Besides, the Malaysian weather is suitable for solar panels made of photovoltaic (PV) cells as the average annual solar irradiance level is mostly above 1500 kWh/m^2 for every state [2]. However, the current solar panels offered limited efficiency in

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sun-light absorption because of its static installation. Even with the existing solar tracking devices designed by some researchers, it still requires external power to sense the sun's movement and to actuate the solar panel. So, the complexity of the technology somehow increased the cost. Thus, simple solar tracking using shape memory alloy (SMA) for affordable and clean energy is designed. In this study, two thin-film solar modules manufactured by First Solar Company with a dimension of 1200 mm x 60 mm x 6.4 mm, weight of 30 kg, and two shape memory alloy (SMA) wires manufactured by SAES Getters Group will be used in the modelling.

2. Adaptive Solar Panel - Benefits and Potential

Based on previous studies in several countries having different climates, the performance of the PV arrays with and without solar tracking systems is investigated. Vieira (2016) compared the PV performance between the static and mobile systems and he found that the performance in power generation was increased by 11%. Nagy et al. (2016) found that the total energy could be saved up to 25% when they used a single axis of rotation solar tracking system with a soft pneumatic actuator in their adaptive solar facade. Compared to the fixed solar panel, Akbar et al. (2017) showed that their sun tracker design increased the efficiency of the output power generation by 25-30%. Seme et al. (2017) proposed a design of a bi-axis solar tracking system, and it generated 27% higher electrical energy compared to the fixed system. Alinejad et al. (2020) assessed the thermo-environomic of an integrated greenhouse with an adjustable solar photovoltaic blind system. They found that the SBG24 performed well in all studied parameter as it controlled the shading, it reduced the annual natural gas consumption by 3.57%, it supplied 45.5% electricity demand to the grid, and it generated 42.69 kWh/m^2 of energy supply compared to the existing greenhouse (GR). In a nut shell, the use of an Adaptive Solar Panel does not only increase the harvested energy but can also meet certain demands in form of shading and electricity supply. However, the performance may vary due to the types of tracking systems, the country's geographical locations, and the weather conditions.

3. Adaptive Solar Panel - Overview of the Existing Design

Solar tracking systems can be categorized based on the drivers, control system, tracking strategy, or degree of freedom of the movement (Awasthi et al., 2020). Overview of solar tracking systems with various mechanisms is summarized in Table 1.

In brief, based on the explored tracking systems, a certain amount of electrical energy is required as input for the controlling units (i.e. FLC, PLC and microcontroller), for the actuators (i.e. electrical motor) and the sensors (photosensor and LDRs). Therefore, electrical energy is required as an external energy source to activate them. By replacing those with smart materials (i.e. SMA wires) that can be activated by solar heating, the use of electrical energy as input is no longer required.

4. Design

4.1. Mechanical

The design of the ASP has three elements as shown in Figure 1; two thin-film PV modules, an actuator, a supporting frame with a stand. The two solar panel modules have a weight of 15 kg. In the following sections, the design considerations for the thin-film PV modules, the actuator, and the supporting frame and stand are described.

4.2. Solar Panel – Thin Film Solar Panel Module

Solar technology is rapidly expanding. In Malaysia, PV research and development explore cutting-edge technologies, cell design, and novel approaches in the development of solar materials and products [19]. Conventional PV cells consist of crystalline silicon which atoms are arranged in a 3D array [20]. Commercially available solar panels have their benefits and drawbacks [20-21]. Generally, PV modules can be categorized into three groups, which are amorphous, monocrystalline, and polycrystalline silicon.

Table 1: Solar tracking system

No.	Author's Name	Design Implemented
1.	Ganesh N. J. et al. (2011)	Sun tracking system with Ni-Ti shape memory alloy (SMA) spring having an average diameter of 5 mm and 52 coils that acts as sensor and actuator.
2.	Degeratu et al. (2014)	Sun tracking system controlled by SIEMENS program logic control (PLC) that requires external power sources actuated by Ni-Ti SMA.
3.	Azwaan Zakariah et al. (2015)	Sun tracking system using a combination of Arduino UNO ATmega328 microcontroller, motor driver (MD30C), two power window motors, maximum power point tracking (MPPT), four light dependent resistors (LDRs), and fuzzy logic controller (FLC). The microcontroller was programmed for control of the overall performance; the MPPT was used to adjust the current and voltage while the FLC provides inference decision to the microcontroller.
4.	Rahimi et al. (2015)	Sun tracking system using two photosensors, and two DC motors with a supply voltage of 6V DC. The sun's movement was tracked by the photosensor and the solar panel was actuated by the two DC motors.
5.	Chakrabory S. et al (2015)	Sun tracking system consists of stepper motor (4SHG-050A 5IS 5V, 5Ω), AT89S52 microcontroller and five LDRs. The microcontroller with the help of LDRs was programmed to sense the sunlight for actuation of the servo motor.
6.	Das K. et al. (2016)	Sun tracking system consists of ATmega328 microcontroller, two LDRs, and servo motor. The microcontroller was programmed to sense the sunlight with the help of LDRs, for actuation of the servo motor.
7.	Canbay C. A. et al. (2016)	Sun tracking system consists of three Cu-Al-Mn-Ni SMA to coat as a Schottky contact on a p-Si substrate to produce four quadrants sensor using vacuum coating.
8.	Hussain S. Akbar et al. (2017)	Dual-axis sun tracking system using a combination of ATmega328 microcontroller, two direct currents (DC) motors, two LDRs, and two relays. The microcontroller was programmed to sense the sunlight with assistance from LDRs and relays, for decision of DC motor rotation.
9.	Riad et al. (2017)	Sun tracking system that works like a sunflower that was actuated by SMA springs with an average diameter of 5 mm and 52 coils.
10.	Riad et al. (2020)	Sun tracking system that used six SMAs in spring form with 10 mm diameter to actuate and move the solar panel.

With the rising development in solar energy production, thin-film technologies are currently improved to achieve higher efficiency by using materials such as cadmium telluride (CdTe), copper indium diselenide (CIS), and gallium arsenide (GaAs) [21]. This is proven by Nowshad Amin et al. (2009) and Sreenath et al. (2020) who conducted an experiment to analyse the performance of several types of solar panels under Malaysia's weather. The study found that crystalline solar modules gave better performance under the hot sun, while the thin-film and amorphous silicon solar panels gave higher performance under cloudy and diffused sunshine weather conditions. Moreover, the efficiency of crystalline silicon solar panels dropped when the temperature increased, unlike thin-film and amorphous silicon solar panels. Debbarma et al. (2017) and Manoj et al. (2019) found that Cadmium

Telluride (CdTe) was suitably and widely used for large-scale PV plant installation. Therefore, the Adaptive Solar Panel was modelled with the CdTe thin-film from First Solar Sdn. Bhd, with a dimension of 1200 mm × 60 mm × 6.4 mm.

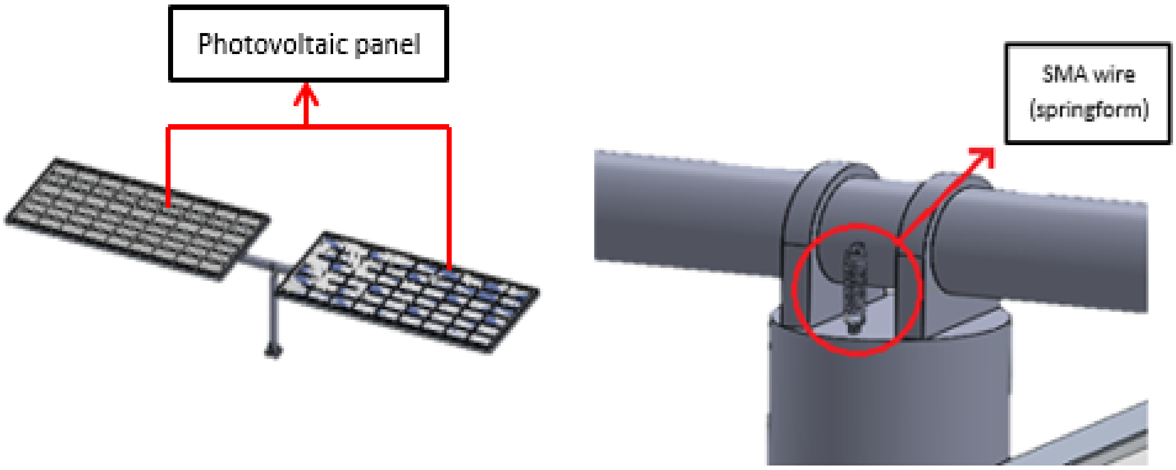

Figure 1. Current adaptive solar panel

4.3. Actuator - Mechanical and Smart Actuation

Solar trackers moved the solar panels so that the surfaces of the panels are oriented towards the sun. By utilizing actuators, the solar panels are able to face the sun throughout the day to capture the optimum energy and to maximize its output. According to section 3, there are two types of actuators: motors (i.e. DC motors, servo motors, and stepper motors) and SMAs.

A motor, which is a device that converts electrical energy into mechanical energy, operates via the interaction between the motor's magnetic field and electric current in wire winding to generate force or torsional moment. Once the motor is powered by external power sources, it generates torque, which actuates the solar panels to the aimed angle, capturing photons from the sun.

Shape memory alloy (SMA) is a unique material that can return back to its original shape after being deformed, when it is heated above the Austenite finishing temperature [17,26]. The SMA possesses excellent thermo-mechanical properties, such as shape memory effect (SME), super elasticity (SE), good damping, and good fatigue and corrosion resistance [27]. The SMAs have two main phases, which are a Martensite phase at low temperatures, and an Austenite phase at high temperatures [17,26]. The shape memory effect occurs when the SMA in the Martensite phase is deformed, and the residual deformation can be recovered by heating the SMA above the Austenite finishing temperature. The SMA also exhibits super elasticity properties when it is in the Austenite phase and is deformed due to the external load, and the deformation can be fully and spontaneously recovered when the load is removed [27].

SMA actuators are promising due to their large recoverable strain and specific energy output [28]. Therefore, the actuator chosen for the design is SMA wire manufactured by SAES Getters Group, with a 0.5 mm diameter and a maximum strain recovery of 8%, because of the simplicity of the smart actuation that requires no external power. The SMA wire was designed in spring form to achieve higher stroke [30]. However, details on the SMA design will be further evaluated based on the actuation, whether the designed SMA can actuate the 30 kg solar panels.

4.4. Numerical Analysis for Support Stand and Beam

According to First Solar Company, the mass of the solar panel is approximately 10-15 kg, depending on the glass thickness. Hence, for safety analysis, the maximum mass considered in the analytical calculation was 15 kg. Based on the maximum distortion energy theory, the structure is safe. The solar panels were assumed in equilibrium condition where the net forces were equal to zero. The formulas used in the analysis are listed below.

i - Equilibrium equations:

$$\Sigma \mathrm{F} = 0, \Sigma \mathrm{M} = 0 \tag{1}$$

where F and M are the forces and moments in the x, y, and z directions.

ii – Normal/axial stress:

$$\sigma = \frac{\mathrm{Force}}{Area} \tag{2}$$

iii - Shear stress:

$$\tau = \frac{VQ}{It} \tag{3}$$

where V is the internal shear force, Q is the statical moment of area, I is the moment of inertia and t is the thickness (width) perpendicular to the shear.

iv - Bending stress:

$$\sigma = \frac{M \cdot y}{I} \tag{4}$$

where M is the internal bending moment, y is the distance from neutral axis, and I is the moment of inertia.

5. Results

The solar panel is rotated by 30° angle in 0.2 seconds. The result of the angle of rotation is shown in Figure 2. The adaptive solar panel rotates by 30 degrees as shown in the figure, when angular displacement was applied to the panel.

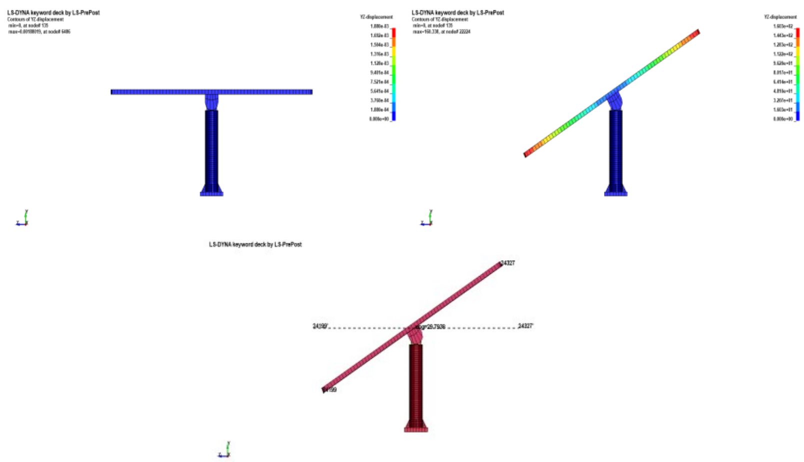

Figure 2. The adaptive solar panel before and after 30° rotation.

6. Conclusion

In conclusion, the design of an adaptive solar panel was made and finalized. The process of the design is mainly divided into three parts which are a selection of the solar panel, selection of actuator and analysis of support stand and beam. In future work, the actuation of the SMA wire will be evaluated by computational simulation method using LS-Dyna finite element software.

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