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A Review on Solar Powered Boat Design

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Abstract

In recent years, numerous advancements occurred in the renewable energy sector. One of the promising area where usage of solar energy has been implemented is the solar-powered boat. Solar powered boat or all electric boat brings the opportunity to decrease greenhouse emissions and shift towards utilization of renewable and sustainable energy. In this paper the research work carried out regarding the design for deployment of solar energy on boat has been presented.

Keywords: Solar Power, PV Module, Hybrid System, Solar Powered Boat.

1. Introduction

Presently, people have tremendous reliance on fossil fuels. Almost every vehicle around a human is powered by fossil fuels. Generation of electricity requires large amount of fossil fuels either oil or coal. Fossil fuels are a limited source of energy and it is a non-renewable source of energy and in near future, there will be limited resource. Because of the speedy raise in electrical energy necessities in marine power systems (MPSs), and to decrease the ingesting of fossil fuel, there is a necessity to use renewable energy sources (RESs) in MPSs [1, 2]. Usage of renewable and unpolluted energy sources has decreased fossil fuel ingesting, consequently, this is the feasible solution for decreasing greenhouse gas production [26]. For the long haul, the expenditure advantage of utilizing sun-based energy would be superior to different sources of energy [51]. Sun-oriented energy is viewed as promising source of energy because of its boundless nature stockpile, comprehensiveness, and natural benevolence [22]. The first solar cell was able to convert sunlight with four percent efficiency whereas present-day solar cells are not able to do a quarter of it [64]. The new advancement in PV cells is building-integrated PV (BIPV). BIPV is advantageous over PV because its construction cost is lesser than silicon PV cells. [36]. Solar energy is a clean source of energy and can be used in Distributed energy systems (DESs) [19]. All through the last two decennaries, both advanced and growing countries have concentrated on the usage of renewable energy [25]. A nautical architecture and engineering syndicate in Spain revealed a renewed all-electric, self-reliant 65-foot seaside boat. It is equipped with 323-square feet of solar panels [59]. Aditya is the first Indian solar-powered ferry whose length is 21m, height 3.7m, depth 1.75m, installed power 18kW, with the capacity of 100 passengers [60].About 90% of shipping transport is used for global trade, which causes pollution. Engine-powered boat has enormous environmental effects, such as carbon gases, global warming, oil pollution, air pollution, and water pollution. In the fourth publication (August 2020), the international maritime organization (IMO) estimated that there has been 40%growth in the maritime trade from 2008-2018, moreover, the carbon intensity of international shipping roughly improved by 30% and total GHG(greenhouse gases) has been decreased to 7%

during the same period. The IMO has targeted to reduce 50% carbon emission by 2050[56], [1]. Solar energy acts as a good alternative as a fuel for diesel-powered boat. The current advancement in marine solar power is the combination of wind turbines and solar power to generate renewable power at sea [54].

2. Solar powered Boat Components

The components of solar PV boat are PV array, DC-DC converter, MPPT, electric propulsion and battery management system. The review of research work related to the solar PV boat components and their function has been discussed in the following section. The PV-diesel hybrid system consists of various components such as PV module, DC-DC converter, MPPT, battery, and its charging-discharging controllers, diesel generator, inverter, coupler. Another type of solar-powered boat is a boat that completely depends on the solar PV output energy which is the only source to serve the load demand in the ship. This type of structure has been designed for small-scale ships, such as entertaining ships and for small fishing boats. Such water boat simply require power to run their electric motor for momentum and little load such as lighting. In such types of boat, PV is solely sufficient to serve all the purposes on small scale. The only difference between the two topologies is the presence of a diesel engine in the hybrid system. All other components for both the boat are the same but there is a slight difference in their ratings of components as this boat serves the low load demand. The average 300-350 watts of power is required by the 30-feet boat and mostly it depends upon the energy use and boat size [64]. The Figure 1 shows PV- Diesel hybrid system topology with different components of solar boat. The components are solar array, dc-dc converter, dc-ac converter, MPPT, management control, charge/discharge control, diesel-generator set, main switch board and electric motor propulsion.

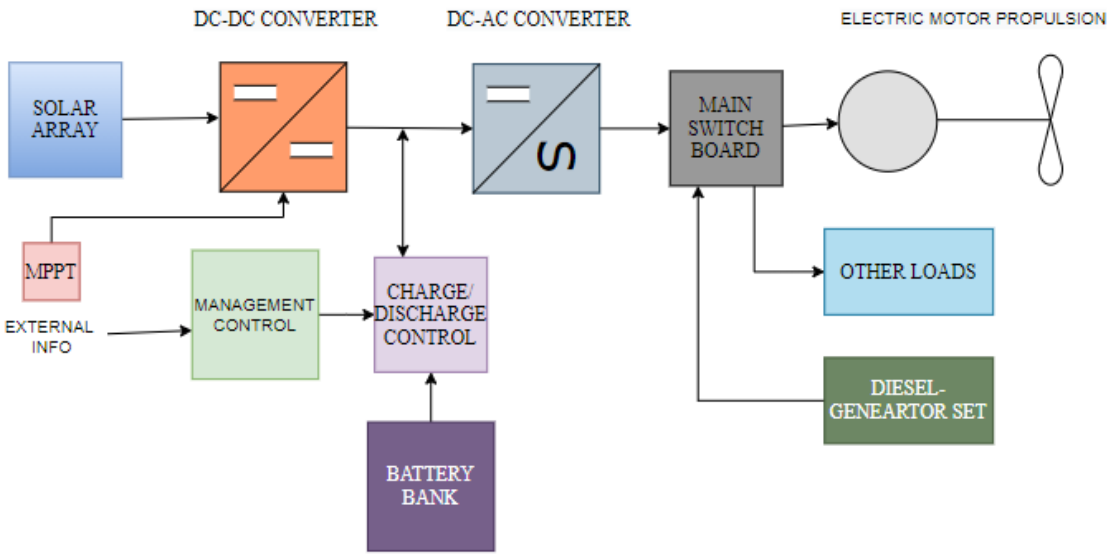

Fig.1 PV-Diesel Hybrid System Topology [34]

The components for standalone PV boat are shown in figure 2 which include PV array, MPPT, battery bank management, charging/discharging control, electric propulsion, and dc-dc converter.

2.1 PV array

The main issue in solar boat is due to the limited space available for solar PV cells installation in the boat. PV modules require space and these must be placed in such a way that they absorb the maximum amount of sunlight. Design such arrangement is a challenging task. PV array or solar array is the collection of different solar modules [58]. The highest the intensity of sunlight absorbed by the PV array, the higher will be the energy output produced from the PV array [32]. The addition of solar PV in boat poses a problem of stability since load of PV module, battery, and other apparatus increase the load on the ship. The other problem is the partial shading which affects the PV performance and it happens due to passing

of clouds, trees, bird droppings, snow covering etc. [33]. Solar PV has the most technological benefits such as zero energy-production costs**,** versatile installation**,** energy production coincides with the times of maximum demand**,** economic savings [20], [65]. Sun-oriented energy falls on the surface of the earth at a pace of 120 petawatts. This implies the energy got from the sun in one day can fulfil the entire world's energy demand for over 20years [21]. Spagnolo et al. [13] proposed a solar electric boat for tourists. For this they have used solar PV arrays, battery of 45Ah, catamaran boat of length 14m and width of 5.50m, MPPT controller, DC-DC boost converter, inverter, charge controller, and power management controller. Stuart et al. [15] focused on the plan and construction of the boat in a PV boat application. Software like Computational Fluid Dynamics (CFD), Computer Aided Manufacturing (CAM), Finite Element Method (FEM) and Computer Aided Design (CAD) programming have been used. However, the cost of the solar powered boat is predicted to be more expensive than the diesel powered boats but its operational cost is lower and also it is a green fuel hence it is promising in long-term use [37].

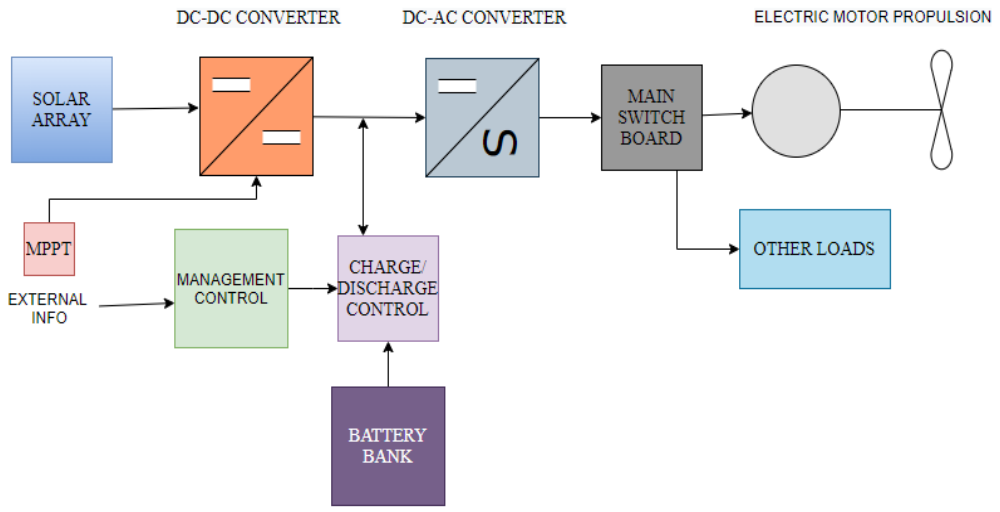

Fig.2 Stand-Alone PV System Topology [34]

2.2. DC-DC Converter as a Power Conditioner

A power conditioner is a necessary element that boosts the efficiency of the system. Power conditioner controls the output of the PV system and also increases its output if connected with MPPT. The power conditioners used in PV systems are the DC-DC converters. There are three types of dc converters are generally used with the PV system. These converters are buck, boost, and buck-boost. Mostly boost converter are used because of its high output. In a buck converter, the yield voltage can be less than input voltage whereas in boost converter the yield voltage is greater than the input voltage. In the buck-boost converter, the yield voltage either be more or less than the input voltage. Kumar et.al [38] in their research used a Cuk converter instead of buck, boost, and buck-boost on the PV grid-associated system. The key benefit of the Cuk converter is that its output voltage is not reversal. The results when compared to the buck-boost converter concluded that Cuk has maximum efficiency and less ripple voltage than the buck-boost. A photovoltaic generator (PVG) can provide good efficacy if it uniformly converts maximum available solar power throughout even in harsh weather conditions[16].For this purpose buck converter can be used to extract complete energy from PV source to meet the load demand[62,35].

2.3 PV MPPT

At any weather condition maximum power point tracking (MPPT) helps to increase the output of the PV array. At different solar irradiations, PV arrays have different maximum power in varied weather conditions. There are different kind of MPPT techniques some are artificial intelligence

(AI) and some are non-artificial intelligence techniques. The Perturb & Observe, incremental conductance, and fractional open circuit methods are the non-AI based techniques whereas fuzzy logic [17] and neural networks are the AI based techniques. To regulate the duty cycle of DC-DC converter different MPPT algorithms are used [57]. MPPT techniques play a major role in enhancing the production of electricity through solar cells [53]. Chakraborty et.al [49] discussed a novel MPPT based solar power system for fishing trawlers to reduce fuel consumption. However, the paper does not give any data of, costing details and payback period of investment. Chao et al. [39] presented a solar-powered boat design using the latest patented distributed PV power system which includes MPPT technology, power optimizer, and the PV power controller. In this design, quadratic maximization (QM) algorithm is used for MPPT which is very efficient for the fast-changing temperature and solar insolation. Besides, the only limitation in this design is the increased cost which enhances due to Li-ion battery which is at least three times expensive than the absorbed glass mat (AGM) lead acid-battery. Mirza et al. [28] presented an innovative bio-inspired method for photovoltaic systems under different meteorological conditions, which uses Salp Swarm Optimization (SSO) for efficient MPPT. It utilize the property of salps to trail the maximum obtainable power, particularly under partial shading (PS), that reduces the output power[28].The researches above on MPPT focused on getting more output by applying various techniques.

2.4 Electric Propulsion

The electric motor acts as electric propulsion in PV-powered boat. PV supplies energy that is needed by the electric motor. Generally, two kinds of an electric motor are there, DC electric motor and AC electric motor. Before advancements, only DC motors were used since it is simple to control the speed of motor rather than the AC motor. With the advancements in power electronics, AC machine's speed control became easier than the DC one. Nowadays AC motor is preferred because it has many advantages over Dc motor such as less weight, cheaper than the DC motor and their size is also small[18]. Many researchers have focused to improve the performance of solar boat electric propulsion for better performance. Simonetti et al. [40] has proposed a controller technique for a solar-motorised vessel which is driven by an indirect vector controlled induction motor for either speed or torque control based on fuzzy logic. Soeiro et.al [41] proposed an indirect vector controller which is fuzzy logic-based to elevate the efficacy of PV boat. The above researches do not have enough information regarding solar energy usage, induction motor performance and impact.

2.5 Battery Management system in solar Boat

Battery is the part of the solar boat. Since solar power cannot serve the load at night and during cloudy, rainy weather. The output of solar panels are more in sunny days. With the help of battery continuity of supply to load will be sustained in the boat. It will be very troublesome situation if electric propulsion stop working in the middle of journey because solar PVs are not getting sufficient sun light to generate power. In such cases battery acts as a backup. A good battery management system is required to increase battery efficiency and lifespan. Due to its long life, high energy density and eco-friendly nature, Lithium-Ion batteries are the most preferable batteries nowadays [29,30].During charging and discharging a battery management system (BMS) monitors and controls the internal operating parameters such as current, temperature and voltage. It estimates the state of charge (SOC) and state of health (SOH) to improve the safety and performance [55].It maintains a charge a limit between maximum and minimum to avoid extra charging and sudden explosions. Duan et al. [31] described that BMS with safety, high energy density and reliability considered for electric vehicles. The researchers have mentioned different techniques such as spectrum analysis, the fiber Bragg grating sensor, gas sensor and microscopy for monitoring and regulation of BMS.

3. Overview of solar-powered boat

A boat is sort of watercraft that has various types and sizes. Generally, it is smaller than ship. The boats are distinguished from the ships on the basis of their size, shape, cargo or passenger capacity, load capacity. In modern marine terms, a boat is small enough to be carried onto ship. There are basically three types of fishing boat that are offshore fishing boat, inshore and river fishing boat, bay and lake fishing boat. Offshore fishing

boat have to deal with many unpredictable situations in oceans so there basic size is 30 feet or more. In coastal areas there are inshore types of boat whose size is in between 17-22 feet whereas lake fishing boat size is between 20-30 feet [61]. However, ship is a large watercraft that explores and travels deep waterways, carry goods and passengers and also used in defense for special missions, research and fishing. Solar-powered boat is the promising technology in marine transportation. Two types of solar boats are there. One is a PV integrated solar boat with an existing diesel- powered engine and the other one boat completely uses solar energy to run all the electrical loads [3,4,57]. The hybrid system is a combination of photovoltaic cell and diesel engine has been mainly used in catamarans that have high electrical load demand. In this type of boat, photovoltaic are not able to handle demand load because of a confined area. The main motive of hybrid system is to reduce the use of energy produced by a diesel-powered engine. It reduces the use of diesel fuel, reduce the operational costs and also reduce environmental pollution. With the variations in ambient temperature and sun irradiations, the PV output also changes because PV is very susceptive to solar irradiance and ambient temperature. A minor variation in solar irradiance or surrounding temperature might modify the energy output generated by solar PV. Al-Alawi et.al [5], proposed an Artificial Neural Network (ANN) predictive controller to control the ON/OFF status of diesel generator. The limitation of this model is that it is only a prototype based predictive model. Suryoatmojo et.al [6] suggested neural network based frequency control approach to overcome frequency deviation occurrence due to weather conditions. However, it has not validated it through real time model. Datta et.al [7] proposed a new technique to smooth PV power. For this frequency controller has been proposed. But this proposed technique could not produce maximum power output. Das et.al [8] presented a new generation solar PV-powered sailing boat using a boost chopper. So as to reduce the cost and weight Cover design with fluoride has been used in place of glass. This proposed modal has not been practically implemented, it has been simulated in the MATLAB/SIMULINK. In harsh weather conditions, the sunlight is not uniform so, there is possibility of fluctuation of output power. Asari et al. [9] has proposed prototype of standalone PV boat whose objective is to reduce pollution that is caused by the usage of internal combustion engines such as diesel and petrol engine. For further improvement of such boat, authors have suggested to use IoT (Internet of Things) for better functionality and for the time monitoring. This model can additionally be improved by considering maneuver system that can control the movement and direction of the boat. Nasirudin et al. [10] focused on to minimise the cost and to determine the size of PV panel. They have proposed two stage optimisation procedure for this. To minimise the PV system size and battery with minimum cost simplex algorithm is used. The proposed methodology has not been implemented in the real time. Mehedi et al. [11] introduced a solar boat that includes PV of 10.6kw, DC gas generator of 1.6kw, and battery bank of 333Ah.The catamarans type passenger boat (CPB) is made of fiberglass polyester material, 12m in length and 4.8 m in width and the carrying capacity of catamaran boat is 20 passengers in a day. For the dynamic analysis and modelling author used MATLAB and HOMER PRO has been used. Peng et al. [50] presented modelling and simulation of ship power system integration of solar energy. V/Q control has been used along with sinusoidal pulse width modulation (SPWM) to achieve good power factor control and to ensure grid waveform quality. It has been concluded that the entire power system with PV system improves the stability and security of the ship power system.Liu et.al [12] studied a model to diminish CO2 and NOx gas discharge and upgraded energy efficiency by conveying sun-powered PV and capacity frameworks on a boat. In this paper it is revealed that the energy storage system might save the battery replacement up to 25% to 35%. Kabir et al. [46] presented a solar-powered boat design and provided a comprehensive design methodology. The conventional boat has been converted into solar powered boat. The boat is 6.5m long, beam is 2 m and it has capacity to carry 1200kg load. The solar-powered boat has been designed to carry 1200kg by converting a conventional boat. The boat has been designed the PV module, motor, and battery storage system however total control

system has not been discussed. Reza et al. [42] used HOMER software for the analysis of marine boat powered by solar PV for fishing purposes in Bangladesh. The major challenge in this is to achieve maximum output from solar PV while the boat is in motion. Yang et al. [43] presented research on modelling and simulation of new energy ship power system. To improve efficiency and to reduce emission of ship Electric propulsion system has been proposed. Ghenai et.al [44] used HOMER software for the configuration and simulation. A boat for Dubai passengers has been designed integrating PV,diesel,fuel cell hybrid power system that meets the power load. The proposed model by authors no doubt is an eco-friendly hybrid system however there is no analysis in regards to the investment payback scheme. Gaber et. al [47] proposed a model and control of naval ship power system by the concept of all-electric ships based on renewable energy. This model introduces a standalone hybrid power system with both AC/DC bus bar powered by different energy sources such as fuel cells, diesel generator and energy storage system connecting through AC/DC and DC/AC inverters. Energy management can be implemented in the model to increase the efficiency in this research work. Obaid et.al [48] proposed a design of solar and diesel hybrid power system for electric boat operating by PV array. Three-phase asynchronous machine is used to power an electric boat. Neural networks has been used for the solar irradiance forecasting. Mamun et al. [23] presents feasibility analysis and design of an on-board assisting system for a hybrid solar diesel-powered boat. HOMER simulation is used for optimal configuration of boat. RET Screen software is used for Feasibility analysis. An intelligent assisting system is used to reduce the possibility of accidents due to overweight and bad weather has been proposed. The sensor installed boat help sailors to operate vessel without compromising safety issues. Obaid et al. [52] proposed a hybrid electric boat using three renewable energy sources. A wind turbine that is used to drive induction generator is the first renewable source, solar PV panel with MPPT is the second and polymer electrolyte membrane (PEM) fuel cell as the third renewable energy power source. The output results of the research has been verified by MATLAB simulation. Dolatabadi et al. [27] presents a hazard-based stochastic prototype to sizing a photovoltaic (PV) ,diesel and storage hybrid power structure of a merchant water vessel. The above researches have been focused on hybrid system for solar powered boats and their outcomes directed towards the system cost minimisation and reduction in the environmental pollution. Nobrega et.al [45], Mahmud et al. [14] presented a paper that shows the research and development of a small solar boat design with minimum environmental pollution and cost by reducing the dependency on the fossil fuel. There is one limitation of boat that it can only be utilise for particular distance and for particular weight. Sunaryo et al. [24] proposed Solar Energy for a Traditional Coastal Fishing Platform which used PV solar cells. The catamaran that they have suggested is constructed of high-density polyethylene (HDPE), which can be recycled and have many advantages such as good buoyancy, lighter density than water, resistance to corrosion as well as great flexibility. But the limitation of proposed modal is that still it has been in the experimental state.

Conclusion

There are two methods to develop innovative solar-driven boat. The first one is a PV-diesel hybrid system for huge water boat and the other one is all alone PV- based for small boat. The results from works shows that hybrid system boat can reduce the consumption of fuel and can decrease the emission of harmful gases.

There exist two challenging issues with the hybrid energy for solar powered boat system .The first one is that the hybrid system is very much intricate since the voltage formed by PV has to be controlled in such a way that it should have the same magnitude, frequency and phase with the voltage produced using a diesel generator. The other one is that it is required to provide source load management because there is the improbability of PV output energy. All PV water boats are simpler than the hybrid one .However solar energy can only be used for the small-scale boats. This paper concludes that the different designs study additionally can improve the efficiency of hybrid as well as all PV ships. In literature several research work has been done on the solar boat but there is scope to further

investigate analysis of effect of marine environment on solar PV arrays, possibility to reduce the charging time and increase the discharging time of the battery bank for a long time operation of solar boat, designing and installing of different sort of solar PV cells, implementation of a total control system for the boat and to improve the accuracy of the weather forecasting so as to achieve higher renewable energy efficiency and its storage.

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