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Solar energy used on board the ship and responding administration countermeasures

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Solar Energy Used on board the Ship and Responding Administration Countermeasures

By

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DECLARATION

I declare that all the materials in this research paper that are not my own work have been identified, and that no materials are included for which a degree has previously been conferred on me.

The contents of this research paper reflect my personal views, and are not necessarily endorsed by the University.

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ABSTRACT

Title: **Solar Energy Used on board the Ship and Responding Administration Countermeasures**

Degree: **MSc**

With the soaring price of conventional energy, the growing energy demand and the increasing environmental concern, human beings are paying more attention to the sustainable energy. It is estimated that the conventional energy only can be used approximately for 50 years, therefore, it is urgent to find out the safety and feasible renewable energy to replace the fossil energy.

Ocean shipping is the vital important transport mean of the international trade, accounting for 90 percent of the total international freight traffic. However, the pollution coming from the shipping industry can not be ignored. According to the research of the International Association of Independent Tanker Owners(INTERTANKO), the shipping industry consumes 20 million barrels of fuel oil and releases more than 1.2 billion tons of carbon dioxide annually which accounts for 6% of the total global emissions. According to projections, by 2020, the shipping industry will consume 400 million tons of fuel oil and its greenhouse gas emissions will be increase 75 percent on the existing basis.

Under this circumstance, IMO has developed a series of instruments to reduce the emission of Greenhouse Gas(GHG), such as the Energy Efficiency Design Index (EEOI) and Energy Efficiency Operational Index (EEDI). However, those instruments are based on the use of the conventional energy and require the ship to

reduce its speed and increase its displacement, so, these instruments have inherent drawbacks because it is impossible to reduce ship's speed and increase displacement unlimitedly.

Thanks to the technological progress, the renewable energy, such as the solar, wind and tidal power, embark on the practical stage gradually. Compared with conventional energy, solar energy is generally permanent, with huge superiority of safety and "green" energy, which is an inexhaustible supply of primary energy and can be used directly. As technology advances, the utilization of solar power has entered a new stage, especially for some small solar yacht.

The emergence of solar-powered ships and solar hybrid power has brought new challenges to the supervision of the maritime administrations.

KEYWORDS: Solar Energy, application, administration, countermeasures

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LIST OF ABBREVIATIONS

AC	Alternating Current
C^o	Celsius
C_dT_e	Cadmium Telluride
CIGS	Copper Indium Gallium Selenide
CO_2	Carbon Dioxide
COSCO	China Ocean Shipping(Group)Corporation
C_dS	Cadmium Sulfide
DC	Direct Current
DMU	Dalian Maritime University
ECA	Emission Control Areas
EEDI	Energy Efficiency Design Index
EEOI	Energy Efficiency Operational Indicator
Expo	World Exposition
FSC	Flag State Control
GB/T	National Technical Standards(China)
GHG	Green House Gas
GT	Gross Tonnage
HPS	Hybrid Power System
HSC	High Speed Craft
IEA	International Energy Agency
IMO	International Maritime Organization
INTERTANKO	International Association of Independent Tanker Owners
I_nG_aN	Indium Gallium Nitride
ISO	International Standardization Organization
MA	Milliampere

MSA	Maritime Safety Administration
NM	Nautical Miles
NOAA	National Oceanic and Atmospheric Administration(US)
NO_X	Nitrogen Oxides
OECD	Organization for Economic Cooperation and Development
PM	Particulate Matters
PPE	Personal Protective Equipment
PSC	Port State Control
PV	Photovoltaic
RO	Recognized Organization
RO-RO	Roll On and Roll off(ship)
SO_X	Sulfur Oxides
SEEMP	Ship Energy Efficiency Management Plan
SOLAS	International Convention for the Safety of Life at Sea
US	United States
UV	Ultraviolet
W	Watt
WMU	World Maritime University

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CHAPTER I - Introduction

1.1 Background of the solar energy

Solar energy has been used as the vital power source for human society for many years. As early as two thousand years ago, our ancestors have learned to make fire using solar energy. At present, solar energy has been widely applied in many fields such as the solar power generation, solar heating for the buildings and solar electricity for spacecrafts. In recent years, driven by the shortage of traditional energy, energy conservation and environmental protection, solar energy is gradually applied to the maritime transport field.

1.1.1 Shortage of the conventional energy

The potential energy crisis pushes the application of the non-conventional energy. In the past 20 century, we mainly used the conventional energy such as the fossil oil, coal, natural gas for the development of our society. An urgent issue is that the conventional energy is unsustainable but there is an ever-increasing demand due to the rapid growth of the population and economy. Meanwhile, the price of the conventional energy is more and more expensive, which may trigger the economic crisis. For those reasons mentioned above, there is a soaring trend of using the non-conventional energy to replace the fossil energy in recent years. As a free and sustainable energy, solar power is an ideal alternative choice

1.1.2 Need of the environment

The environmental protection pushes the solar energy into the center of the stage. Although the utilization of the conventional energy is relatively convenient, however, the conventional energy also triggers a series of problems like the green house effect and pollution. In the past 100 years, the global temperature has increased 0.3 to 0.5 degrees and the sea level has rose approximately 100 meters accordingly because of the green house effect. As for the different kinds of green house gas (GHG), carbon dioxide plays a significant role in the increase of the global temperature and the rise of sea level.

The GHG emission has increased dramatically in the past years, especially after the industrial revolution. According to a research in the Journal of the U.S. National Academy of Sciences, it is estimated that global carbon dioxide emissions increased by 13% in the past 10 years. The GHG growth rate of the global transport sector was up to 25% during this period. More seriously, the carbon emissions from global transportation industry would have increased by 30% to 50% by 2050.

Admittedly, seaborne trade is the cheapest and most cost-effective way of the international cargo transportation. Accounting for 90 percent of international cargo transportation, the seaborne trade only emits nearly 2 percent of the total carbon dioxide. Although the emission percentage of the seaborne trade is not huge, however, it is estimated that the emission of carbon dioxide from the seaborne trade will increase 5 percent annually (Yuan& Dong, 2011). Therefore, it is necessary for the shipping industry to find out the available clear energy to reduce the emission of GHG. In addition, removing of CO_2 factors, statistics show that other exhaust emissions from ships, such as Sulfur Oxides(SO_X), Nitrogen Oxides(NO_X) and Particulate Matters(PM) have also increased significantly in the past years due to the rapid increase of the maritime transportation. Among these harmful gases and substances, sulfide from the shipping industry accounts for 10% of the overall global emissions and Nitrides from the shipping industry share of global emissions approximately 25%. Obviously, it is necessary for the ships to find out clear energy for environmental protection.

1.1.3 Factors of international laws and regulations

With people's increasing awareness of environmental protection, the pollution from the shipping industry is increasingly attracting people's attention. Therefore, various countries in the world and international organizations have established a series of regulations and instruments to control the GHG emission from ships. For example, IMO has been established the Energy Efficiency Design Index(EEDI), Energy Efficiency Operational Indicator (EEOI)and Ship Energy Efficiency Management Plan(SEEMP) to regulate the design and operation of ships. Thereby, the requirement from the international laws and regulations urge the shipowners to utilize the new technology to reduce the burden from the public.

1.2 Objectives

The first purpose of this paper is to introduce and discuss the features of solar energy, including its inherent advantages and disadvantages compared with the conventional energy which are widely used in the shipping industry. As the foundation of the detailed discussion and analysis, the timeline of the solar energy used on board the ship will be summarized firstly in the context of the research of various countries, especially the advanced countries which are keen on investing in the solar ships. As one of the largest manufacturers of photovoltaic products, the development status of solar ships in China will also be introduced. The author also tries to present the technical issues concerning the solar energy used on board the ship, including the photovoltaic system which applies to the solar-powered ship. This article mainly focuses on the characteristics of the solar propulsion system primarily utilized on board small ships, especially the yacht, recreational boats, working boats on harbour, followed by the feasibility analysis of using the solar energy as the main propulsion power for cargo ships. More importantly, the challenges for the stakeholders within the shipping industry resulted from the solar energy used on board the ship will be discussed in detail. Despite some shortcomings and challenges of the solar energy used onboard the ship, it does not mean that it is nonsense to take advantage of the solar energy by the ship,whereas, those challenges can be overcome in the foreseeable future. There are also some recommendations for the development of solar ships and responding countermeasures for the maritime administration authority related to the legislation, safety supervision and solar ship survey.

1.3 Methodology

Comparative analysis is the most commonly used tools in this paper. by comparing the conventional energy with the solar energy, the purpose is to dig out the benefits of the solar energy to the shipping industries. Through comparison, the superiorities of the solar energy to the fossil energy are presented comprehensively and advantages of the solar-powered ship are also illustrated in detail. Data statistics is also used in collecting the solar ship servicing in commercial use in order to illustrate the development trend of the solar ship clearly. Some models are also to be specified in the course of technical analysis of the solar energy and the mathematical calculation is also used for the quantitative analysis to determine whether the PV modules installed on given ship can provides sufficient energy for the propulsion system of the solar ship or not. In addition, a series of tables and figures are adapted to assist the author to specify the technical features of solar-powered ships.

CHAPTER II – Overall Features of the Solar Energy

2.1 Basic knowledge Concerning Solar Energy

Typically, solar energy is regarded as inexhaustible and important renewable energy. As one kind of non-conventional energy, solar energy may replace the fossil energy and will become one of the most important natural energy in the post-fossil fuel era. Although solar energy technology has been widely used in land today, however, its practical application as the power of the ship is still uncommon and not widespread. Nevertheless, it is noteworthy that the solar technology used on board the ship is gradually maturing.

2.1.1 Terminology of "Solar energy"

Solar energy is the energy provided by the sun. It is one kind of radiant light energy derived from the sun. As we know, through the thermonuclear reaction, the sun generates significant amounts of energy in every second. Some of the energy produced by the sun was transmitted to the space by means of electromagnetic radiation (including visible light, infra-red light, and ultra-violet radiation) and a small percentage of energy reach the surface of the earth eventually. Although only a very small part of the total energy produced by the sun reaches the earth, it is enough for the living of the creatures in the earth and can be used as the alternative energy source for our society.

2.2 Characteristics of the solar energy

As non-conventional energy, solar energy has its own characteristics. For example, the solar energy varies in different factors, mainly including the weather condition and season. In addition, solar energy has its inherent advantages and drawbacks. In order to utilize the solar energy in a reasonable way, it is significant important to fully understand its properties .

2.2.1 Basic principles of solar radiation

In fact, solar energy is mainly carried by the electromagnetic radiation. Due to the features of the sunlight and the earth, there are several factors affecting the solar energy which reaches the surface of the Earth. In other words, solar energy in the surface of the earth is not constant. However, the radiation reaching the earth follows certain rules.

Firstly, irradiation intensity of the radiation is determined by the angle of the sunlight reaching the surface of the earth. Because of the round shape of the Earth, the sunlight strikes the Earth's surface at different angles, ranging from 0º (just above the horizon) to 90º (directly overhead). If the sunlight is vertical, more energy can be captured. Otherwise, less energy can be absorbed. The reason is that the energy of the radiation is scattered and dispersed more when the sunlight is slanted resulting in the longer distance of the sunlight passing though the atmosphere. Secondly, the earth's revolution also influences the absorb of solar energy. In the summer, the earth is closer to the sun than the winter. In other words, in the summer, we can obtain more solar energy. However, the 23.5° tilt is another significant element which should be taken into account when discussing the revolution factor. Tilting results in longer days in the northern hemisphere from the spring (vernal) equinox to the fall (autumnal) equinox and longer days in the southern hemisphere during the other 6 months(http://www.eere.energy.gov/basics/renewable_energy/solar_resources.html). Thirdly, the earth's rotation also contributes to the light length of the sunlight. Obviously, in the morning or afternoon, the sunlight is weaker than the noon.

2.2.2 Factors affecting the amount of solar radiation

For those reasons mentioned above, the amount of solar radiation reached the surface of the earth is affected by these factors listed in the following.

(1)Geographic place

Geographic place plays a vital role in the utilization of solar energy. The reason is that solar energy varies in different ocean regions due to the changes of the latitude and longitude. In the higher latitude region, the intensity of the sunlight is weaker than that of the lower latitude region. That is to say, in the Arctic and Antarctic regions, the solar energy is too scarce to be used as the power for ships. Whereas, the ocean located near the equator is the optimal region for the utilization of the solar energy. The following picture gives different UV wavelength of different place. The place near the equator can receive the highest UV wavelength. This means that it allows solar panels to operate effectively while on cargo ships. (Photovoltaic Technology in the Shipping Industry, P. 8)

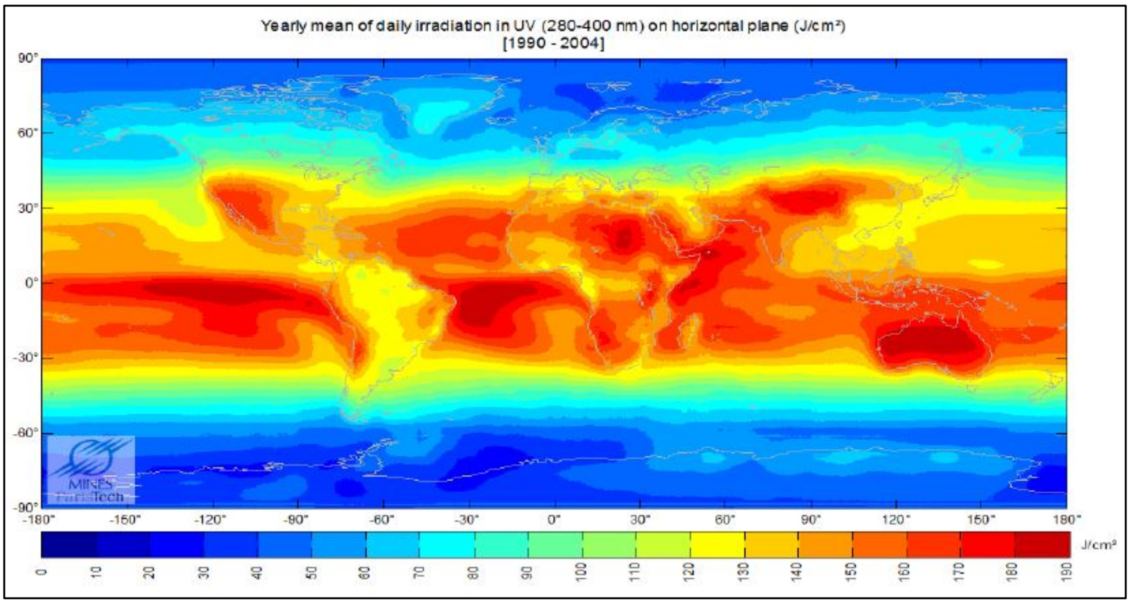

Figure-1 Chart of solar intensity in UV wavelength
Source: ESRL NOAA. (2011).

(2)Time of day

Continuous illumination time is another important factor affecting the utilization of the solar energy. It is obvious that the more time of exposure to the sunlight, the more energy can be taken.

(3)Time of year

Season is another important factor affecting the absorb the solar energy. It is obvious that there is a longer daylight hour in summer than in winter.

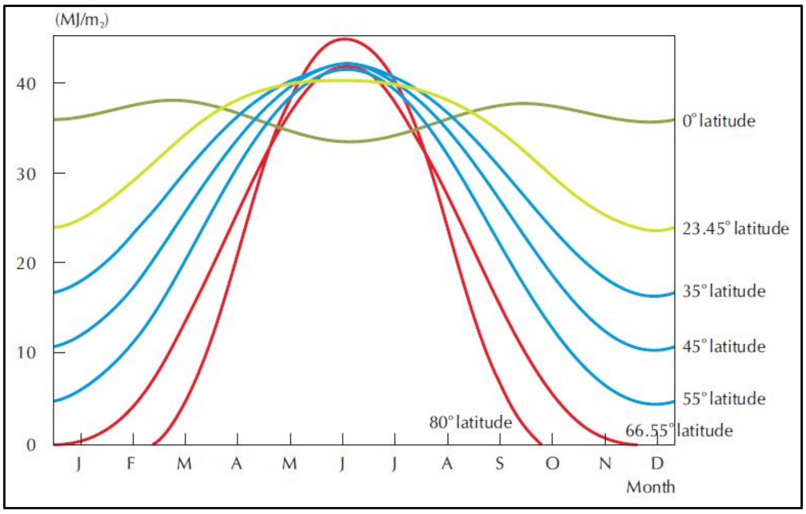

Figure-2 Daily amount of extraterrestrial irradiance on a plane horizontal to the earth surface.
Source: Cedric Philibert, (2011).

(4) Local climatic conditions

The indigenous weather condition has significant influence on the utilization of the solar energy. Obviously, the more sunny days in a place, the more sunlight can be absorbed by solar panels.

2.3 Advantages and disadvantages of the solar energy

2.3.1 Advantages of the solar energy

(1) Solar energy is nearly free except for initial capital expenses. Unlike the conventional energy sources, solar energy does not need the continuous investment to fuel oil, coal or gas. It is attractive for the shipping industry, especially under the high oil price circumstance. The shipowners just needs one piece of solar panel for their ship, saving the overall spending on the energy.

(2) It is undeniable that the solar energy is one kind of renewable energy. Compared with the conventional energy such as the fossil energy, solar energy is never going to run out. The sun can provide the energy forever.

(3) Solar energy is more environmentally friendly than the fossil energy. As we know, fossil energy has adverse impact on the environment. First of all, the fossil energy does the most contribution to the greenhouse effect. In addition, it also

results in the acid rain. By contrast, solar energy is one kind of "zero emission" energy. Therefore, it causes less pollution to the vulnerable environment.

2.3.2 Disadvantages of the solar energy

Although there are many advantages of the solar energy, however, some shortcomings are also attached to the solar energy. Firstly, the solar energy is un stable. It varies according to several factors and fluctuates dramatically even one day. Secondly, its energy density is very low. Even though sunlight is optimal, the solar energy only can be collected in an area of 1 square meters on the surface of earth is just 1 watt(W). Thirdly, due to different geographic environments, weather condition, season as well as day and night alternation, the radiation of sunlight fluctuates every time, which results in the difficulty of the utilization of the solar energy.

CHAPTER III - The Development of Solar Energy Applications on Board the Ship

3.1 Timeline of the solar energy used onboard the ship

Solar energy was initially used on land, such as the solar power plant, heating appliance for buildings, solar light and solar water heater. With the development of the photovoltaic technology, the solar energy gradually steps from the land into the ocean, beginning to be used on board the ship. This trend began to accelerate, especially from the beginning of this century.

3.1.1 First ship using the solar energy in Switzerland

The first solar ship named "Sea Cleaner 400" was born in Switzerland in 1997, using the solar as its main power. Switzerland built one solar boat sailing from Lausanne to Saint-Sulpice in the district of Lake Geneva. The boat used the electric motor powered by the 14 square meters solar panels which are installed on the top of the ship. This solar boat firstly provided a no-emission waterway transportation in the world.

3.1.2 Solar ship in Australia available for commercial use

Back in 2000, Australia built a commercial catamaran ferry using solar, wind, fuel cells and fuel oil as the unique "Hybrid Power System" (HPS) of the ship named "Solar Sailor". The ship has eight adjustable wings covered with solar panels which also can be used as wind sailing. That ferry's capacity is about 100 passengers. The ship was the first attempt to put the solar ship into commercial use. As shown by the following picture, the ship was stalled two solar wings, which are covered with a large amount of solar panels. During daylight, the solar panels can absorb solar energy for the ship, meanwhile, the wings can be used as the sailing providing the power for the navigation.

Figure-3 Picture of the "Solar Sailor"
Source: http://www.solarchoice.net.au/blog/floating-on-to-greener-pastures/

3.1.3 World record made by the solar ship "Sun 21"

Shown in Figure 5, the "Sun 21" is a solar ship having catamaran configuration and about 14 meters in length and 4 meters width. Its weights about 12 t and is served by 5 crew members. The ship's energy is wholly provided by an area of 60 square meters of solar panels. By design, the ship's service speed is 6 knots and can continue to sail18 hours in the case of no sun.

Figure-4 Picture of the "Sun 21"
Source: http://news.cnet.com/2300-11395_3-6123102.html

On may 08, 2007, a solar ship "Sun 21" reached its final destination New York, after crossing the Atlantic. During the whole voyage, the catamaran ship only used the solar energy as its main power, covering approximately 7000 nautical miles(NM).

This voyage created a record in term of the solar ship sailing across the ocean and it was regarded as a milestone in the development of solar ships. The significance of the "Sun 21" is that it firstly verified the solar ship's safety and reliability.

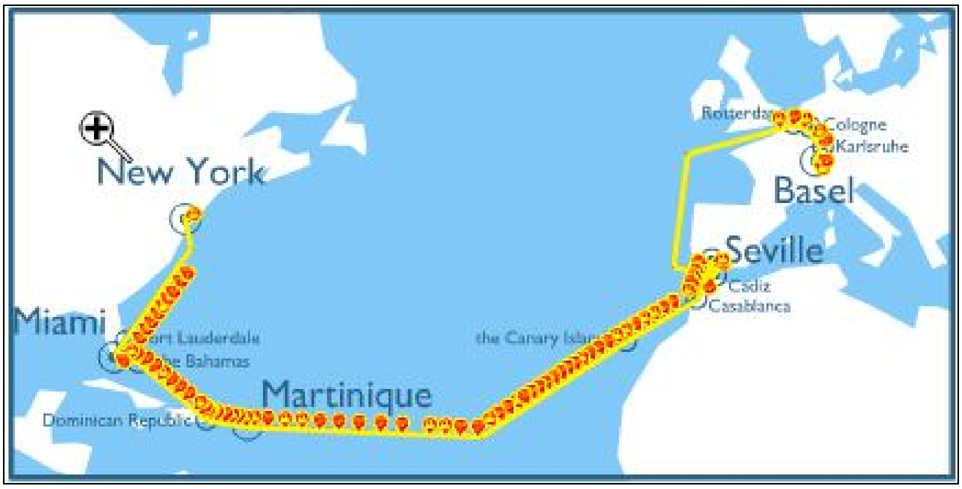

Figure-5 First trip across the the Atlantic by "Sun 21"
Source: http://www.transatlantic21.org/

3.1.4 First solar ship completed the voyage around the world

"Planet Solar" is the world's largest pure solar-powered ship so far. It was built in German in March 2010. Planet Solar is a triple-hulled vessel and it is 31 meters long, 15 meters wide, and weighs in at 95 metric tons. The obvious feature of that ship is that its maximum speed can reach nearly 15 knots, which is a dramatic technological advance of the solar ship.

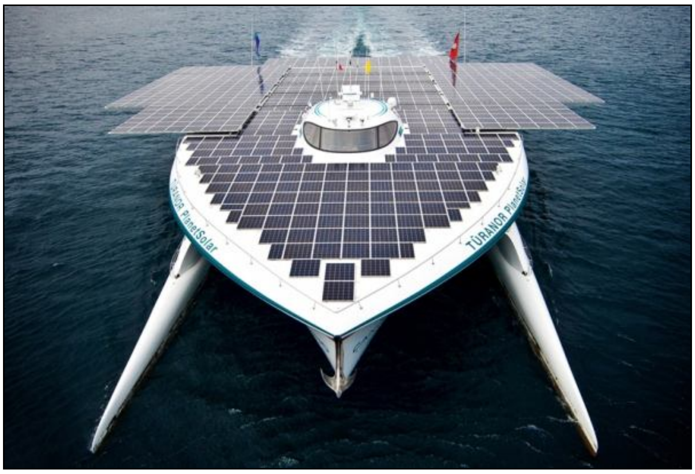

Figure-6 Image of the "Planet Solar".
Source:http://www.thecoolist.com/the-planetsolar-solar-powered-boat/

3.1.5 Solar energy used in RO-RO ship

On August 26, 2008, Japan launched a RO-RO ship named “Auriga Leader”, which is 200 meters long and 32 meter wide, consisting of 328 solar panels cell array on the top of the up deck. The gross tonnage(GT) of that ship is 60213 and is the biggest ship using solar energy in the world. The output power of the solar photovoltaic(PV) system installed is up to 40 KW, which can meet 6.9% lighting needs or 0.20% to 0.3% of the propulsion power demand of the ship. Although the “Auriga Leader” still uses heavy oil as its main driving force, solar power is only used in the machinery compartment of the machine or the engine braking and other dynamic systems. Nevertheless, the appearance of that ship is a significant advance of the solar technology because it was the first time for the solar energy to be practically been used in a cargo ship.

Figure- 7 Image of the “Auriga Leader”.
Source: http://www.marineinsight.com/marine/marine-news/headline/auriga-leader-the-worlds-first-partially-propelled-cargo-ship/

3.2 Overall trend of the development of the solar ship

At present, there are two main trends of the solar energy used on board the ship. Some smaller ships use solar energy as their unique propulsion power source, therefore, there are classified as the purely solar-powered boats. On the other hand, some ships use solar energy combined with the other power source such as the wind or diesel oil, therefore, there are hybrid powered ship.

3.2.1 Solar energy used on board small ships

The first trend is that solar energy is popular in the small boats, especially in the domain of tourism. Generally speaking, the environmental protection requirements in the water area of tourist attractions are dramatically sensitive because these water areas are vulnerable to the pollutants from the conventional boats, which install the combustion engine generating air pollution as well as oil water mixture. In addition, conventional boats result in the considerable noise. Unlike conventional boats, solar boats are zero-emission boats that don't pollute lakes and rivers. Furthermore, neither people nor animals are bothered by noise for solar boats are intrinsically quiet by using the electric motors as the main power. For these reasons, solar boats are particularly suitable for water tourism and recreational activities in nature reserves. For example, in some water areas, such as the cities' rivers, lakes and wetlands, the gasoline boats are prohibited. Thereby, it gives a tremendous opportunity for the development of the solar boat.

3.2.2 Solar energy used on board cargo ships

The second trend of the solar energy used on board the ship is that it was gradually experimentally utilized as the auxiliary power of the large-scale cargo ships. With the soaring price of the fossil energy, it was hard for the shipowners and operators to bear the cost of fuel oil. Therefore, they seek to find out an alternative energy to replace the fuel or reduce the dependence on the fuel oil in order to cut down the cost. In addition, international organizations and the public gives the shipping industry more burden concerning saving energy and reducing GHG emission, therefore, the shipping industry are now taking active action to find out the renewable and cleaner energy for the ship. Although the application of solar energy used on board the cargo ship is not so mature like the technology on the smaller yacht, however, some countries have made an attempt in this regard. Japan is a good example.

3.3 Mainly developed countries in the research of marine solar energy

Although dozens of countries can manufacture ship, however, there are few countries which are proficient at the marine solar energy. The developed countries in the research of marine solar energy including those countries, namely Switzerland,Spain, German, Australia, Japan, and China. The table 1 lists some typical solar ship made by those countries in recent years.

Table 1-Solar energy ship made by various countries in recent years

Ship name	Gross tonnage	length （m)	width （m)	Sailing speed(knot)	Passenger number	Nationality	Building time
Solar Sailor	**	22	7.5	7	100	Australia	2001.7
Sun sea	3.5	10	3.5	6	28	Spain	2004.8
Sun 21	4.0	14	6	6	10	Spain	2006.12
Auriga leader	60213	200	**	15	RO-RO ship	Japan	2008.12
Turanor Planet Solar	60	31	15	15	50	Germany	2010.4
Shang de guo sheng	278	32.6	9.96	5	134	China	2010.5
1280Ssolar power boat	4.2	12.8	4	8	36	China	2010.6

Source: Compiled by the Author.

3.4 Development of solar powered yacht in China

In recent years, the solar power technology gradually becomes mature in China. As early as in September, 2008, the first solar-powered yacht for commercial use made by Duo Yang company in Zhuhai Pingsha Industrial Zone and was successfully sold to Unite States(US). The yacht is 12 meters long and weighs 15 tons. Its speed can reach 7 to 10 knot when using solar power. In 2009, Hai Te Far East yacht Co. Ltd in Qingdao successfully produced full solar-powered yacht and put it into the market in batch, where Sunsea700 solar-powered yacht was elected as special yacht by the Wudalianchi Geological Park in Heilongjiang province. Sunsea700 solar powered yacht is 7 meters long and 2.9 meters wide. With a set of solar panels with 20 m^2, it uses charger to charge the energy storage battery after PV conversion, and it can sail for 5 hours if the batteries are fully charged. Its rated crew is 22 and meets the requirements on navigation in B graded region. In 2010, the World Exposition(Expo) was held in Shanghai. The theme "better city, better life" and "low carbon, green life" has became a topic attracting increasing attention. On June 5, 2010, the 39th World Environment Day, a grand inaugural ceremony for China's first large-scale solar hybrid cruise "Shang De Guo Sheng" was held on the Huangpu River, and it was put into operation in the World Expo Park. The operation of "Shang De Guo Sheng" in World Expo turned a new page for the rapidly development of solar-powered yacht in China. The characteristics of solar power include enough reserve, less environmental pollution and great market potential, etc. The solar-powered yachts are considered as a kind of energy-saving green products with advantages in environmental protection, economy and safety, and will become the new development direction of yacht manufacturing industry in China.

CHAPTER IV - Application Analysis of the Marine Solar Energy

Typically, solar energy can be used on board in two ways. The first is that it can be used as the main propulsion power for ships. The second is as the auxiliary energy for a variety of equipments on board the ship. This chapter mainly discusses the overall technical situation of solar energy used on board.

4.1 Main components of the photovoltaic system on board the ship

The photovoltaic system is the foundation of the solar energy used on board. Solar energy used on board needs a reliable photovoltaic system which provides the energy for the ship. It depends on the certain materials to convert the radian energy into electrical energy for the various loads on board the ship. Typically, a basic photovoltaic system consists of four main components: the solar panel, the batteries, the regulator, and the loads. The four components are responsible for different functions respectively. Batteries are responsible for storing the electrical energy. The regulator coordinates the solar panel and the batteries working together harmonically. The loads are the various devices connected to the photovoltaic system consuming the electrical energy.

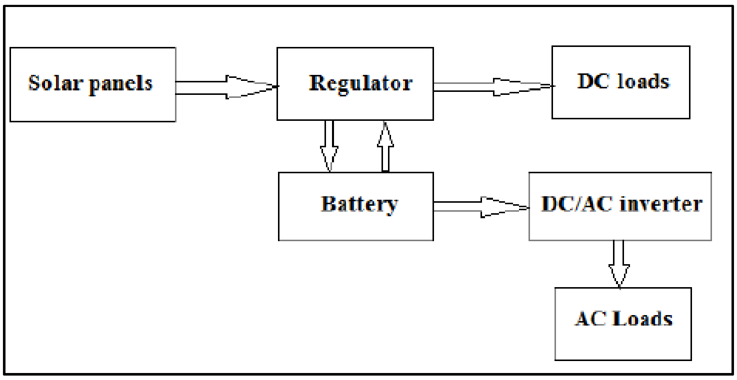

Figure-8 Typical photovoltaic solar energy system
Source: Dianguina,(2013).

4.1.1 The solar cell technology

The solar cell can absorb the sunlight and converts the energy into the electricity directly for the needs of loads or storing in the batteries. “The development and implementation of effective photovoltaic cells is hindered by two primary components: cost and efficiency”

4.1.1.1 Materials of the solar cell

The materials of the solar panel are the determining factor of the performance of the solar cell. As we know, some materials are semiconductor, which can be used in the solar cells. Although there are several stuffs available for the manufacturing of the solar cells, such as the Crystalline silicon, Cadmium telluride(C_dT_e), Copper Indium Gallium Selenide(CIGS), Indium Gallium Nitride(I_nG_aN) and Gallium Arsenide(G_aA_s), not all the materials are suitable for solar cell using in the field of shipping when take into account the fabricating cost and environmental factors. For example, The conversion efficiency of Cadmium Sulfide(C_dS), Cadmium telluride(C_dT_e) poly crystalline thin film cell are higher than that of the amorphous silicon thin film solar cell and are cheaper than the single crystal silicon cells. In addition, they are also easy to large-scale production, however, cadmium is highly toxic material which can cause serious environmental pollution, therefore, Cadmium Sulfide(C_dS), Cadmium telluride(C_dT_e) poly crystalline thin film cell are not the alternative source to the crystalline silicon solar cells. Because of these factors, there are two materials used in the manufacturing of the solar cells for ships, namely polycrystalline and mono-crystalline silicon.

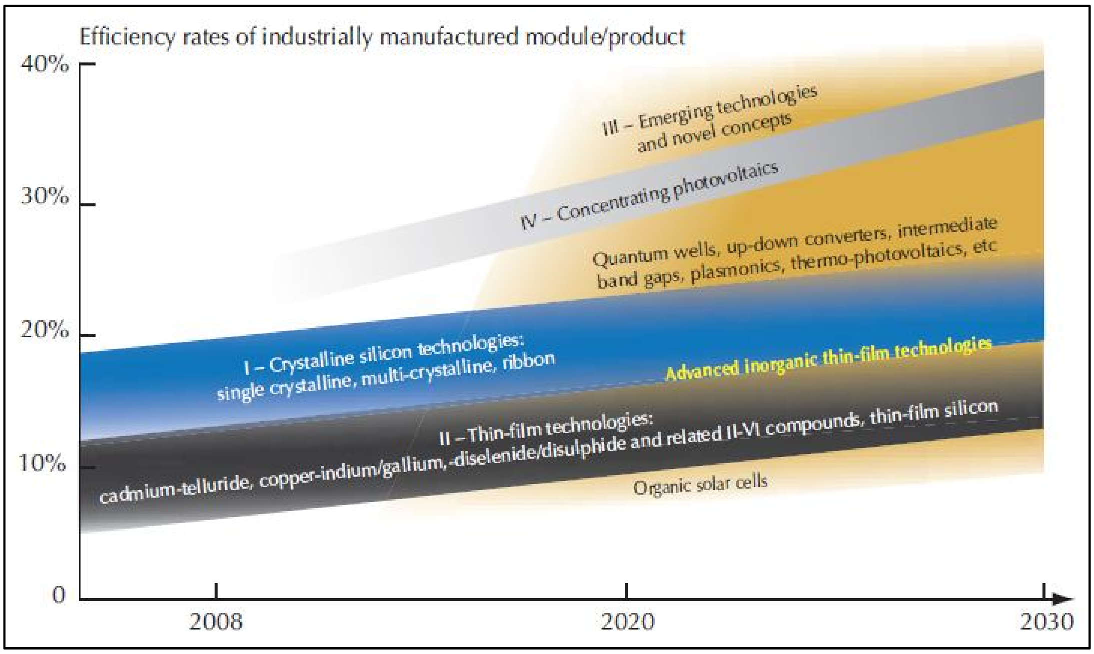

Figure-9 PV technology status and prospects
Source: IEA PVPS, (2002).

4.1.1.2 Conversion efficiency of the various solar panels

Finding out the cheaper and more efficient solar cells has been under way for several decades. Currently, there are many available materials which have the high conversion efficiency; however, finding out the most suitable material for the solar cells on board needs extraordinary consideration.

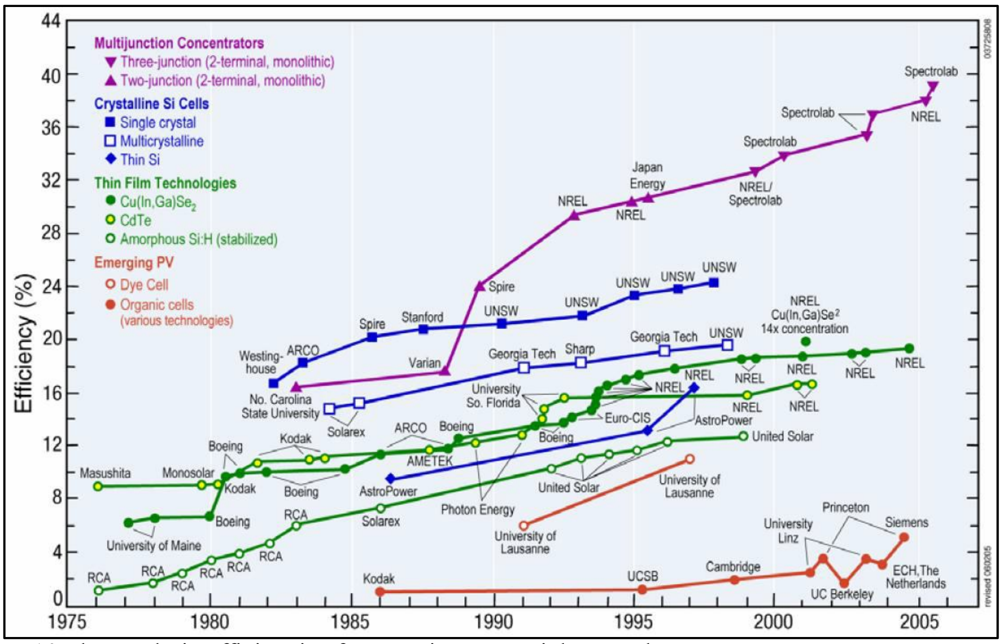

Figure-10 Photovoltaic efficiencies from various materials over the years
Source:Shaheen, S.E.,Ginley,D.S.& Jabbour, G.E. (2005).

Theoretically, the efficiency of the crystalline silicon solar cell has reached up to 24% in the laboratory. However, commercially used cells only can achieve nearly 16% at the optimal level. It seems that the conversion efficiency of the crystalline silicon solar cell is too low to be used effectively. Nevertheless, it has been proved that the silicon-based solar cell is particularly reliable and stable, especially in the harsh condition at sea.

4.1.1.3 Basic units of the solar panel

The solar panel is made up of solar cells, sometimes it also refers to solar module or photovoltaic cell. Solar photovoltaic monomer is the smallest unit and the size is generally 4 to 100 square centimetres. The operating voltage is about 0.45 to 0.5v and the operating current is approximately 20 to 25 milliampere (MA) per square centimetre. However, this voltage is far below the voltage required for the application. In order to meet the needs of the application, it is necessary to connect the basic solar photovoltaic monomer to a module. Typically, a standard solar module consists of the 36 or 40 solar photovoltaic monomer, which can produce approximately 16 volt voltage. This module is sufficient to the battery whose nominal voltage is 12 volt.

4.1.1.4 Design and installation of PV module on board

The most frequent design and installation mode of PV module on solar powered yacht is the "piggyback type", while others adopt "sail type". For piggyback type, the PV modules are paved over the ships' superstructure. For the sail type, the solar panels are installed on the sail type parts. Each design has its own merits. For piggyback type, its advantages include the ample space for PV modules and thus it can be heavily paved in order to fully absorb sunlight and provide greater power for yacht. However, such arrangement also has its disadvantages. As the installation position is fixed, the PV modules are difficult to adjust and thus it can not get the best position angle and affect the absorption efficiency. For example, the world's largest solar yacht "Planet Solar" adopts such installation mode. For the sail type, its installation mode is relatively complicated, some of the solar powered yacht install multiple pieces of sail in order to achieve the best effect. By adjustable sail, solar PV modules can adjust with the changes of heading and altitude of the sun and thus get the best angle. However, its disadvantages include: (1)the installation method is complex; (2)additional resistance emerges along with the increasing speed when sailing; (3)the sail area is insufficient, and the quantities of PV panels installed is limited which will affect the stability of the yacht if the sail is too big; (4)the sail must put down if the wind reach a certain scale in order to decrease its effect on navigation safety.

4.1.2 Role of batteries

The function of the batteries is to store the energy conducted by the direct current (DC) from the solar panel array and readily provide electrical energy to loads in the photovoltaic system. The working model of the battery is the floating discharging state. It means that when the sunlight is sufficient, the solar cells not only supply solar power to the loads, but also charge the batteries by using the left solar energy.

Whereas, when the amount of sunlight is weak and there is no sufficient solar, the batteries will gradually release its stored energy to the loads to ensure the regular work condition of the whole system.

The harsh working condition at sea requires a suitable battery system. Firstly, the batteries should have a long life cycle for the purpose of less maintenance and cost. Secondly, the batteries used in the photovoltaic system should have a high energy density or high storage capacity when compared to its weight (Photovoltaic Technology in the Shipping Industry, p.15) .

Currently, the following types of batteries are prevalent in the shipping industry: lead-acid battery, nickel-based battery and lithium ion battery. Different kinds of batteries have different properties. Among those batteries mentioned above, the lead-acid battery is most mature one compared to the others. The greatest advantage of the lead-acid battery is that it is relatively cheap so that most users can afford. In addition, it has no memory effect, which exists in the other kind of batteries, such as the nickel-based battery. However, there are also some inherent disadvantages of the nickel-based battery, such as the high pollution coming from the heavy metal lead, huge weight and volume of battery, low energy density and life cycle. Compared with the lead-acid battery, the nickel-based battery and lithium ion battery have the long life cycle, higher energy density, smaller volume and lower weight (figure 11). However, those two kinds of batteries are very expensive for the mass applications. Therefore, determining which kind of battery is optimal to the photovoltaic system should be taken a comprehensive consideration. Actually, the lead-acid batteries are the broadly used on board the solar ship at present.

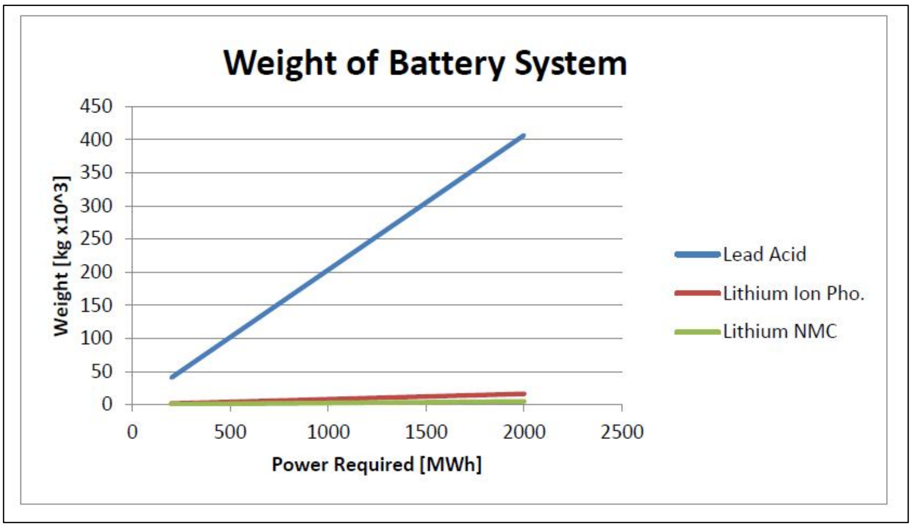

Figure11- The weight of the battery system as a function of power requirements
Source: Photovoltaic Technology in the Shipping Industry

4.1.3 Function of regulator

The regulator is the device controlling and managing the whole system. The PV system works under the monitoring of the regulator, which is the "central nervous system" of the whole system. Generally speaking, the function of the regulator can be achieved through using a variety of techniques. Currently, the most common methods are the logical control and computer control. In summary, there are a series of functions conducted by the regulator.

(1) Signal auto-detect function. It can inspect the status and parameters of the various devices and small units automatically in order to judge, control and protect of the system.

(2) Regulator is a vital component which protects the batteries from the deep discharge and overcharge. Some batteries such as the lead-acid batteries are sensitive to the working condition, especially when the current or voltage exceeds the rated limitation of the batteries. If the PV system works in a disorder way, the life cycle of batteries will decrease dramatically. Thereby, it is necessary to use the regulator to control the current and voltage so as to avoid the damage of the batteries.

(3) The regulator can protect the loads in the PV system in some cases. For

example, the over-current or short-current caused by the failure of the inverter in the system may result in the damage of the loads. This situation can be avoided if there is a regulator in the PV system.

(4) The regulator can detect the position, types of the failures automatically which makes it convenient to the maintain the PV system.

4.1.4 Loads in the photovoltaic system on board

Normally, the loads in the PV system on board the ship can be divided into two categories: direct current loads and alternating current loads. Because the direct current provided by the solar panels can not be taken advantage of by the alternating current loads directly, so it needs a special device called "inverter" to transform the direct current coming from the batteries or solar panel into the alternating current.

4.2 Analysis of solar energy used as the propulsion power source of the small ships

Until now, small vessels, such as work boats, small tourist boats and passenger ferries, often use the solar as the main propulsion power. Some of those ships used solar energy as their unique power, in other words, they are purely solar-powered ships. However, the other kinds of the solar ship just utilize the solar energy as one kind of energy source as the main power. That means they use the Hybrid Marine Propulsion & Power (HMP) providing the main propulsion power.

4.2.1 Purely solar-powered ships

Purely solar-powered ship has its special technical properties. Firstly, its tonnage is not huge and the weight is light. Secondly, they use the electric drive systems as their propulsion system. Thirdly, they are always the catamaran or triple-hulled vessel.

4.2.1.1 Basic propulsion system structure of the purely solar-powered ship

Compared with the conventional propulsion system, the purely solar-powered ship has a very different main power system in terms of the energy transformation and working model. In order to specify these special features, it is necessary to figure out the basic propulsion system structure of the purely solar-powered ship.

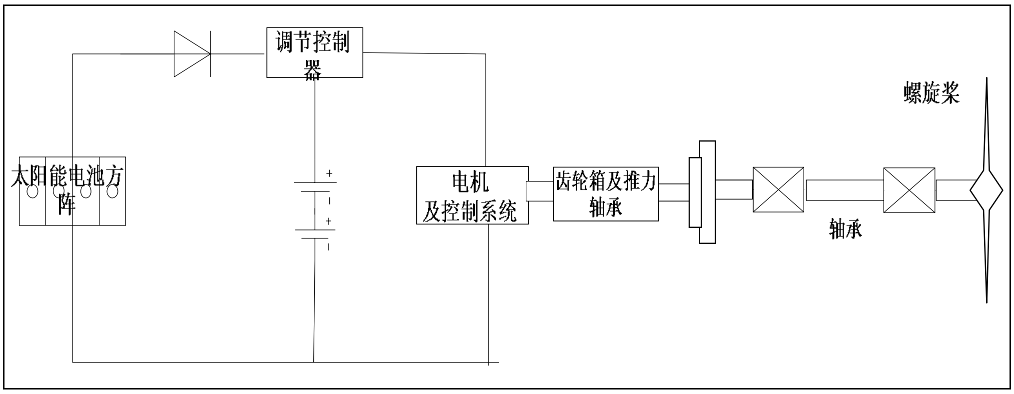

Figure12 -The development of solar technology and propulsion system of solar-powered yacht
Source: Feng & Wang, (2000).

From the picture shown above, a basic propulsion system of a purely solar boat consists of photovoltaic cells, oriented diodes, power battery bank, controller, electric motor and control system, the reduction gearbox and thrust bearings, shafting, propellers. Unlike conventional combustion engines providing the power for the ship, the photovoltaic cells installed on the purely solar-powered ship are responsible for absorbing the solar energy as the power source of the ship. Battery bank stores the energy coming from the photovoltaic cells and supplies the energy to the whole system given that there is no sunlight or during night. Electric motor and control system convert electrical energy into mechanical energy and promote the propeller's rotation. The reduction gearbox and thrust bearings, shafting are responsible for transforming the mechanical energy to the propeller and coordinating the smooth work of the various rotatable parts.

4.2.2 Hybrid propulsion system of the solar ship

Although part of small ships are purely solar-powered, however, there are also a large amount of boats are installed with hybrid propulsion system. There are several different kinds of hybrid combinations according to the energy source of propulsion. The most common one is that the solar energy is combined with the diesel oil, followed by the solar energy combined with the wind energy. When selecting the first composed solution, the diesel generator and solar panels in the system both generate the electric energy for the main propulsion motor. Similarly, the solar and wind combination method also provides energy for propulsion together. In addition, some solar ships use diesel fuel, solar energy as well as wind energy as a joint propulsion energy source for the optimal output of the hybrid system. Furthermore, some system incorporates the fuel cells into the hybrid propulsion system for reliability

The following picture gives a basic illustration to one kind of typical hybrid system. In the system, the internal combustion engine generates the energy to the drive vehicle. Meanwhile, the battery bank also provides the electrical energy for the drive motor. As for a solar boat, the energy from the PV system is temporarily stored in the batteries preparing for the readily need.

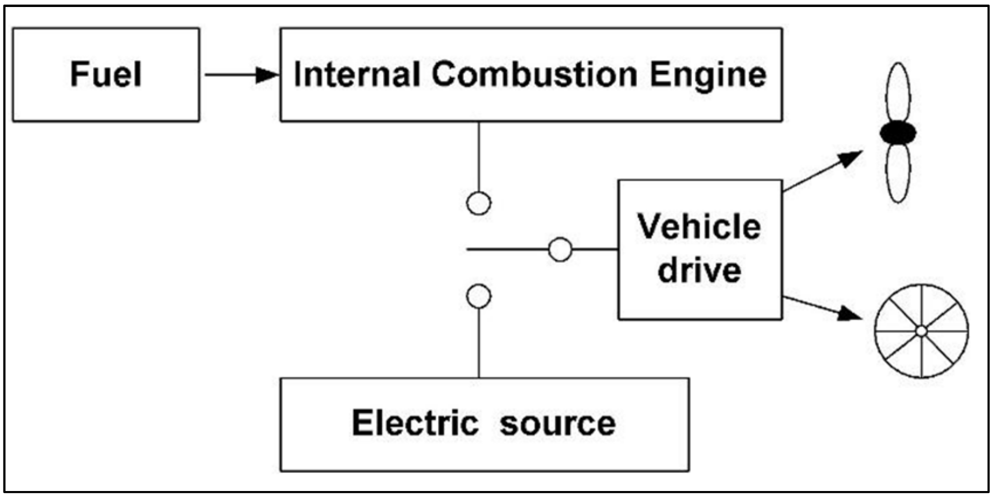

Figure-14 Illustration of the Hybrid propulsion system
Source: http://www.hybrid-marine.co.uk/10.html

4.2.3 Solar-electric propulsion systems available for the solar ship

Due to the direct current generated by the PV system, the solar-powered ships usually use the electromotor as the propulsion motor. Currently, there are two kinds of electromotors available for the electric drive systems of solar-powered ship,

namely direct current motor and the alternating current motor. Before the 1970s, ships mainly use the DC electric propulsion system because the DC motor has a wide and smooth speed adjustment range, good overload starting capacity and big braking torque as well as excellent characteristics of reversal run. while the AC motor has the following advantages: high output power, high limiting speed, simple structure, low cost, small size and reliable operation, but due to the technical limitations, the speed adjustment of the AC motor was difficult than the AC motor in the those years, therefore, it was seldomly used. With the development of the modern control theory, digital control and other electronics technology, the speed adjustment of the AC motor has been comparable with DC drive system(Zhang, 2003, p.27-30). Currently, the alternating current(AC) electric propulsion system dominates the field of ship's electric drive, such as the AC induction motors, AC asynchronous motor, AC synchronous motors, permanent magnet synchronous motor. Thereby, the AC electric propulsion system application has become the mainstream of the development of marine electric propulsion.
However, it does not mean that the DC motor is not suitable for the solar-electric propulsion system because of its inherent advantages. The biggest advantage of the DC motor is that the ship's engines can be adjusted at any time according to the external needs. In this way, the engine can achieve an optimal fuel consumption status. It can also save a large amount of space for passengers or cargo by eliminating the need for bulky transformers and main switchboards.

At present, electric propulsion system used on board the ship varies according to the requirements of different ship, however, they can be divided into the following five categories:

① Silicon controlled rectifiers +DC motor
②Variable pitch propeller + AC induction motor
③Current Source Inverter +AC synchronous motor
④AC-AC frequency converter +AC synchronous motor
⑤Voltage inverter + AC induction motor

Selecting what kinds of electric propulsion system for propulsion system of the solar ships is determined by the various needs of the ship builder. Generally speaking, they mainly focus on the price, power range, propulsion efficiency, starting current, starting torque, dynamic response, power factors, power loss, harmonics and other indicators.

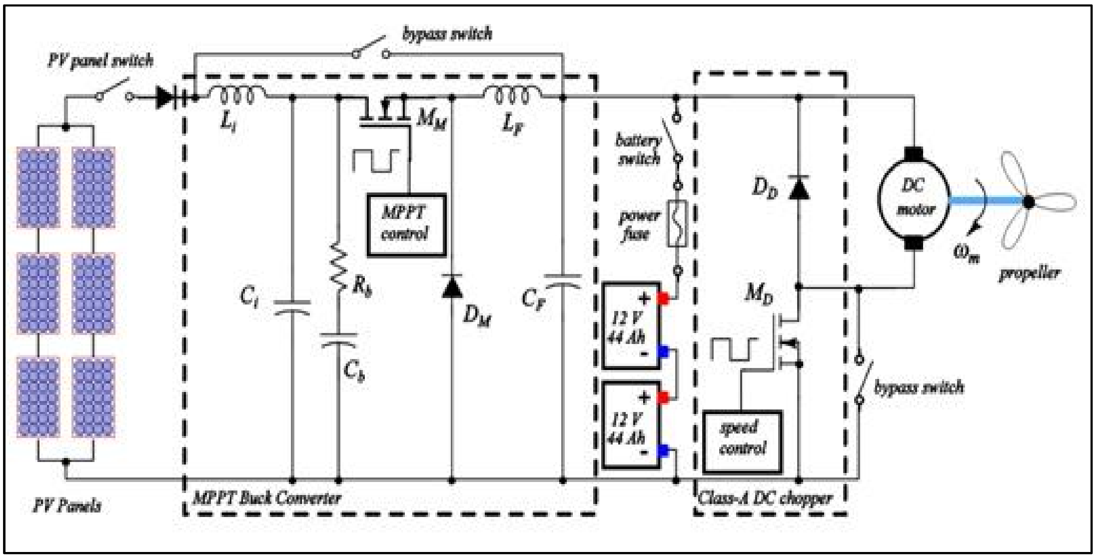

Figure-15 Endurance race complete electrical diagram.
Source: Fonseca, N.& Farias,T. (2009).

4.2.4 Advantages and disadvantages of the solar-electric propulsion system

Due to the inherent features of the solar energy and electric propulsion system, there are several advantages and shortcomings of the solar-electric propulsion system used onboard the ship.

4.2.4.1 Benefits of the solar-electric propulsion system

Firstly, solar energy is sustainable and renewable, and thus is most superior to the conventional energy. As long as the sun shines, power can be generated, and so electric propulsion systems do not have to rely on the expensive or rare fuels for power. Therefore, the solar-electric propulsion system is suitable for saving the fossil energy and can be used freely, which is a huge contribution to the energy saving.

Secondly, the solar-electric propulsion system is quieter than the conventional combustion engines. The reason is that the electric motor generates less vibration than the combustion engine when working because that it has few moving parts. Whereas, a conventional combustion engine needs tine fuel explosions for working which can provide energy but also generate loud noises.

Thirdly, the solar-electric propulsion system causes less pollution than the conventional propulsion system. The solar-electric propulsion system, especially the drive system of the purely solar-powered boats, nearly generates "zero exhaust" compared with the conventional combustion engine. By contrast, the conventional combustion engine releases a series of byproducts such as the GHG, toxic gases and oil-water mixtures when the engine is working. In addition, the electric motor consumes less lubrication oil than the internal combustion engine, therefore, the risk of oil leakage is relatively low.

Fourthly, the solar-electric propulsion system is relatively smaller than the conventional internal combustion engine because the electric motor's volume is not very huge. It means that the engine room of the solar-powered ships takes less room space and the saved space can be used to accommodate the passengers or load cargo.

Fifthly, the propeller of the solar-electric propulsion system has less adverse impact on the ship's hull and engine because the vibration and shock of the electric motor is far less than the internal combustion engine. Obviously, it is benefit to ship' s structure and living condition for people.

4.2.4.2 Shortcomings of the solar-electric propulsion system

Firstly, the conversion efficiency of the PV cells is still not very high currently. As a result, the low conversion efficiency may lead to potential risk such as the insufficient energy providing for the propulsion system. Due to the low conversion efficiency, the PV cells could not absorb enough solar energy in the sunny day resulting in the battery bank can not be charged fully. under such a situation, the batteries may lose the capacity to provide electrical energy to the propellers or other devices in continuous rainy weather.

Secondly, requiring large area to install the PV modules is another drawback of the solar-electric propulsion system. In order to generate sufficient electrical energy, a deck area or roof area should be left enough for the large-scale installation of the solar panels. However, the space on board the ship, especially the small ship like yachts, working boats and ferries, is too limited to provide the deck with large area.

Thirdly, the short endurance of the solar-electric propulsion system is another disadvantage affecting the application of solar ships. Due to the limited store capacity of the battery bank, it is impossible for the solar boat to sail as long as the conventional vessels.

Fourthly, the cost of the PV cells is very expensive. Although the solar energy is free, however the manufacture of the solar cells is not cost-effective, whereas, they are very expensive. It means that the cost of PV system will account for large amount of initial capital of ship builders.

4.2.5 Economic performance of the solar-electric propulsion system

Solar-electric propulsion system is highly efficient as for the fuel consumption, especially for small solar boats. As we know, small boats like the yachts, working boat on harbor and ferry normally sail at low speed so that the power needed by the propulsion system is not very high. The reason is that the ship's resistance is proportional to the square of the ship's speed (formula 1).

$$R = C_f \times V^2 \text{ .... (Formula 1)}$$

Where the R is the resistance on the ship's hull, C_f is the coefficient related to the navigational situation and hull form. V is the ship's speed.

$$P_R = R \times V = C_f \times V^3 \text{ .... (Formula 2)}$$

Where P_R is the power consumed by the ship under the given speed V.

From formula 2, it is clear that the power has a tremendous soaring when the speed increases. In other words, the solar-electric propulsion system is suitable for the small ships like the yachts, working boats and ferries. In addition,

> *the efficiency factor of electric drives is 80 to 90 %, which is much higher than the efficiency factor of combustion engines. For example, a drive power of 3 to 5 kW is sufficient for a boat with a length of 10m.* (Reichel, 2009).

The advantages of electric propulsion for small ships and vessels are well known: zero local emissions and free of noise and vibration propulsion. However, there are constrains to the implementation of this solution, namely the limited amount of energy that can be stored onboard and the higher cost of the electric systems. In fact, the energy density (kWh/kg) of battery systems, or the alternative hydrogen fuel cells plus the storage systems, is much lower than the conventional diesel fuel. The consequence is that the speed and autonomy of whole electric vessels must be small, therefore the concept is viable only for specific applications where the needs in terms of energy are small.

4.3 Feasibility analysis of the solar energy used as the main propulsion power of the huge cargo ship

From the above analysis, it is clear that solar energy used as main propulsion power of small ships has been push into practice stage. However, whether the solar energy can be used as main propulsion power for the large-scale cargo ship is another issue. Unlike the small ship, cargo ship' power demand is far higher and the related system is more complicated. Therefore, it should be a reasonable feasibility analysis for that issue.

In 2011, a research conducted by four scholars coming from the Buffalo University shown that:

> *Photovoltaic technology can be implemented on board a Handymax class cargo ship in order to reduce the use of diesel in the ship's auxiliary generators, however, the power and design requirements needed to integrate solar energy for propulsion is not feasible at this time.* (Daniel, R. & Dustin, M.2011, p.24).

The reasons for the above conclusion can be concluded as follows:

①The space for installation of solar panels is limited resulting in the insufficient solar energy for the propulsion system. On board the cargo ship, the large-scale installation of solar panels only applies to the main hatch covers. Although it seems that the area of these hatch covers is large, however, the solar energy generated by the solar panels installed still can not fulfill the power requirement for promoting such a large vessel.

② The weight of the batteries of the PV system will decrease the ship's cargo capacity dramatically. Despite the free energy provided by the PV system, the batteries also occupy a large amount of space and weight. That means that the available space for loading cargo is reduced.

③There are too many adverse conditions that will limit the application of solar energy used on board the cargo ship, such as sailing on the high latitude area, bad weather etc.

4.4 Solar energy used as the auxiliary power of related devices on board the ship

Although it is not feasible for the solar energy to be used as the main power source of large vessels currently, however, it can provide energy for the auxiliary electrical equipments on board the ship. For example, the PV system can also be used to provide supplementary DC energy sources for facilities on board a ship such as the navigational equipments, accommodation lamps and recreational equipments. The RO-RO ship "Auriga Leader" is a good example (see figure 16).

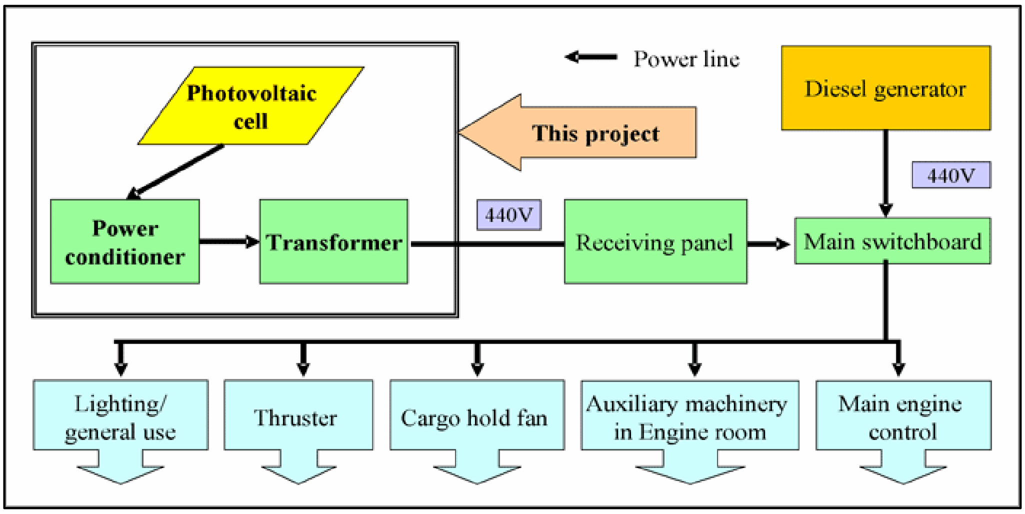

Figure16 - Hybrid solar power system of the “Auriga Leader”
Source: WORKSHOP ON GREEN GROWTH IN SHIPBUILDING

From the figure shown above, the PV system of the “Auriga Leader” generates the direct current which is converted to the alternating current for the whole power system. The PV system combined with the diesel generator provides the main electrical energy to various loads on board the ship. In addition, it can be seen that the electrical energy is distributed by the main switch board to devices such as the lighting, thruster, cargo hold fan, auxiliary machinery in the engine room and main engine controller. Through the use of PV system, the CO_2 emission of this ship is expected to be reduced by 40 tons per year.

Compared with the huge carbon emissions from the large vessels, the contribution of solar energy to reduce the GHG emission seems trivial. However, it makes significant sense from the point of the environmental protection. It is undeniable that the solar energy can reduce the fuel consumption, air pollution and cost of the shipowner. In addition, it also enables the shipowners to find out a new way to comply with the requirement of the EEDI, which is a mandatory instrument made by IMO. Furthermore, the use of solar energy can assist the shipowners or operators in fulfilling the requirements of some Emission Control Areas (ECA).

4.5 Features of hull structure of the typical solar yacht

Catamaran is more often adopted in the design of solar powered yacht, while monomer design and trimaran design are much more less adopted. The catamaran is composed of two identical demihulls and a transverse connecting bridge. The connecting bridge does not come into contact with water and thus it does not affect the performance of the yacht, while it provides all the used space and area. Meanwhile, the two demihulls provide all the buoyancy, and their geometric characteristics determine the performance of the yacht. The demihull of SWATH can be divided into two parts. The upper part acts as pillar and passes through the water surface, and its horizontal section is a long narrow symmetrical airfoil section. The lower part acts as the main body, it is a slender body and its cross section is round or ellipse.

Solar-powered yacht meets the requirements on capacity and comfort by catamaran hull, and its characteristics include spacious deck area, large capacity, enough stability, short rolling period, strong unsinkability and good maneuverability, etc. However, its disadvantages include large resistance in low speed, complex hull structure and inconvenient management. With catamaran design, solar-powered yacht has relatively large superstructure area, and it not only meets the requirements on large capacity, but also provides ample space for the placement of the PV modules.

CHAPTER V - Challenges Confronted by the Application of Solar Energy on Board the Ship

5.1 Reliability problems of PV system in marine environment

It should be noted that renewable energy utilization systems can have some negative impacts to the human and ecological environments(Song, 2006,p.5). Due to the harsh conditions in the marine environment, the PV cells are vulnerable to the adverse effects imposed by the vibration, temperature variation, the hail and corrosion caused by the salt or moisture. Although most of the solar panels on board the ship are made up of the toughened glass and protected by using weather proof and anti-salt spray protection device, however, they are still prone to contamination, coloring, corrosion and wear-out due to the long-term exposure of the fierce temperature variation, high salinity and humidity environment. In addition, a research conducted by China Ocean Shipping(Group)Corporation (COSCO) shows that the glass surface of the solar panels will generate the black spots which are difficult to be removed under long time corrosion of salt and humidity(Yuan & Dong, 2010, p.10). Under this circumstance, the conversion efficiency of photovoltaic cells will decline dramatically, which result in the low efficiency of the whole system. Furthermore the other components such as inverters, controller and batteries of the photovoltaic systems are mainly installed within the closed compartments, but the protection level should be higher than that of the devices used in land when taking the harsh marine environment into account. Thus it can be seen that the reliability of PV system on board the ship plays a vital important role in the effective use of solar energy.

5.2 Adverse impact of the PV system on the ship's safety

The working condition on board is poorer than that in land, especially for ocean-going vessels. In addition, oil pollution, mold and other corrosive materials will make the degradation of the insulation performance in the solar power system.

Similarly, the ship's swing and frequent vibration caused by main engine may result in the damage to the equipment of the solar system. If the broken parts of the solar system can not fulfill the protection function of the system, there may be a spark, electric arc or even an explosion when the system is working. Furthermore, if the PV system is operated in an abnormal way or has mismanagement, failure will occur and fire will be ignited.

Generally speaking, the reasons listed following may cause a five:

①Insulation value falls of the solar equipments results in short circuit which causes fire.

②Long-term overload operation of solar equipment, causing the temperature rise exceeds the allowable value.

③Poor contact of the conductor causes local overheating.

④Solar photovoltaic systems fire caused by lightning.

5.3 Negative influence of the PV system on the crew's safety

If the PV system equipment are arranged the accommodation or working area, there will be a hazard of leakage of electricity, which is extremely dangerous to the personnel safety. In addition, island effect is another risk for the personnel safety. The so-called island effect refers to that the isolated generating equipment continue to provide the electricity to the whole system. However, this situation is difficult to be detected. If a maintainer cuts down the main switchboard to do some repair work, he may regard that the whole power grid has no power. In this situation, it will be extremely dangerous and may cause casualty. Therefore, it is necessary to provide sufficient Personal Protective Equipment(PPE) for the crew working on board the solar ship because the PV system has potential hazard to them.

5.4 Influence on the ship's normal operation

5.4.1 Affecting normal cargo loading and unloading

The installation of solar panels may have some adverse impact on cargo loading and unloading of bulk carriers. When lifting the cargo, the operator should be very careful to avoid the fallen goods from breaking the solar panels installed on the deck or hatch covers. Therefore, the handling efficiency of the ship will be affected. On the other hand, it is inevitable for some goods to fall on the deck area and damage the solar panels. The problem is that the damaged solar panels are very difficult to be repaired due to the fixed installation.

5.4.2 Potential interference with the ship's sailing

The large-scale installation of solar panels may interfere with the ship's normal sailing . In order to provide enough space for the installation of solar panels, some solar ships set wings to enlarge the effective area for the installation. The solar ferry "Solar Sailor" is a good example. But the problem is that the movable wings may influence the ship's maneuvering ability. For example, when the wings are lifted, the ship may not pass through some bridges with the low headroom. Moreover, most solar boats adopt the Catamaran configuration. That kind of hull structure is beneficial to the installation of the solar panels because the surface of the superstructure is increased. Thereby, it will have more deck area left for the solar panels. However, a bigger superstructure also increases the air resistance of the ship, resulting in extra energy consumption. Furthermore, the extending outboard solar panels may affect the ship's berthing manipulation.

5.5 Potential risks of environmental pollution

Although solar panels can generate the "free" energy for ships, however, the potential environmental pollution caused by the application of solar energy could not been ignored. Firstly, the manufacture of solar panels is high energy consumption and high pollution industry. Due to this reason, the initial cost of the PV system is relatively high. Secondly, the recycling of solar panels is another problem. If the wastes of the solar panels are not recycled reasonably, there will be a secondary pollution. Thirdly, the light pollution from the solar panels is another problem which should be paid more attention. As we know, glasses can reflect the sunlight, thereby, if there are too many solar boats or ships concentrating on a spot, people may suffer from the interference of the reflected light.

CHAPTER VI- Responding Countermeasures to the Application of the Solar Energy

Although the use of solar-powered ships is not yet universal in China, but it has launched a technological revolution as a new type of ships. It also brought out a series of challenges to maritime safety management. Therefore, the Maritime Safety Administration authority should do some research about technical features of this new type of ship in advance and formulate scientific and rational management regulations for those ships.

6.1 Legal dilemmas confronted by stakeholders concerning the solar energy and responding solutions

6.1.1 Shortage of uniform international standards concerning the solar technology and equipment

Currently, there are no specific international conventions, regulations and instruments concerning the design and construction of solars ships. Solar ships are still at an early stage of development, thus the laws and regulations for this new type of ship are not comprehensive. Although there are some laws and regulations regarding such vessels, but just generalities and lack of operability content.

6.1.2 Existing standards related to solar-powered ship in China

In China, there are only parts of the normative documents as a reference available for the design and construction of solar-powered ship:

(1) The Appendix 2: Guidelines for Direct Calculation of Hull Structure Strength of High Speed Craft(HSC) in the "Rules for Construction and Classification of Sea-going High Speed Craft" formulated by China Classification Society presented the catamaran's structural strength calculation method. Part of the contents in this rules specify the construction requirements and technical specifications about the

catamaran crafts which are also applied to the catamaran solar-powered boat.

(2) In 1992, the National Solar Energy & Photovoltaic Standardization Committee of China formulated a standard called "General Specification for Marine for Sea-use Solar Cell Modules" (GB/T 14008-92), concerning the PV cells used on board the ship. This standard provides the specific provisions and requirements concerning the product classification, technical requirements, test methods and inspection rules of marine solar modules. The solar-powered ships should follow the requirements given by this standard.

(3) Ship's Electric Propulsion System Technical Conditions (GB/T 13030-91) of China. This standard was proposed by the China Shipbuilding Industry Corporation and was approved the National Bureau of Technical Supervision of China in July 1991. The standard regulated the detailed technical requirements and relevant tests for marine electric propulsion system. It is also applicable to the electric propulsion system of solar-powered ships.

6.1.3 Lack of uniform international standards

Despite of those standards and rules listed above, it is obvious that those regulation and rules only apply to the solar-powered ship in China. As for the solar ship all over the world, they are built according to the various standards of different countries. Eventually, different standards generate different solar ships. In addition, different countries survey and certificate the solar ships according to the own standards or even there is no international survey and certification standards for compliance.

6.1.4 Potential problems aroused by the absence of uniform standards

First of all, the absence of uniform standards is harmful to shipbuilders. Due to various standards, some low-quality products may flow into the market resulting in unfair competition. Therefore, some honest shipbuilder may suffer from economic loss. In addition, the lack of uniform standards is also a bad news for the maritime safety administration departments because they do not know which country's standard is more reasonable and scientific. In this situation, the safety administration may be very difficult to be conducted, especially for the port state control.

6.1.5 Feasible solutions to the legal dilemmas

Establishing suitable international laws and regulations for solar-powered ships is essential to resolve legal embarrassment. Solar ship is the model from the point of energy-saving and environment protection, so the administration authority should establish policies to support the development of the solar ship. In addition, IMO should pay more attention to the emergence of this new type of ships and establish proper regulations or guidelines to guide the development of marine solar technology.

6.2 Issues related to the crews serviced on board the solar ships

Crew's training is important for the safety of solar ships. Solar ship is very different from the conventional ship. The conventional ship used the internal combustion engine for the propulsion, whereas, solar ship used the solar-electric propulsion system to sailing. Obviously, the two kinds of propulsion system is totally different from each other. In order to cultivate the qualified crew for the solar ship, several issues in the existing training system should be adjusted and some special training should be given to the crew servicing in the solar ship.

6.2.1 The importance of the implementation of special training

Special training plays a significant role in the ability enhancement of crew servicing on board the solar ship. Besides the general skills required by seamen serving on board the the conventional ships, the crew also needs additional knowledge and skills for the work on board a solar ship. For example, the operating characteristics a Catamaran is obviously very different from the single hull ship. Through special training, seamen's knowledge of the solar ship can be updated and the practical operation skills can be assessed. For example, the engineer and electrical engineer on board the solar ship must have specialized knowledge and competency, therefore, carrying out special training for the solar ship crew is imperative.

6.2.2 Current status of the solar ship crew training

Currently, there are no training standards for the crew servicing on board the solar ship. More seriously, some solar ships are still manned with the crew for internal combustion engine ship, without taking into account the ship' s hi-tech, which exists hazards. To strengthen solar ship crew training, the present seafarer training system should be improved and should fully take the special technical factors of the solar powered ship in to consideration for the purpose of ensuring the quality of training.

6.2.3 Categories of special training for the solar ship's crew

(1) Particular training for officers servicing in solar ships

Using the catamaran structure, the maneuver ability of solar ship is very different from the conventional ship. In addition, the solar-electric dynamic forms of the solar ship requires the officer or pilot to understand the technical features of that kind of ship and grasp the operation skills of the electric propulsion. Therefore, prior to the issue of the competency certificates serving in the solar yacht, Maritime administrations should ensure the seafarer's relevant knowledge updated. In particular, for the pure solar-powered yacht, the officers should fully be aware of the limitations of current electric propulsion system and yacht's steering performance to avoid accidents.

(2) Professional training for engineers in solar ships

The traditional assessment and certification exam of crew are basically for the internal combustion engine. However, there is no special requirement for electric propulsion ship. The electric propulsion system used in the solar-powered ships requires the professional knowledge and skills of engineers. Therefore, the certification assessment of the solar-powered ship should be fully taken into account the relevant knowledge of electric propulsion for strengthening the special training of engineers and increasing relevant examination contents. Only in this way, the engineer can obtain the competency required by the solar-electric propulsion system.

(3) Manning and training of electrical engineers

The PV system of the solar ship requires the professional knowledge and skills of the crew. However, most of the present ships have canceled the position of the electrical engineer for cut down the fixed cost. The problem is that how can a general engineer solve the potential problems during the operation of the PV system. Obviously, it is necessary to man the solar-powered ship with a professional electrical engineer. The maritime administration authority should take this technical factor into consideration when issuing the Minimum Safety Manning Certificate of solar-powered ships. In addition, the continuous training of the electrical engineer servicing in the solar ship is also imperative.

6.3 Survey of the solar-powered ships

Special survey should be conducted for the solar-powered ships because the hull structure and dynamical system are extremely different from the conventional vessel. To ensure the sea worthiness of the solar-powered ship, the maritime administration authority should carry out special inspection and survey before issuing the ship's safety certificates and the Recognized Organizations(RO) should train their surveyor to obtain the sufficient professional competency to survey such a kind of ship. The author believes that the special inspection should be focused on the features of the ship's propulsion system, PV cells and batteries. The detailed survey measures are the actual experiments for inspection of the endurance and turning performance of the solar ship.

At present, there is no inspection specification for solar-powered ships. Flag states have not established the survey standards for that kind of ship and the survey work is still in the exploratory stage. Incorporating the survey of solar-powered ship into the existing survey system is urgent for avoiding the disorder status of the survey of solar ships. IMO should also establish relevant umbrella regulations or guidelines for the Flag State to encourage the development of solar ships.

6.4 Flag State Control and Port State Control concerning the solar ship

Currently, the maritime administration authorities are still lack of enough capacity for conduct the Flag State Control(FSC) and Port State Control(PSC) of the solar ship. However, there are already lots of solar ship, especially the solar yacht, are launched for commercial use. Therefore, it is necessary to prepare the prior work for the Flag State Control and Port State Control of those ships.

6.4.1 Establishing reasonable inspection guidelines for solar ships

The suitable inspection guideline is necessary. Until now, there is no inspection guideline for the Flag State Control and Port State Control work of the solar ship, however, the technical requirements of the solar ship is dramatically different from the conventional ship using the internal combustion engine. Therefore, the Flag States and Port States should establish responding guidelines referring to the standards given by the international organizations such as the IMO or IEC. Eventually, the mature inspection standards will be achieved gradually.

6.4.2 Knowledge renewable of the Port State Control officers and Flag State Control officers

Generally speaking, Port State Control officers and Flag State Control officers are very familiar with the conventional vessels, including the ship's certificates, technical equipment and manning requirements. However, as for the solar ship, it is another story. In order to coordinate the inspection work smoothly, it is necessary to train the Port State Control officers and Flag State Control officers. PSC and FSC officer' s knowledge update is a prerequisite to conduct safety inspections of solar yacht. Maritime administrations should have foreseen the development trend of solar ship as soon as possible and offer ship safety inspectors a systematic training in order to increase safety staff's technical expertise to improve normative of the safety inspection of solar ship.

6.4.3 Strict safety inspection on solar-powered ships

The device on board sola-powered ships is still in the developing stage. Therefore, some crew is unfamiliar with the operation and management of this kind of ship. There are also technical limitations of the solar ship, so the inspectors from the maritime administration authority should strictly follow the procedures and conduct the inspection professionally. In addition, inspector should focus on the endurance and maneuverability of the solar ship, which is directly related to the safe navigation. It is also very necessary to focus on the examination of crew's emergency operation ability to avoid overwhelmed crew in an emergency.

CHAPTER VII - Conclusion

As an inexhaustible and green energy, Solar power will be an unprecedented development in the next years. Solar energy used on board the ship is a new conception which attracts people's attention in recent years. It has been improved that solar energy can be used as the main power of the small ships, especially for the yachts, recreational boats and small working boats on harbour. Although solar energy is seldomly used on board the cargo ship currently due to the technical limitations, however, the solar energy can play an important role in the reduction of carbon emission if it can be used in a reasonable way.

Admittedly, the emergence of the solar ship triggers several challenges to the maritime safety administration, however, those challenges can be overcome by the competent authority by taking several responding measures. Reasonable measures including establishment of the relevant regulations concerning the solar ship should be taken in advance in order to guide the development of the solar ship. In addition, the competent authority should administrate the operation of the solar ship for avoid potential safety risk in the course of using solar energy on board the ship. Hopefully, solar energy can be widely used on board and the seaborne trade will be more cost-effective.

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