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DESIGN AND MODELING OF TREE-SHAPED SOLAR PV TOWERON MARINE VESSELS IN COASTAL AND OFFSHORE AREAS OF BANGLADESH

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ABSTRACT

Marine vessels could be a good site for solar photovoltaic (PV) plants because solar energy is the best renewable energy to replace the fossil fuels used in the ships. The most efficient approach to power marine tankers with solar energy is with solar towers fashioned like trees. Such PV on ships is anticipated to increase efficiency because it does not require land mass, which is a limited resource in Bangladesh. In this study, a PV panel layout that resembles a "Christmas tree" and is called a "tree-shaped solar PV tower" is suggested. To maximize power, solar towers are designed such that they may be freely rotated on their vertical axes and that the tilt angles of their solar panels can be adjusted from 0° to 50° on their horizontal axes. The vessels travel between Bangladesh and India as well as Bangladesh and Malaysia, Singapore, Indonesia, Mumbai, and Sri Lanka. Using high-performance AC module-based technology, a novel approach to the "tree shaped solar tower" layout of the PV array on maritime vessels is proposed in this research. The ship's appliances, including lighting, fans, TVs, laptops, and smartphone chargers, will be run on the generated electricity. The addition of solar PV on marine ships may improve environmental sustainability and eventually serve as the energy source for the future generation.

Key words: Solar Energy; Marine Vessels; tree-shaped solar PV tower; coastal and offshore area

Introduction

Local and global air pollution from marine transportation is a serious concern (Gossling, Meyer-Habighorst, and Humpe 2021; Walker *et al.*, 2019; Wang *et al.*, 2019; Viana, 2014; Wang and Corbett, 2007). In many areas, marine transportation services are growing quickly at the same time. In 1970, the quantity of global total cargo ship was 2605; in 1980, it was 3704; in 1990, it was 4008; in 2000, it was 5984; in 2010, it was 8408; in 2019, it was 11,071 (United Nations Conference on Trade and Development, 2022). With regard to greenhouse gas (GHG) emissions and local air pollution, these trends pose a serious environmental issue. Different nations have diverse rules for using different fossil fuels like diesel oil, HFO etc. when the vessel is at that territory that emits a lot of greenhouse gases into the atmosphere (International Council on Clean Transportation, 2007). Besides, it has been assessed that global fossil fuels are scarce, expensive, and soon going out of production worldwide (Shezanand Ping, 2017). Good news is that, by applying this research, solar PV on marine vessels with tree shaped PV tower, have the potential to help mankind maintaining its energy security while also helping to reduce the demand for fossil fuels and can reduce a lot of GHGs emissions into the atmosphere. As a result, many nations are partially switching to renewable energy sources to meet their energy requirements (Zafar *et al.*, 2018). As the costs of solar energy continue to decline and power systems get better, solar power is expanding quickly (Abdullah-Al-Mahbub, 2022).Several works have done regarding conventional solar energy in Bangladesh, few of them are solar home system, solar pump/irrigation, and solar parkHowever, a few works on marine vessels have been done (Chowdhury *et al.*, 2011; Hoque and Das, 2013; Amin *et al.*, 2014; Islam *et al.*, 2014; Hossain *et al.*, 2015; Islam, Sarker, and Ghosh, 2017; Liza and Islam, 2020; Rahman, Akhter, and Sarker, 2020) etc., they all studied conventional stand-alone solar PV. No one has worked on the design of a "tree-shaped solar PV tower. In this paper, a novel approach to the “tree shaped solar tower” layout of the PV array on marine vessel is presented for a sustainable future.

Materials and Methods

The study used a variety of methods to determine solar energy coverage in selected marine vessels. The overall methodology of the research can be divided into three stages. First step involves gathering of data from different sources, second stage involves analysing data, and third stage involves the design of PV panel orientation. Marine vessels or ships of Bangladesh are mainly sails on the Bay of Bengal because all the ships are counted in Bangladeshi owners. Geographically the area is located in between 5°N to 22°N latitude and longitude 80°E to 100°E, shown in Fig.1. There are about a number of 1008 ships of Bangladesh that sails on the Bay.

Fig. 1. Location of the study area. The red arrow stands in for the tanker ships, the green arrow for the cargo ships, and the indigo arrow for the passenger ships

There are numerous databases that are accessible on a global scale that can be used, including the NASA SOLPOS Calculator (Measurement and Instrumentation Data Center, 2022), the NREL pvwatts calculator (National Renewable Energy Laboratory, 2022), the globalsolaratlas (globalsolaratlas), the Vessels Database AIS Ship Positions (vesselfinder), Bangladesh Shipping Corporation (BSC) (Bangladesh Shipping Corporation), and the database of the Bangladesh Meteorological Department (BMD purchased data) (Bangladesh Meteorological Department),which provide historical data of several years of from any quadrant of the globe defined by geographical location or longitude and latitude. Data on solar radiation and temperature were gathered from the National Renewable Energy Laboratory and the Bangladesh Meteorological Department (BMD) (NREL). The entire number of marine boats is obtained from Bangladesh Shipping Corporation in order to determine the solar panel count and energy output (BSC).

Results and Discussion

Design and Modelling of Solar Tower on Tanker Vessels

Novel creative approach "tree-shaped solar PV tower" architecture is innovated to the installation of the solar panels on the tanker ship. For this, a robust structure is intended to accomplish on the perimeter of the ship's top floor, as depicted in Fig.2. The solar tower is set up such a way that it may freely rotate on its axis. For optimal power, solar modules are positioned so that their inclination or tilt angle can be flexibly adjusted from 0° to 360° on their horizontal axis. Due to the absence of different deck systems, including cargo lines, a crane, and a specific location for helicopter landing, this construction may be feasible to construct for the stated tanker ship. The area behind the accommodations is not intended to have solar panels because they will be in direct sunlight and will be heavily shaded.

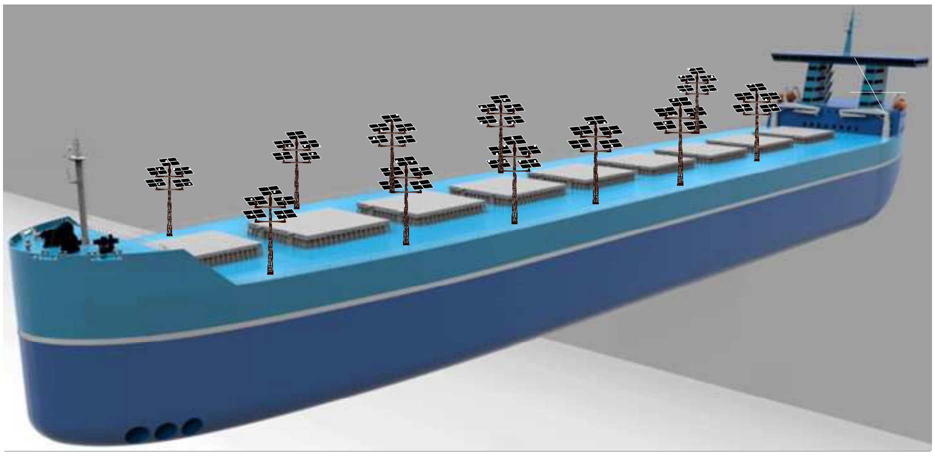

Fig. 2. Tree-shaped solar PV tower model. The solar panel will automatically move and vary its tilt angle from 0° to 50° so that it faces the sun as the earth moves in its daily and yearly movements.

Design and Modelling of Components of PV System and Typical Solar PV Arrangement

A photovoltaic system consists of several components, each of which performs a specific role. Fig. 3 shows the schematic diagram of the typical solar PV system and power arrangement. In general, photovoltaics generate electricity and store it in a series of rechargeable batteries for future use. During sunshine hour, electricity generated by PV panel is directly send to the power loads via solar inverter (Fig.3a). During semi-cloudy weather condition, stored electricity from batteries is send to the power loads via solar inverter (Fig.3b). During night or extreme cloudy and bad weather condition, stored electricity from batteries is send to the power loads (Fig.3c). If the batteries are fall down or unable to send electricity-generator will supply the electricity in the ac loads.

(a) PV panel:A PV system consists of several PV modules that are wired together. Connecting the negative (-) cable of one module to the positive (+) cable of the second module initiates a series connection. By connecting the modules in series, the respective voltages of the two modules are added. Solar panel efficiency is the measure of how much sunlight (irradiation) reaches a solar panel's surface and is converted into electricity. The average panel conversion efficiency has grown from 15% to well over 22% as a result of the numerous developments in solar technology over the past few years. Due to this significant increase in efficiency, a common size panel's power rating went from 250W to over 400W. Solar panels' efficiency is a typical metric used to assess solar panel efficiency. Solar panels' efficiency is crucial in two situations: (a) the more efficient solar PV produces more energy and the fewer panels you need to completely powered on marine vessel. Higher initial costs are frequently associated with larger long-term energy savings; and (b) the more efficient solar PV also save the area and it will benefit most from using fewer. In this research, Sun Power Maxon solar PV modules have selected for analysing and calculation of energy.

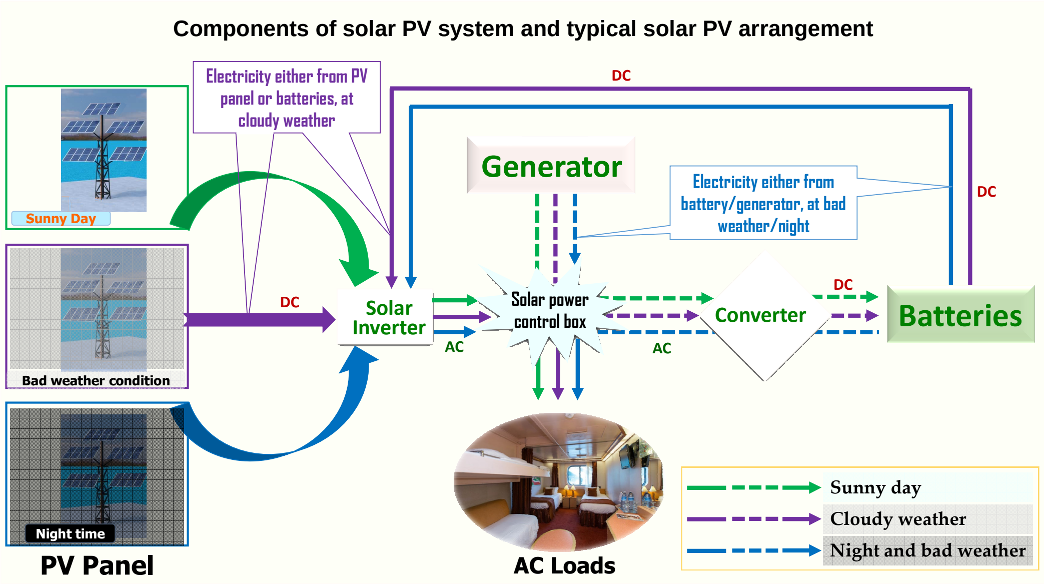

Fig. 3. Components of solar PV system and typical solar PV arrangement: (a) during sunshine hour, (b) during semi-cloudy weather condition, and (c) during night and extreme cloudy weather condition.

A photovoltaic system or PV system consists of a PV panel, mounting frame, solar inverter, energy storage device, and other accessories i.e., cables and connectors, and distribution board and AC disconnect switch, etc.

(b) Mounting Frame: To support the solar panel, a fixed mounting frame will need to be built. To receive the most of the sun's radiation, the top surface of the mounting frame that will hold and carry the solar panel should set appropriately as it tilts and move/orient freely. It is advised to set adjustable panel frames. An inclinometer and a Pyranometer is stored on the PV panel to measure the tilt angle and the solar irradiance for maximum energy from sun.

(c) Solar Inverters and converter: Inverter is electronics devices which convert the voltage of an electric device, usually direct current (DC) to alternating current (AC) whereas; converters convert the alternating current (AC) to direct current (DC). Fig.4 shows the inverter systems of traditional string types vs. modern AC module types. Most of the conventional solar panels use string inverters. Compared to traditional solar system architecture, some AC module solar PV system is more reliable. For instance, traditional string inverter-based PV systems have a single point of failure. In this system, if the inverter fails, the entire system fails. In contrast, the PV system that updated with the micro inverter-based AC module technology, is very reliable than traditional inverter-based solar system architecture.It is necessary to take precautions to avoid overcharging and excessive discharging of batteries. A solar charge controller, must be available with solar inverter, regulates the charging current of the solar panel to charge the battery as efficiently as possible without overcharging it. It also prevents the battery from back feeding into the solar panel at night) (Grebenchikov*et al*., 2020).

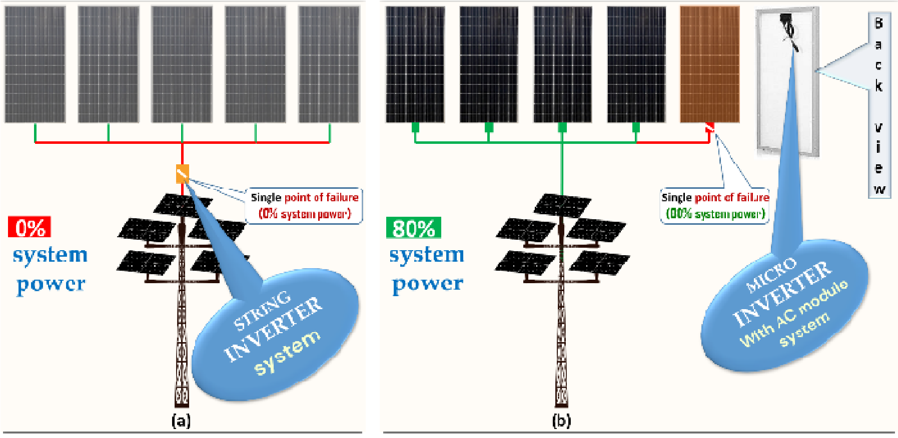

Fig. 4. Inverter system of typical solar PV arrangement: (a) string inverter system, (b) Micro inverter AC module system.

(d) Energy Storage Device/Battery: As the electrical energy is stored in the batteries, the solar powered system is also required storage battery. During sunshining time, solar panels charge the battery as the PV system uses rechargeable batteries. Batteries of photovoltaic systems are subjected to regular charging and discharging process. The lead-acid battery with deep discharge (up to 80% of its storage capacity) is commonly used (Manimekalai, Harikumar, and Raghavan, 2013) and the cheapest solar battery where the cost can up to 2-3 times less than lithium batteries (Solarreviews, 2022) that is most frequently used for residential PV applications (solarenergyscout, 2022).In this research, for solar energy storage device, a 12V 200AH rechargeable deep cycle hybrid gel battery is proposed which is capable enduring -4°F to 140°F temperature. Multiple batteries are banked together when the total voltage requirement is greater than a single battery can supply.For example, two 12-volt batteries in series (positive to negative) create a battery bank that can supply up to 24 volts of DC,and four batteries in series produce 48 volts. The battery bank is sized so that the array can run the load for several days in cloudy weather when the battery bank cannot be charged. Batteries have a limited lifespan. One cycle consists of discharging and then fully charging the battery. Battery life can be extended if the battery is not discharged to 0%. A smart design is to discharge the battery to 50% and then fully charge it again.

(e) Other accessories

(i) Cables and connectors: Cables and connectors are used to transfer electricity from PV system to the batteries and ultimately to the load.

(ii) Distribution board and AC disconnect switch: To securely disconnect and isolate the inverter from the AC circuit, the National Electric Code (NEC) mandates a safety disconnect switch on the inverter's AC side. It is used to carry out maintenance work and troubleshoot the system.

Design and Modelling of Direction and tilt angle of PV panel

In off-grid systems, the batteries receive DC electricity from the solar panels, which is then converted into AC electricity on demand via an inverter. The excess electricity is stored in batteries. When the sun is not shining, the system may still supply electricity from the batteries. This arrangement is suitable in marine vessels where a grid connection is not possible and when the solar system is able to produce more electricity than the ship’s demand for a portion of the day. To maximize the performance, when designing a photovoltaic solar system, it is essential to carefully consider the (a) Direction and tilt angle of PV panel, and (b) shade analysis:

(a) Direction and tilt angle of PV panel: The module should face the equator, pointing south in the northern hemisphere and north in the southern hemisphere. While traveling over the equator, when the latitude is changed through zero, the module is facing the reverse direction. It is amazingly happened that average sun shine hour is 12 hours daily everywhere in the world over the course of the year.To gain the maximum radiance from a panel, it is necessary to place it at a certain tilt angle. The tilt angle should ideally match the latitude. The optimal tilt angle in spring, summer, fall, and winter are 15.2°, 0.2°, 15.2°, and 30.2°. The optimal year-round tilt angle of the research area is 15.2° from horizontal (Footprinthero, 2022). As our proposed solar ship move from place to place all over the Bay of Bengal, a GPS, an Inclinometer and a Pyranometer is fixed on the PV panel to measure the geographical location, the tilt angle and the solar irradiance to harness the maximum energy from sun. The solar panel will move automatically and faces perpendicular to the sun as the earth moves in its diurnal and annual motion, shown in Fig.5. During night, the solar panel will fold inward and fall off or fixed in horizontal position and reopen during day. This type of solar panel is also available in the market.

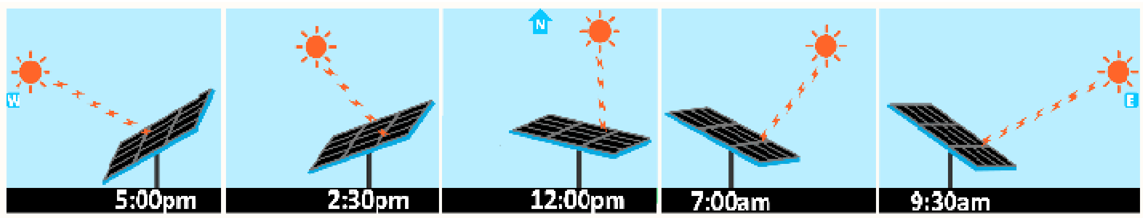

Fig. 5. Automatic orientation of solar panel during day to maximize solar energy output

(b) Shade Analysis: Shading can be a trouble for the solar panels as they reduce the maximum output. The most common causes of shading are trees, buildings, clouds, and nearby solar panels (Solar Choice, 2019). Only clouds are the main cause of shade analysis but others are excluded in this research.

Conclusion

In this research, we propose a high-performance AC module-based technology with more than 22% efficiency of N-type heterojunction (HJT) cell-based solar panels to install on vessels. Because, AC module technology based micro inverters is far more dependable than the traditional solar system architecture. Solar panel must be positioned at an average tilt angle of 15.2° from horizontal in the Bay of Bengal area. To harness the most sun's irradiance, solar panel must be positioned at the ideal tilt angles determined as 15.2°, 0.2°, 15.2°, and 30.2° in the spring, summer, fall, and winter. The produced electricity will be utilized to power the ship's appliances, including lighting, fans, TVs, laptops, and smartphone chargers.Installation of solar PV on naval vessels may increase environmental sustainability and provide the next generation's energy source in the future.

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