International Journal of Marine Engineering Innovation and Research, Vol. 8(2), Jun. 2023. 289-294
(pISSN: 2541-5972, eISSN: 2548-1479)

Stability Analysis of Double Axis Retractable Solar Panel Mechanism for Harbour Tug Application

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(Received: 16 May 2023 / Revised: 24 May 2023 /Accepted: 25 May 2023)

***Abstract*— Due to the use of fossil fuels in recent decades, maritime researchers and stakeholders have started to become concerned about energy efficiency and environmental protection. The larger social and economic facets of society may suffer as a result of these problems. In an effort to offer a remedy, this research created the B-Solar Wings, the double axis retractable solar panel mechanism design concept for harbor tug applications. B-Solar Wings was created using a variety of strategies to make the most of harbour tugs' constrained space for solar energy absorption while taking into account challenging ergonomic and safety concepts. B-Solar Wings can assemble 7 solar panel units for a total power of 3150 based on the design results. In order to assess the viability of stability brought on by the installation and use of solar panels, this study also offers a modeling analysis. The B-Solar Wings are stable in terms of stability, according to the results of the modeling and validation with the guidelines stated in IMO A. 749 (18). The minimum required value for one of the categories, code 3.1.2.1: Area 0 to 30, is 3.15 m.deg, and the harbour tug's stability value is 17.11 m.deg in the folded position and 17.10 m.deg in the full-open position. Solar energy produced by solar panels can be stored in a battery and integrated into the main distribution panel through multiple stages of voltage conversion and stabilization in the power system for B-Solar Wings.**

Keywords— harbor tug, solar panel, stability, retractable, maritime, port

I. INTRODUCTION

Several maritime stakeholders are currently focused on environmental and energy issues as a result of recent developments [1]–[3]. Following this, international organizations developed a number of policies to maintain stability and lessen the negative effects of their operations [4], [5]. Additionally, according to Di Vaio et al. (2018), the negative effects of environmental and energy problems caused by maritime activities can have fatal effects on a wider dimension of social and economic aspects, not only for port business actors and the shipping industry but also on the larger community [6].

The program to increase energy efficiency and environmental protection is currently focusing on maritime activities such as shipping, loading and unloading, activities in ports, and the operation of tug services [7], [8]. A number of measures have been taken to lessen the negative effects of maritime activities, such as restricting the use of fossil fuels, utilizing new and renewable energy sources, and improving operational and management efficiency to use less energy while still performing more effectively. Green ports are practices and strategies used, particularly in port operations, to increase energy efficiency and protect the environment [9], [10].

The use of solar panels is being increased in a number of initiatives to use renewable energy. One of the essential planning steps required to be able to capture sunlight in a particular place is the placement of solar panels. In a sufficiently large open area, the placement of solar panels can be planned as much as possible to take full advantage of the radiation already present. Solar panels are installed in a constrained space in order to maximize sunlight capture by adjusting the installation area. In accordance with their performance analysis, Karatuğ & Durmuşoğlu (2020) have completed a planning design for solar panels to be installed on the Roro ship. In order to maximize the absorption of sunlight while operating, solar panels can be laid over a specific area when mounted on a wide Roro Ship [11]. In order to maximize the number of solar panels that can be installed, Diab, Lan, and Ali (2016) have also planned the placement of solar panels on tankers that take advantage of a wide deck position [12].

Solar panel planning may take a different approach to maximizing sunlight capture and utilizing available space when there is a limited amount of space. Harbour tugs are one of the port facilities that present unique design challenges for solar panels.

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The ship that is responsible for supporting towage operations in the port area has a specific shape and typically still relies on fossil fuel engines for propulsion. By incorporating an energy recovery system in the ship's propulsion, Shiraishi et al. (2013) have developed a hybrid concept that can be applied to harbour tugs, allowing for the conversion of unused power back into electricity and use for the ship's accommodation load [13].

The hybrid idea can reduce the amount of energy used by harbour tugs even though renewable energy has not yet been implemented. Furthermore, Bouhouta et al.'s (2022) implementation of solar panel use on harbour tugs included the design of a hybrid scoring system that combined generators, solar panels, and windmills. However, it remains difficult to create a design that can take into account ergonomics and safety while allowing for the placement and blending of solar panels and windmills [14].

To find effective solar panel designs that can be mounted on moving or confined surfaces, numerous theories have been developed. In order to minimize damage to solar panels, Sharif et al. (2013) published a paper on a retractable solar panel design that was influenced by the leaves of the black walnut leaf [15]. By designing and examining a small-scale (1U Cubesat) SMA-based application device for solar panels, Wheeler et al. (2015) have also created a retractable solar panel [16]. More recently, Jasim & Taheri (2018) have created a rectable solar panel that makes use of available space when placing solar panels. The design was inspired by the art of paper folding known as origami. This system has a wide range of applications, including in the home, during emergencies, and on other planets [17].

Based on a number of perspectives in this study, we offer a double axis retractable solar panel design concept, including the need for solutions to improve energy efficiency and protect the environment in port activities, including harbour tugs even though they have a limited amount of space. mechanism that makes the most of the harbour tug's solar panels. The main goal of our research is to create a solar panel system that can be installed on harbour tugs while taking stability, ergonomics, and safety considerations into account. This study was conducted by taking into account the design strategies and innovations for solar panels that have been created by various researchers and then modified for use on harbour tugs. This study is divided into several sections, beginning with an introduction in section 1, then a methodology presentation in section 2, a summary of the design and stability analysis results in section 3, and conclusions in section 4 as the study's final section.

II. METHOD

The development of a retractable solar panel design that is suitable for mounting on a harbour tug and an analysis of the ship's stability comprise the two main phases of this research. All retractable solar panel designs that can be folded when not in use and stretched when needed were developed during the design phase. On harbour tugs, the design of retractable solar panels allows for maximum space utilization while maintaining ergonomics and safety. Three conditions in general require stability testing based on the design planning. The first conditions is the existing in which there are no solar panels installed; the second conditions is when there are solar panels installed but they are folded and have not been used; and the third condition is when the solar panels are in full-open position and used to capture sunlight. Simulating the calculations and criteria required by IMO A. 749 (18)- Design criteria applicable to all ships- allows for the testing of ship stability.

III. RESULTS AND DISCUSSION

The main consideration when creating a design for solar panels on a harbour tug is where to position numerous solar panel units that can be folded when not in use and opened when activated. A number of methods for conducting literature studies have been used by several prior researchers in the design development process. One of these methods involves the use of solar panels that can be folded and then modified to fit the shape of a harbour tug. The general details of the B-Solar Wings solar panel design that was created for this study are shown in Table 1. On a retractable mechanism, there are solar panel pieces arranged in various configurations.

With an effective operating time of 5 hours per day and an estimated power that can be absorbed, namely 15.75 kilowatts per day, the total power planned for this solar panel design is estimated to be 3150 watts. According to the simulation's findings, the level cost of electricity, also known as the estimated cost of electricity, is 2860 cents per kilowatt. Due to the fact that this solar panel's design allows for folding, there are two dimensions that can be used as a guide. When the solar panel is folded, its dimensions are 2 meters in lenght, 2.5 meters in weight, and 1.6 meters in height.

When the solar panel is in full-position, a solar panel's dimensions can be as much as 2.5 meters in lenght, 8.2 meters in width, and 4.2 meters in height. To ensure that the position of the solar panels does not exceed the ship's dimensions for safety reasons, the harbour tug's width is 8.6 meters.

TABLE 1.
SOLAR PANEL DESIGN SPECIFICATION

Item	Value	Unit
Solar Panel Quantity	7	Pcs
Watt-Peak Total	3150	Watt-Peak
Effective Operational Time	5	Hours / Day
Estimated Output Power per Day	15,75	Kw - Day
LCOE	2.860	Rp/Kw
Weight	948	kg
Dimension (Folded)	2,0 x 2,5 x 1,6	meter
Dimension (Full-Open)	2,5 x 8,2 x 4,2	meter

The design of the double axis retractable solar panel mechanism used on harbour tugs is depicted in Figure 1. In general, there are two main positions for the solar panel: the folded position, which is when the solar panel is not in use, and the open position, which is the position when the solar panel is in use. There are five steps in the movement process from the solar panel's folded-up stage to its open stage in order to reach these two positions. The solar panel, which was initially in the folded position (stage 1), will first be raised (stage 2) in order to achieve an open condition. After turning 90 degrees (stage 3), the solar panel will continue to expand (stage 4) until it reaches the desired width (stage 5). Figure 1 shows specifics of the stages of solar panel movement.

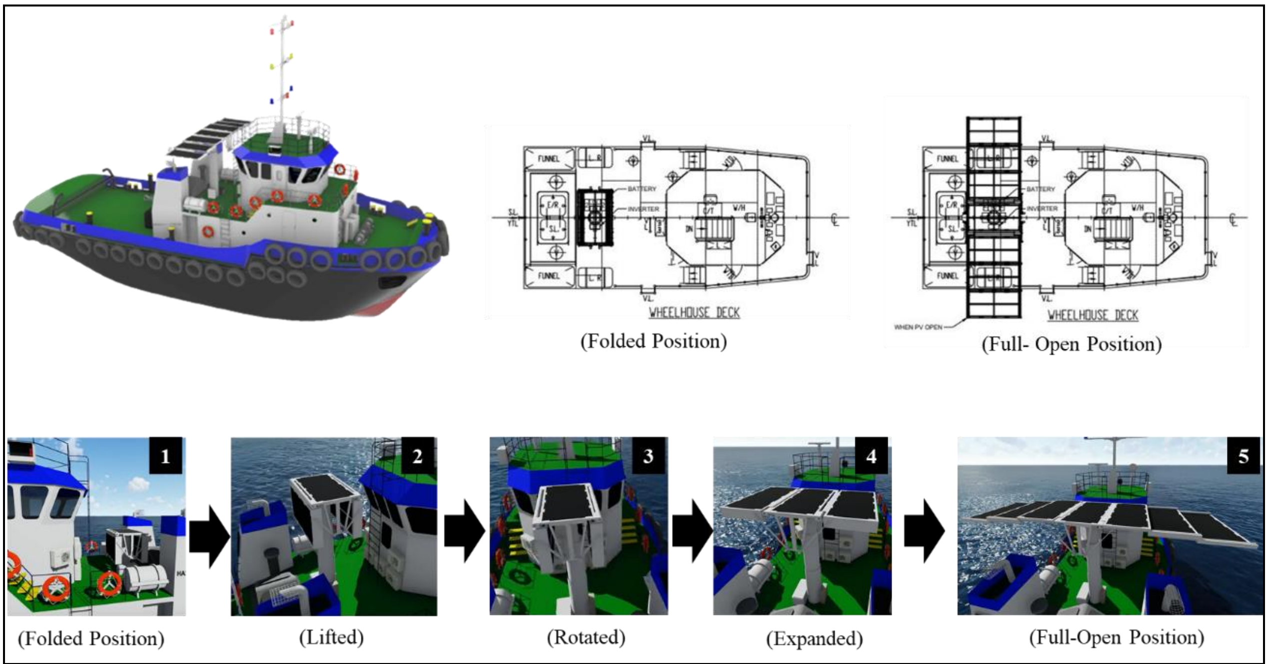


Figure 1. Design of of Double Axis Retractable Solar Panel Mechanism for Harbour Tug Application

The double axis retractable solar panel mechanism for harbour tug applications, also known as B-Solar Wings, uses hybrid concept in plans to combine solar panel power with generator power, similarly to the hybrid concept on harbour tugs that was also developed by Shiraishi et al. (2013) [13]. The solar panels are made to produce a direct voltage that is directly stored in the battery via a battery charger after being stabilized beforehand by a voltage stabilizer device. When in use, a number of converter and stabilizer devices will combine the energy from the battery with the use of the generator in the main distribution panel. We also update the wiring diagram design as a reference for ship owners to use when declaring modifications to the classification society due to changes that will be made to the ship's electrical system. Figure 2 shows examples of solar panel design references from the hybrid system.

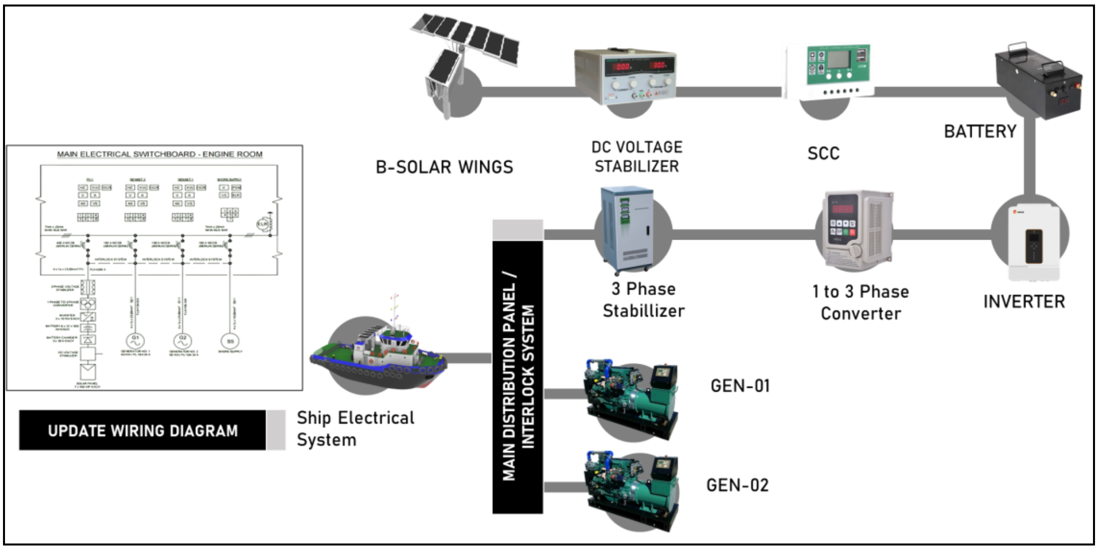


Figure 2. Solar Panel Design in Ship Hybrid System

As mentioned in the previous section, the stability caused by the installation of solar panels on a harbour tug will be examined as part of this study's initial phase. Through modeling with software, ship stability testing simulations are conducted. In solar panel installations, there are three stability testing procedures: when the ship is in its current state without solar panels (Figure 3), when the solar panels are folded (Figure 4), and when the solar panels are fully open (Figure 5).

Based on the outcomes of the simulation, it is known that the level of stability decreases for ships without panels, ships with panels folded, and ships with panels fully open. It is necessary to compare the results of this simulation with regulations in order to determine the results of the stability simulation against the stability reference value. The IMO A. 749 (18)- Design criteria applicable to all ships regulations were used to verify the stability of solar panel installations.

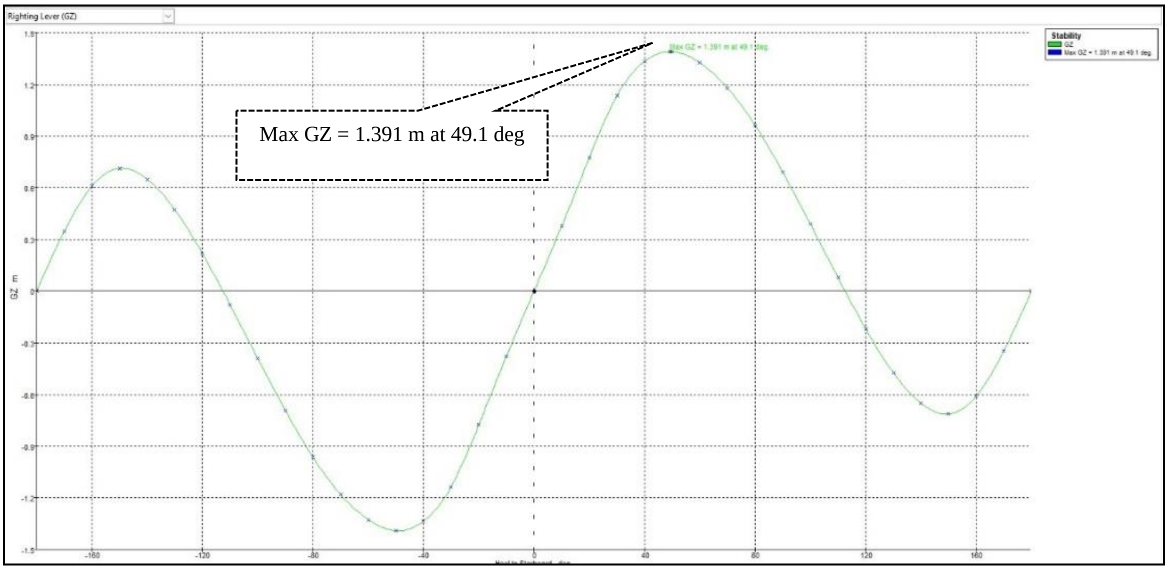


Figure 3. Loadcase Stability Analysis: No Solar Panel

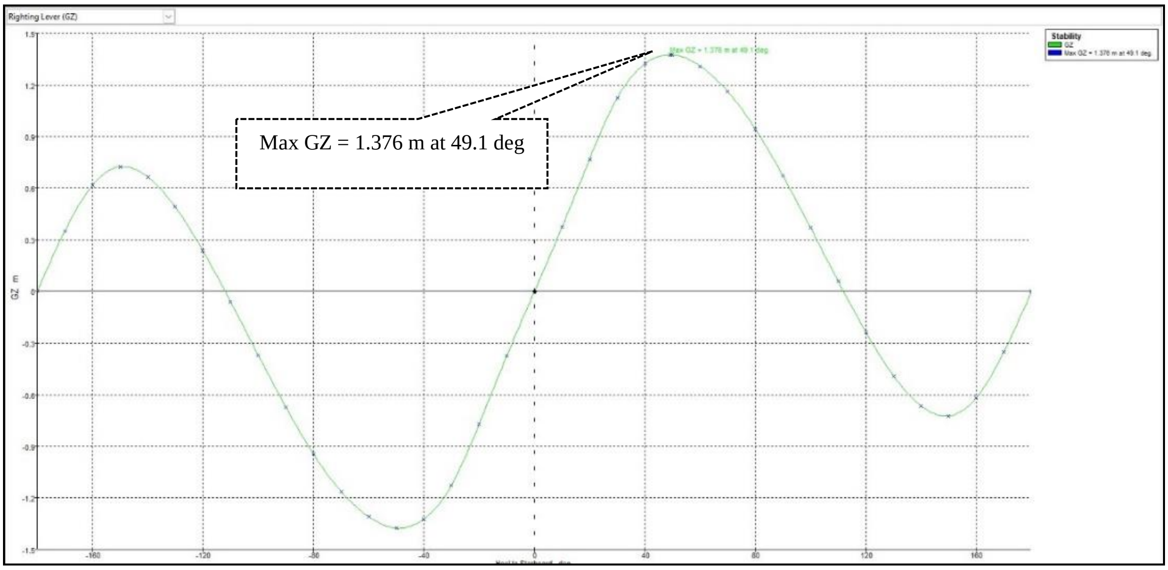
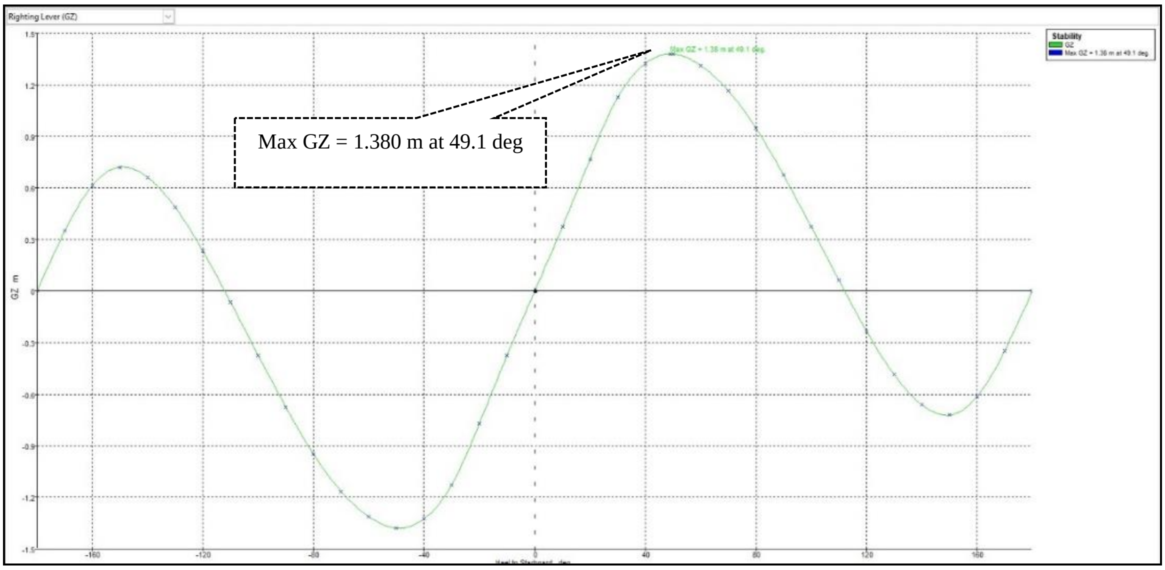


Figure 4. Loadcase Stability Analysis: Folded Position



(c)

Figure 5. Loadcase Stability Analysis: Full-Open Position

Table 2 below compares the stability value of the solar panel installation to the reference value from the IMO A. 749 (18)- Design criteria that apply to all ships. As was mentioned in the previous section, the installation of solar panels will inevitably reduce the stability of harbour tugs. However, when compared to the necessary values, the stability of the double axis retractable solar panel mechanism is still in satisfactory condition.

The harbour tug stability value in one of the categories, code 3.1.2.1: Area 0 to 30, is at the level of 17.11 m.deg in the folded position and at the level of 17.10 m.deg in the fully open position, from the minimum required value of 3.15 m.deg. This value, which is 17.26 m.deg or a decrease of 0.8%, is lower than ships without solar panels. Table 2 provides thorough comparisons of harbour tug stability values as a result of solar panel installation.

TABLE 2.
COMPARISON OF TUG'S STABILITY VALUE

Code	Units	No Solar Panel	Folded Position	Full-Open Position	Req. Value	Note
3.1.2.1 : Area 0 to 30	m.deg	17,26	17,11	17,10	3,15	Pass
3.1.2.1 : Area 0 to 40	m.deg	29,75	29,50	29,47	5,15	Pass
3.1.2.1 : Area 30 to 40	m.deg	12,48	12,39	12,37	1,71	Pass
Max GZ at 30 or Greater	m	1,391	1,376	1,380	0,20	Pass

IV. Conclusion

According to the findings of the studies that have been done, it is clear that there is a pressing need for researchers to pay attention to environmental protection and energy efficiency, particularly in maritime activities. The development of a solar panel installation design concept, specifically the design of a double axis retractable solar panel mechanism for harbour tugs known as B-Solar Wings, is one of the innovations that have been carried out in this study. The outcome of several design strategies for solar panels on harbour tugs while still taking into account ergonomics and ship safety principles is B-Solar Wings. A hydraulic system mechanism is used to assemble and integrate 7 solar panels so that they can be folded and opened in accordance with their mode of operation. B-Solar Wings are predicted to be able to absorb power of 15.75 kilowatts per day and can have specifications of 3150 watts peak. B-Solar Wings are thought to be feasible in terms of stability and meet the conditions required by IMO based on the results of simulations performed using modeling software. In order to integrate the power produced by solar panels for use with ship generators through the main distribution panel, B-Solar Wings' power system plan employs a hybrid concept.

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