DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

ENERGY ANALYSIS AND OPTIMIZATION OF A SOLAR BOAT

by
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September, 2015
İZMİR

ENERGY ANALYSIS AND OPTIMIZATION OF A SOLAR BOAT

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İZMİR

M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"ENERGY ANALYSIS AND OPTIMIZATION OF A SOLAR BOAT"** completed by **CENNET ÖZLEM BİLİR FİDAN** under supervision of **ASST. PROF. DR. AYTAÇ GÖREN** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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ENERGY ANALYSIS AND OPTIMIZATION OF A SOLAR BOAT

ABSTRACT

Nowadays solar energy, which is one of the renewable energy resources, is a good alternative to fossil fuel based energy by considering the impact of fossil fuel on the environment. Efficient use of solar energy is helping to reduce both environmental and economic concerns. Solar energy is widely used on marine vessels, as well as the use of terrestrial facilities and vehicles, especially on yachts and pleasure boats. In addition to this it began to be used in commercial ships. The aims of this research are to determine the daily energy needs of a two-seater hand line fishing electric boat for optimization and to form an implementation of renewable energy use on a solar boat for a vocational school education. Besides, the use of electric powered vehicles is environmentally friendly and effective. It is appropriate for the selected area of usage by adequate selection of the propulsion system based on the power need and adequate selection of the storage capacity based on the use need. Therefore, the design of propulsion system and energy optimization have major significance for the electric powered vehicles.

Keywords: Solar boat, photovoltaic, energy efficiency, energy optimization, MPPT

GÜNEŞ ENERJİSİ İLE ÇALIŞAN BİR TEKNENİN ENERJİ ANALİZİ VE OPTİMİZASYON

ÖZ

Yenilenebilir enerji kaynaklarından biri olan güneş enerjisi fosil yakıtların çevreye etkisi dikkate alındığında günümüzde fosil yakıtlı enerjiye iyi bir alternatiftir. Güneş enerjisinin verimli kullanımı, hem çevresel hem de ekonomik kaygıları azaltmaya yardımcı olmaktadır. Güneş enerjisi karasal tesisler ve taşıtlarda kullanıldığı gibi yaygın bir şekilde deniz taşıtlarında da yaygın bir biçimde kullanılmaya başlanmıştır, özellikle yatlarda ve gezinti teknelerinde. Buna ek olarak, ticari gemilerde kullanılmaya başlanmıştır. Araştırmanın amacı, elektrikli teknelerden eğitim amaçlı iki kişilik bir tekne modeli ele alınarak, teknenin enerji sarfiyatı ve kullanım alanı ile günlük enerji ihtiyacına göre sistem kapasitesi ile gücünün optimizasyonuna dayalı bilimsel bir çalışma yapmaya yöneliktir. Elektrik enerjisinin taşıtlarda kullanımı, çevreye dost ve efektif bir kullanım olmasına karşın, güç ihtiyacına göre belirlenen tahrik sistemi ile kullanım ihtiyacına göre belirlenen depolama kapasitesinin yeterli seçilmesi ile kullanılan alanlara göre uygun olmaktadır. Bu nedenle, tahrik sisteminin tasarımı ve enerji optimizasyonu elektrikle çalışan taşıtlar için büyük önem arz eder.

Anahtar kelimeler: Güneş enerjili tekne, güneş pili, enerji verimliliği, enerji optimizasyonu, MGNT

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CHAPTHER ONE
INTRODUCTION

Nowadays solar energy, which is one of the renewable energy resources, is a good alternative to fossil fuel based energy by considering the impact of fossil fuel on the environment. Efficient use of solar energy is helping to reduce both environmental and economic concerns.

Energy use has become a crucial concern in the last decades because of rapid increase in energy demand. Moreover, environmental issues of conventional energy resources such as climate change and global warming are continuously forcing us for alternative sources of energy. According to the statistics released by World Health Organization (WHO), direct and indirect effects of climate change leads to the death of 160,000 people per year and the rate is estimated to be doubled by 2020. Climate change causes natural disasters such as floods, droughts, and remarkable changes in atmosphere temperature (Mekhilef, Saidur, & Safari, 2011).

Marine solar vehicles are boats propelled by direct solar energy. These vehicles use solar cells that transform the usable solar energy into electrical energy, which is then stored temporarily in accumulator batteries to be used in propelling the boat through an electric motor and a drive system. Power values vary from a few hundred watts to a few kilowatts. Solar power started to be used in boats in around 1985, and the first commercial solar boats are introduced in 1995 (Ozden & Demir, 2009).

Solar energy is widely used on marine vessels, as well as the use of terrestrial facilities and vehicles, especially on yachts and pleasure boats. In addition to this it began to be used in commercial ships. The Planetsolar and the Auriga Leader are the most known example for solar powered marine vessels. The Planetsolar is the most popular and largest solar powered boat in the World. The Auriga Leader which was built in Japan is the first solar power driven commercial ship in the world.

There are many types of handline fishing at the Aegean Region of Turkey. Trolling fishing is one of them. Trolling is the name given to the type of fishing in which a natural or artificial bait, fitted with hooks, is towed from a line attached to a moving boat. The appearance and motion of the bait is intended to excite carnivorous fish into attacking it, and becoming hooked. This fishing method therefore aims to catch predatory fish, that is the types of fish which chase and eat other fish (Preston et al., 1987). A number of lures or baited hooks are towed astern at a speed depending on the target species, from 2.3 knots up to at least 7, the fish being hooked after snapping at the lure and held by the mouth until they can be brought aboard as the line is hauled in (FAO). A trolling line consists of a line with natural or artificial baited hooks and is trailed by a vessel near the surface or at a certain depth (FAO). There are many variations to the equipment and techniques used in trolling fishing.

In Turkey, trolling is generally used by amateur fishermen which have a small boat. Carnivorous fishes such as sea bass, sea bream, blue fish, pike can be caught by trolling (Hoşsucu, 2002). In trolling fishing if a fishermen catch a fish, he/she should not leave the area where they catch the fish (Alpbaz & Özer, 1991). Because the chance of catching another fish is very high possibility at the same position. But for this reason it must be avoided from scare of fish by noise or sound at the positon (Alpbaz & Özer, 1991). Source of the noise and sound at the sea are human, motor and sea. So fishermen prefer the electric motor driven for their fishing boat because of eliminating the noise of motor. The advantages of electric motors in trolling fishing is working with minimum noise according to internal combustion engines.

According to taken feedback from fishermen who are interested in handline fishing, even if they use internal combustion motor on their small boat, they state that it is very useful of having an extra electric motor on their boat. They are interested in minimum noise and fuel saving of electric motors.

The aims of this research are to determine the daily energy needs of a two-seater hand line fishing electric boat for optimization and to form an implementation of renewable energy use on a solar boat for a vocational school education.

Besides, the use of electric powered vehicles is environmentally friendly and effective. It is appropriate for the selected area of usage by adequate selection of the propulsion system based on the power need and adequate selection of the storage capacity based on the use need. Therefore, the design of propulsion system and energy optimization have major significance for the electric powered vehicles.

CHAPTER TWO
SOLAR ENERGY SYSTEM COMPONENTS

2.1 Photovoltaic

Photovoltaic (PV) is the direct conversion of light into electricity. It uses materials which absorb photons of lights and release electrons charges. It can be used for making electric generators. The basic element of these generators is named a PV cell. (Rekioua & Matagne, 2012)

Commercial PV modules can be categorized into two technologies. First, the conventional PV modules which exist out of single or multicrystalline (c-Si) PV cells embedded in a laminate of glass, encapsulation material (usually EVA) and a backsheet (usually Tedlar). Secondly, Thin film PV module technologies that are either produced on glass, metal or plastic substrates and that can have a variety of forms. PV use on boats is only feasible when the limited surface area available on board would be efficiently used to generate electrical energy. Therefore, for this application, PV cells with high efficiencies are required. The best affordable candidates to be used on boats are c-Si PV cells with efficiencies around 20%. Although various multijunction PV cells offer efficiencies well above 25% (Gorter & Reinders, 2012).

A typical solar cell consists of a PN junction formed in a semi-conductor material similar to a diode. Semi-conductor material most widely used in solar cells is silicon. Each material gives different efficiency and has different cost. There are several types of solar material cells:

- monocrystalline silicon (c-Si)
- polycrystalline cells
- Thin films

Thin-film solar cell (TFSC), also called a thin-film photovoltaic cell (TFPV), is a solar cell made by thin film materials with a few lm or less in thickness. Thin film solar cells usually used are:

- Amorphous silicon (a-Si) and other thin-film silicon (TF-Si). The efficiency of amorphous solar cells is typically between 10 and 13%. Their lifetime is shorter than the lifetime of crystalline cells.
- Cadmium Telluride (CdTe) which is a crystalline compound formed from cadmium and tellurium and its efficiency is around 15%.
- Copper indium gallium selenide (CIS or CIGS) is composed of copper, indium, gallium and selenium. Its efficiency is around 16.71%.
- Dye-sensitized solar cell (DSC) is formed by a photo-sensitized anode and an electrolyte. Its efficiency is around 11.1% (Rekioua & Matagne, 2012).

The electrical power output from a photovoltaic panel depends on the incident solar radiation, the cell temperature, the solar incidence angle and the load resistance. Manufacturers typically provide only limited operational data for photovoltaic panels, such as the open circuit voltage (V_{OC}), the short circuit current (I_{SC}), the maximum power current (I_{mp}) and voltage (V_{mp}), the temperature coefficients at open circuit voltage and short circuit current ($\beta_{V_{OC}}$ and $\alpha_{I_{SC}}$, respectively), and the nominal operating cell temperature (NOCT). These data are available only at standard rating conditions (SRC), for which the irradiance is 1000 W/m² and the cell temperature (T_C) is 25 ºC (except for the NOCT which is determined at 800 W/m2 and an ambient temperature of 20 ºC) (De Soto, Klein, & Beckman, 2006).

The electrical power available from a photovoltaic (PV) device can be modeled with the well-known equivalent circuit shown in Figure 2.2 (Duffie & Beckman, 1991; Nelson, 2003). In Figure 2.1 shown that simplified equivalent circuit of solar cell (Rekioua & Matagne, 2012). This circuit includes a series resistance and a diode in parallel with a shunt resistance. This circuit can be used either for an individual cell, for a module consisting of several cells, or for an array consisting of several modules (Duffie & Beckman, 1991; De Soto et al., 2006). Cells, photovoltaic module and panel are represented in Figure 2.3.

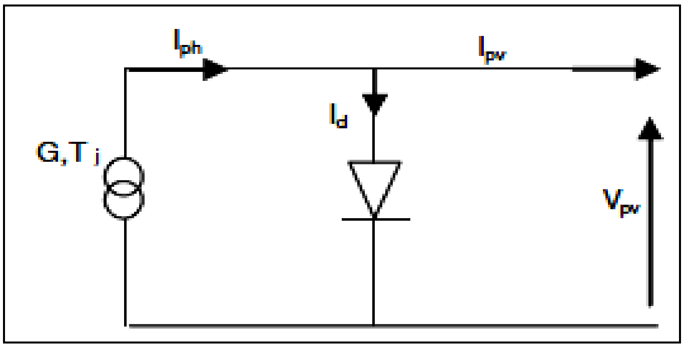


Figure 2.1 Simplified equivalent circuit of solar cell (Rekioua & Matagne, 2012)

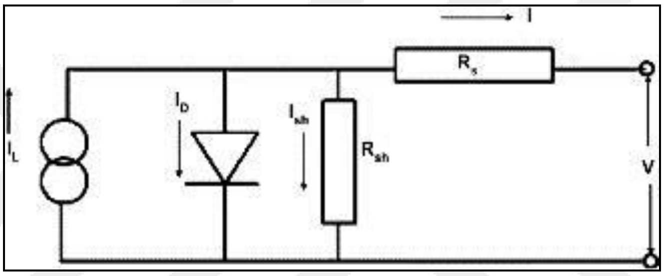


Figure 2.2 Equivalent circuit representing the five-parameter model (De Soto et al., 2006)

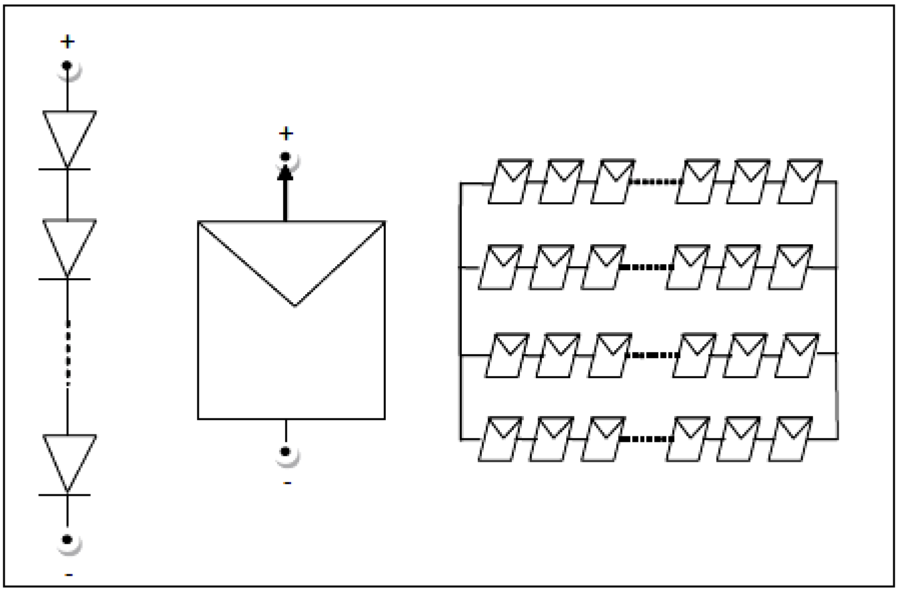


Figure 2.3 Cells, photovoltaic module and panel (respectively)

2.2 Battery Systems

Cell is the basic electrochemical unit used to generate electrical energy from stored chemical energy or to store electrical energy in the form of chemical energy (Rekioua & Matagne, 2012). The cell is the basic electrochemical unit in a battery, consisting of a set of positive and negative plates divided by separators, immersed in an electrolyte solution and enclosed in a case (Martinez, 2011). Battery cell composition can be shown in Figure 2.4.

Battery is necessary to store electrical energy that is produced by the PV array as well as to supply energy to electrical loads. It can supply power to electrical loads at stable voltages and currents, and it can supply surge or high peak operating currents to electrical loads or appliances (Rekioua & Matagne, 2012).

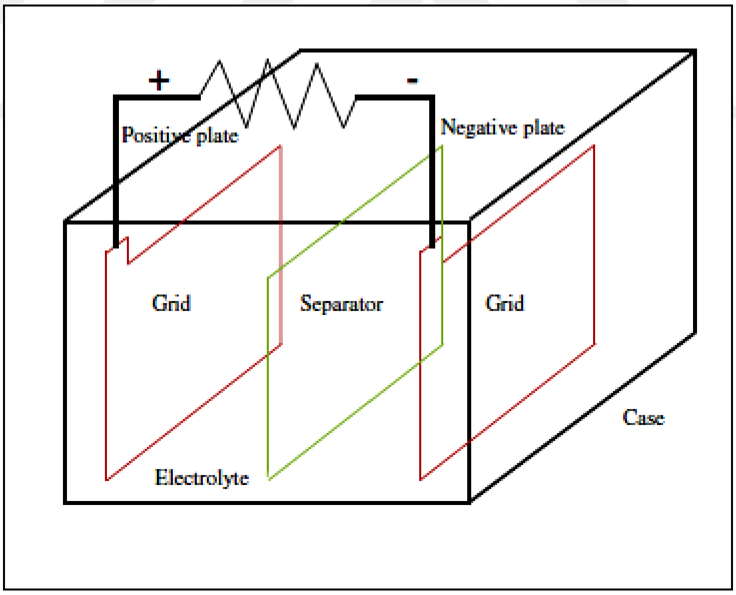


Figure 2.4 Battery cell composition (Rekioua & Matagne, 2012).

Several types of batteries are used for large scale energy storage. In PV systems, lead-acid batteries are most common as we said before, due to their wide availability in many sizes, low cost and well understood performance characteristics. In a few critical, low temperature applications nickel-cadmium cells are used, but their high initial cost limits their use in most PV systems (Poullikas, 2013).

2.2.1 Lead Acid Batteries (Pb – Acid)

Lead–acid batteries, invented in 1859, are the oldest type of rechargeable battery and they use a liquid electrolyte, as illustrated in below Figure (Poullikas, 2013). They have the major disadvantages associated with handling acid substances, the presence of lead in their construction, a low stored energy/weight ratio and low stored energy/volume ratio. Because of their inexpensive manufacturing technology and a high ratio electric power/weight ratio they are a cheap solution to equip electric vehicles (Manzetti & Mariasiu, 2015).

The lead acid batteries are the most used in PV applications especially in stand-alone power systems because its spill proof and the ease to transport (Linden & Reddy, 2002; Rekioua & Matagne, 2012).

Drawbacks of this technology include limited cycle life, poor performance at low and high ambient temperatures, failure due to deep and continuous cycling, and environmentally unfriendly lead content and acid electrolyte which result in a large eco-footprint (Nirmal-Kumar & Garimella, 2010).

2.2.2 Nickel-Cadmium Batteries (NiCd)

The NiCd batteries are commonly known as relatively cheap and robust (Rekioua & Matagne, 2012). Nickel-cadmium (Ni-Cad) batteries have several advantages over lead-acid batteries that make them attractive for use in stand-alone PV systems. These advantages include long life, low maintenance, survivability from excessive discharges, excellent low temperature capacity retention, and non-critical voltage regulation requirements. The main disadvantages of nickel- cadmium batteries are their high cost and limited availability compared to lead-acid designs (Martinez, 2011).

2.2.3 Lithium-ion Batteries

This type of battery is characterized by a large power storage capacity with very good energy density/ weight ratio. However, the limitations in the way of massive use of this type of battery are given by: high costs, a potential for overheating and a limited life cycle (Manzetti & Mariasiu, 2015). Although the use of lithium-ion batteries currently is predominant in the portable electronics market, their use for automotive and renewable energy storage applications is very plausible in the not-so-distant future. Li-ion batteries achieve energy storage efficiencies of close to 100% and have the highest energy density (Hall & Bain, 2008).

The operation of Li-ion batteries is based on the transfer of lithium ions from the positive electrode to the negative electrode while charging and vice versa while discharging .The positive electrode of a Li-ion battery consists of one of a number of lithium metal oxides, which can store lithium ions and the negative electrode of a Li-ion battery is a carbon electrode. The electrolyte is made up of lithium salts dissolved in organic carbonates (Rekioua & Matagne, 2012).

2.2.4 Sodium-Sulfur Batteries (NaS)

Sodium–sulfur batteries are rechargeable high temperature battery Technologies that utilize metallic sodium and offer attractive solutions for many large scale electric utility energy storage applications. This type of battery has a high energy density, high efficiency of charge / discharge (75–86%), long cycle life, and is fabricated from inexpensive materials. However, because of the operating temperatures of 300–350°C and the highly corrosive natüre of the sodium poly sulfide discharge products, such cells are primarily suitable for large-scale, non-mobile applications such as grid energy storage (Poullikas, 2013).

2.2.5 Nickel-Hydrogen Batteries

Nickel-Hydrogen battery has some advantages as long cycle, resistance to overcharge and good energy density, but it has high cost, high cell pressure and low volumetric energy density. It is generally used in space applications and communication satellites.

2.2.6 Nickel-Metal Hydride Batteries (NiMH)

NiMH battery manufacturing technology and operation resembles that of NiCd battery. The main advantage of NiMH batteries is the lack of memory effect, which affects the maximum load capacity of the battery. Compared to the Li-ion, NiMH batteries have lower energy storage capacity and also a high self-discharge coefficient (Manzetti & Mariasiu, 2015).

2.2.7 Nickel-Zinc Batteries (NiMH)

The positive electrode is the nickel oxide but the negative electrode is composed of zinc metal. In addition to better environmental quality, this type of battery has a high energy density (25% higher than nickel-cadmium). Its operation is based on the following redox reaction (Rekioua & Matagne, 2012).

2.2.8 Sodium Nickel Chloride Batteries (NaNiCl)

This is also known as the “Zebra battery” and it uses a molten salt electrolyte with an operating temperature of 270–350°C. It offers the advantage of having a high stored energy density. The major disadvantages are related to its operational safety and its storage for longer periods (Manzetti & Mariasiu, 2015).

2.2.9 Lithium-Ion Polymer Batteries

The major difference with Li-ion batteries is that the electrolyte consists of a solid ion-conducting polymer material. The polymer electrolyte also serves as a separator. The advantage of this architecture is related to the absence of liquid in the battery which increases the energy density, the safety and life (Rekioua & Matagne, 2012).

2.2.10 Li-Metal Batteries

The biggest advantage of storing lithium in its metallic form, instead of its ionic form surrounded by carbon atoms in the maximum ratio of 1:6, is a gain in energy density and specific energy. However, the use of metallic lithium introduces the severe problem of its very high reactivity (Rekioua & Matagne, 2012).

2.3 MPPTs

However, the performance of PV depends on solar radiation, ambient temperature, and load impedance. In order to achieve maximum power point (MPP) output of a PV system, different method to track the MPP has been addressed in many literatures. Among the MPPT techniques, the perturbation and observation (P&O), open-circuit voltage (OCV), incremental conductance (IncCond), hill climbing (HC) and short-circuit current (SCC) algorithm [2-10] are the most popular because of the simplicity of their control structures or few measured parameters for the maximum power point of PV system tracking. However, when solar irradiation changes rapidly and is high, most of those control processes are likely to converge at the local MPP, which is not the true peak power point in the I-P curve of the PV generator, and the efficiency is low.

MPP, where SC output power reached the maximum value, varies depending on the angle of sunlight on the surface of the panel and cell temperature. Hence, the operating point of the load is not always MPP of PV. Therefore, in order to supply reliable energy to the load, PV systems are designed to include more than required number of modules. In this case, the system cost and the amount of energy loses greatly increase. The solution to this problem is that switching power converters can be used that is called as maximum power point tracker (MPPT). Thus, the continuous operation of photovoltaic panels at MPP can be provided. Generally in uniform conditions (absence of sudden shading or climate changes), using of MPPT is quite considerable increases in output power such as 20%–30% (Onat, 2010).

2.3.1 Definitions of MPPT Algorithms

One of the classification forms of MPPT algorithms may be according to the used control techniques. Commercially, the most widely used algorithm is the method called perturb and observe (P&O) in PV system market. Despite this, the algorithm which gives the best results has occurred in the no consensus.

Perturb and Observe (P&O) Algorithm. P&Q is the most widely used algorithm due to the simplicity of implementation practically. In this method, P-V characteristic of PV cell is used. As known, produced power by PV array varies as a function of voltage. In P&O algorithm, a small increase in operating voltage of PV array is realized, and the amount of change in power (ΔP) is measured. If ΔP-value is positive, operating voltage is increased again to reach MPP, thus, sign of power error track by these small voltage errors.

Artificial Intelligence-Based MPPT Algorithms. In recent years, fuzzy logic (FL), artificial neural networks (ANNs), and genetic algorithm (GA) techniques known as artificial intelligence techniques have been used widely in the MPPT process. Especially under non-uniform and partially shading conditions, power and current characteristics of PV cells are more complex (as shown in Figure 2), and it is also more difficult to track MPP. Therefore, for a satisfactory result, all environmental conditions (especially instantaneous climate changes and partially shading) must be taken into account in the design process of MPPT. Artificial intelligence can produce appropriate solutions for these conditions.

Constant Voltage (or Current) Algorithms. Constant voltage (CV) algorithm is based on approximately constant ration between voltage of MPP (Vmax) and open-circuit voltage as given in the following equation:

$$\frac{V_{max}}{V_{OC}} \cong K < 1 \tag{2.1}$$

In this algorithm, solar panel is temporarily separated from MPPT, and open-circuit voltage is measured. Later, voltage at MPP is calculated by using (1). By the adjusting of array voltage to this calculated value, the operation at MPP is achieved. This process is repeated periodically and the position of MPP is tracked continuously. Although this method is quite simple, it is difficult to determine the optimal value of constant K. In literature, K value was revealed to be between 73% and 80% (Onat, 2010).

2.4 Electric Motor

Electric motors, with a background of more than 100 years, had an impact on the human civilization deeply, replacing human muscle power in industry (Şahin, 2010). These motors range from small "servo" motors to large motors used to lift thousands pounds. Each electric motor converts electrical energy to mechanical energy. Motors are selected for each application based on the amount of mechanical power. However, mechanical power is not the only criteria for choosing a motor. Different types of motors have different characteristics such as how much starting torque they provide, whether they operate at one speed or variable speeds and how efficient they are, etc (Cengiz, 2003).

With the introduction of AlNiCo, the first commercial permanent magnet (PM) motor was introduced in 1950s (Merill, 1954). However, this new technology had to wait long to be widely accommodated in industrial applications. With the discovery of rare earth magnets in 1970s, permanent magnet motor technology has followed footsteps of developments in magnet materials. In 1980s first in DC motors, followed by synchronous motors, more interest and effort has gone to this new technology (Şahin, 2010).

Conventional DC motors are highly efficient and their characteristics make them suitable for use as servomotors. However, their only drawback is that they need a commutator and brushes which are subject to wear and require maintenance. When the functions of commutator and brushes were implemented by solid-state switches, maintenance-free motors were realized. These motors are now known as brushless DC motors.

The growing performances/costs ratio is leading the industry to new approaches in the motor control field in order to satisfy EMI/EMC laws, quality and reliability standards, etc (Cengiz, 2003). Brushless DC (BLDC) motor satisfies these requirements. BLDC motor is a basically a permanent magnet synchronous motor which currently plays an increasing role in many industrial applications due to the following reasons.

- High power mass ratio
- Good heat dissipation characteristics
- Low rotor inertia
- High-speed capabilities (Subaşı, 1998).

A Brushless DC motor driver is more complicated than brushed DC motor driver. Because the motor cannot commutate the windings, so the control circuit and software must control the current flow correctly to keep the motor turning smoothly (Kurdoğlu, 2007). BLDC motors have many advantages, most of which are listed in Table 2.1.

Table 2.1 Brushless Motor Features (Miller, 1989)

BLDC Advantage	**Why BLDC provides this advantage**
Improved efficiency	Eliminate brush voltage drop and brush-friction.
Reduced electrical noise	Eliminate arcing from brushes to commutator.
Reduced acoustic noise	Eliminate brush bounce, especially at high speeds.
Reduced debris	Eliminate brush wear.
Increased speed range	Remove mechanical limitations imposed by brush / commutator interface.
Reduced size due to superior thermal characteristics	Brushless motors have windings on the stator; brush motors have windings on rotor. Windings are the main heat generators on PM motors and it is easier to remove heat from the stator than from the rotor, if stator is the outer part of the machine
Reduced maintenance	Eliminate brush wear.
Reduced weight and size	Eliminate commutator, brush, and brush holders.
Improved MTBF	Reduce parts count and electrical interconnects by eliminating mechanical commutation.

CHAPTER THREE
EXPERIMENTAL SYSTEM SETUP

The main dimensions of the boat are; Length of Overall (LOA): 3.20m, Beam (B): 1.40m, Height (H): 0.55mm (Figure 3.1). Criteria of selection on body type of solar boat are shown in Table 3.1. This powered by direct solar energy. The boat uses solar cells that transform the solar energy into electrical energy, which is stored temporarily in batteries, and used to drive the boat through electric motors. Required electric energy is derive from 5 pieces PVs, each consisted of 24 cells. 2 pieces 12V, 26Ah lead acid type batteries are used for storage of electric energy. MPPTs are shown in Figure 3.2 which are the parts of system. Electrical circuit diagram of solar boat is shown in Figure 3.3.

Figure 3.1 Constructed solar boat and gauges.

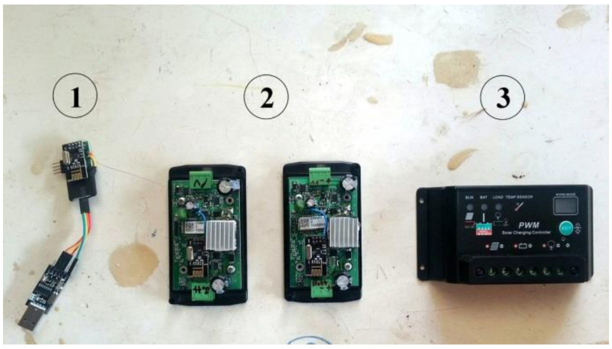
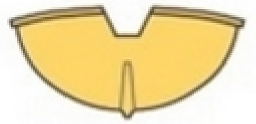


Figure 3.2 Tested MPPTs which are designed for DesTech Solaris Solar Car (1), its telemetry system (1-2), tested commercial MPPT in market.

Table 3.1 Boat body type selection criteria

Body Type	Body Type	Example	Advantages	Disadvantages
	Flat bottom	handline fishing boats	could be sail in shallow water, light weight and suitable for land transportation	suitable for still waters and lakes
	Deep "V" Hull	speedboats	less risk of capsizing	requires greater engine power
	Multi-Hull	Catamaran, Trimaran	wide deck area	Less maneuverability in narrow spaces
	Round Bottom	Sail Boat, canoe	opens water easy	high risk of capsizing

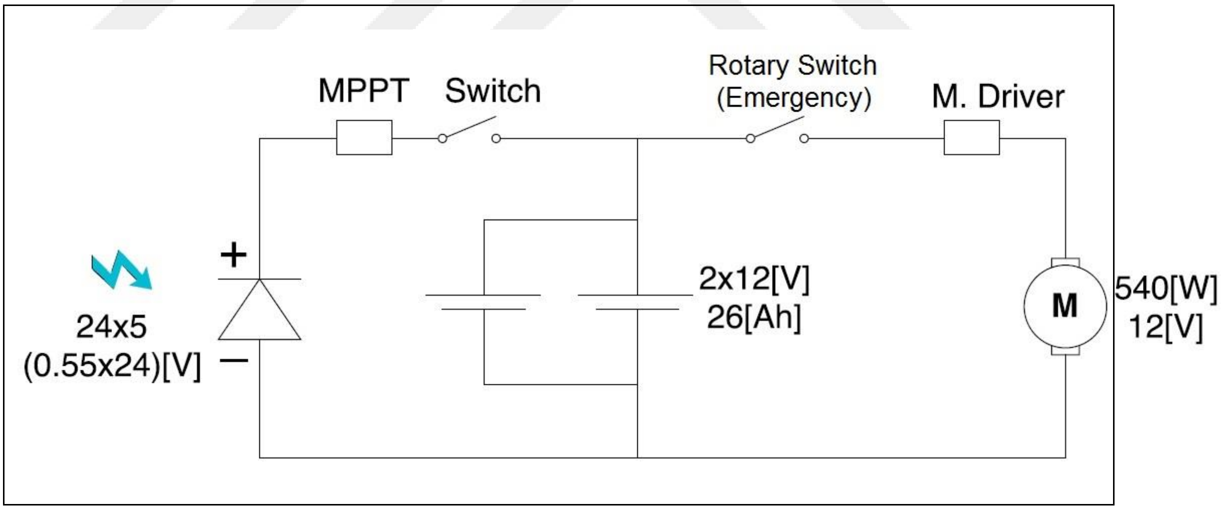


Figure 3.3 Electrical circuit diagram of solar boat

3.1 System Dimensioning

In the boat the area available for laing a photovoltaic array is about 1.31 m² and 5 PV modules are installed on this area (Figure 3.4) One module has 24 cells and one cell dimension is 100 x 100 mm.

$$0.1 \times 0.1 = 0.01\, m^2 \quad \text{(cell)} \tag{3.1}$$

$$24 \times 0.01\, m^2 = 0.24\, m^2 \text{ (module)} \tag{3.2}$$

$$5 \times 0.24\, m^2 = 1.2\, m^2 \quad \text{(panel)} \tag{3.3}$$

The solar panel on the boat can provide 0.15kW in theory, as illustrate in the equation 5.

$$0.8\, \frac{\text{kW}}{\text{m}^2} \times 0.16 \times 1.2\ \text{m}^2 = 0.15\ \text{kW} \tag{3.4}$$

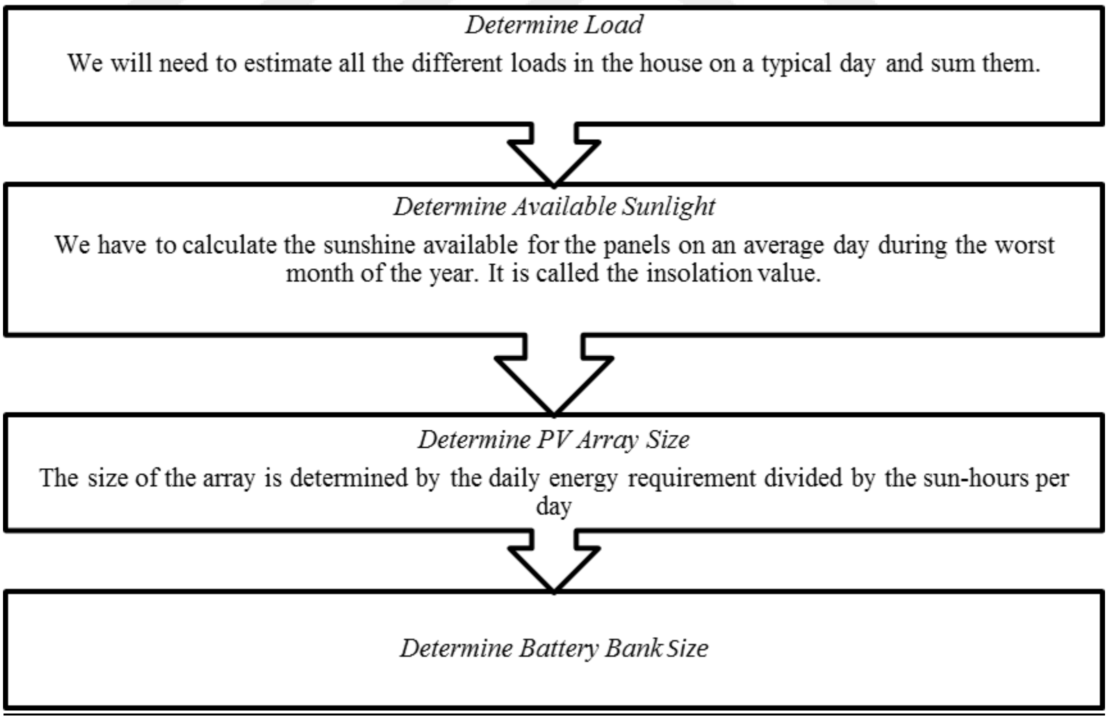


Figure 3.4 How to estimate the size of a photovoltaic array and battery bank

The boat is assumed that it sails when beaufort scale is 1 (See A.1) and the calculations are based on that assumption. Experimental case is created according to the information received from people who are handline fishermen. The handline fishermen sail before the sunrise and they spend only four hours including sailing to fishing area and sailing back to shore.

Table 3.2 Specifications of batteries

Specifications of Battery model ES 1226	
Normal Voltage	12 V
Normal Capacity	26 Ah *2
Weight	Approx 7.25 kg*2
Dimension (L x W x H)	166 × 175 × 125 mm
Standard discharge (*V*coff , Id)	12.8 V, 1.3A 2 paralel 2.6 A
Standard charge (*V*ch, *I*ch)	14.8 V , 2.6 A (When DOD is %50)
Internal resistance	Approx 14 mΩ

Table 3.3 Specifications of electric motor

Haswing Osapian 55lbs	
Voltage - Rated/Max	DC 12V
Depth Adjustment	Depth Collar
Max Thrust (lb/kg)	55lbs/24.6kg
Prop Type/Size	3 blade prop/9.3inch diam
Prop Speed at Full Power	Max. 1200 rpm underwater
Battery Type (suggested)	105AH deep cycle
Max Boat Length/Load	5.5m/400kg
Power - Rated/Max	540W/660W
Amp - Rated/Max	45A/55A
Decibel Level (db)	50db
Shaft Type	Composite
Shaft Length	36inch/914mm

On 15th of July 2015 time of sunrise was 0555. Distance between Urla İskele and Pirnarli Island is approximately 3.5 km. The trip to island takes 0.64h.

0530 departure from Urla to Pirnarli island

- 0610 arrival to island
- 0850 departure from island
- 0930 arrival to Urla

Battery capacity is 318.24 Wh. Solar Radiation Mean is 210.72 Watt/m² (based on pyranometre data) and the energy which is generated from PV panel is 40.46 Watt. Energy need to propel the boat is 397.8 Watt on the conditions that mentioned before. Energy need to propel the boat to Pirnarli Island is 254.53 Wh. The possible energy usage from PV during the sailing is 25.89 Wh. Energy drawn from batteries to get the island is 228.65 Wh. The amount of energy left in the battery only if it is drawn from the batteries is 63.71 Wh.

The energy need for sailing back to Urla is also 254.53Wh. The stored energy in batteries during the hole experiment is 161.83W. In that case there is some extra energy ensued which could be generated from PVs in extra 0.72 hour. Because of extra time need the endurance is stringed out for approximately an hour.

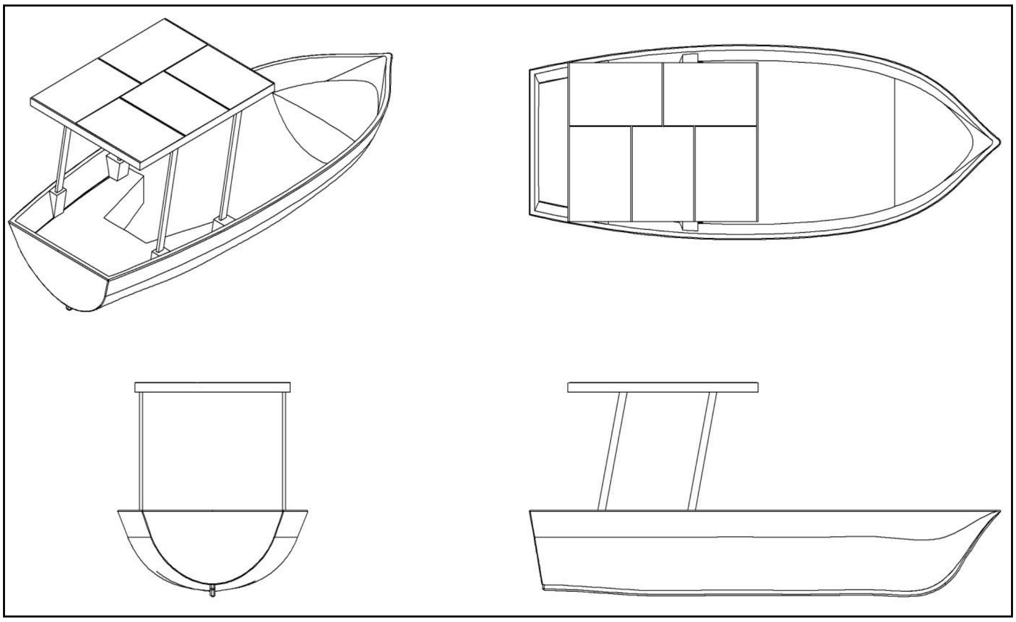


Figure 3.5 Model of solar boat

On 24th of December 2014 time of sunrise was 0720. Distance between Urla İskele and Pirnarli Island is approximately 3.5 km.

The trip to island takes 0.64h approximately 40 minutes.

- 0700 departure from Urla to Pirnarli island
- 0740 arrival to island
- 1020 departure from island
- 1100 arrival to Urla

Battery capacity is 318.24 Wh. Solar Radiation Mean is 202.18 Watt/m² (based on pyranometre data) and the energy which is generated from PV panel is 38.82 Watt. Energy need to propel the boat is 397.8 Watt on the conditions that mentioned before. Energy need to propel the boat to Pirnarli Island is 254.53 Wh. The possible energy usage from PV during the sailing is 24.84 Wh. Energy drawn from batteries to get the island is 229.70 Wh. In three and half hours the batteries could be charged 135.86 W by PVs.

The energy need for sailing back to Urla is also 254.53Wh. The stored energy in batteries is 135.86W. In that case there is some extra energy ensued which could be generated from PVs in extra 1.42h hour. Because of extra time need the endurance is stringed out for approximately one and half hour.

Calculations are made by the information which is shown in Table 3.2 and 3.3, Figure 3.6, 3.7, 3.8 and 4.3.

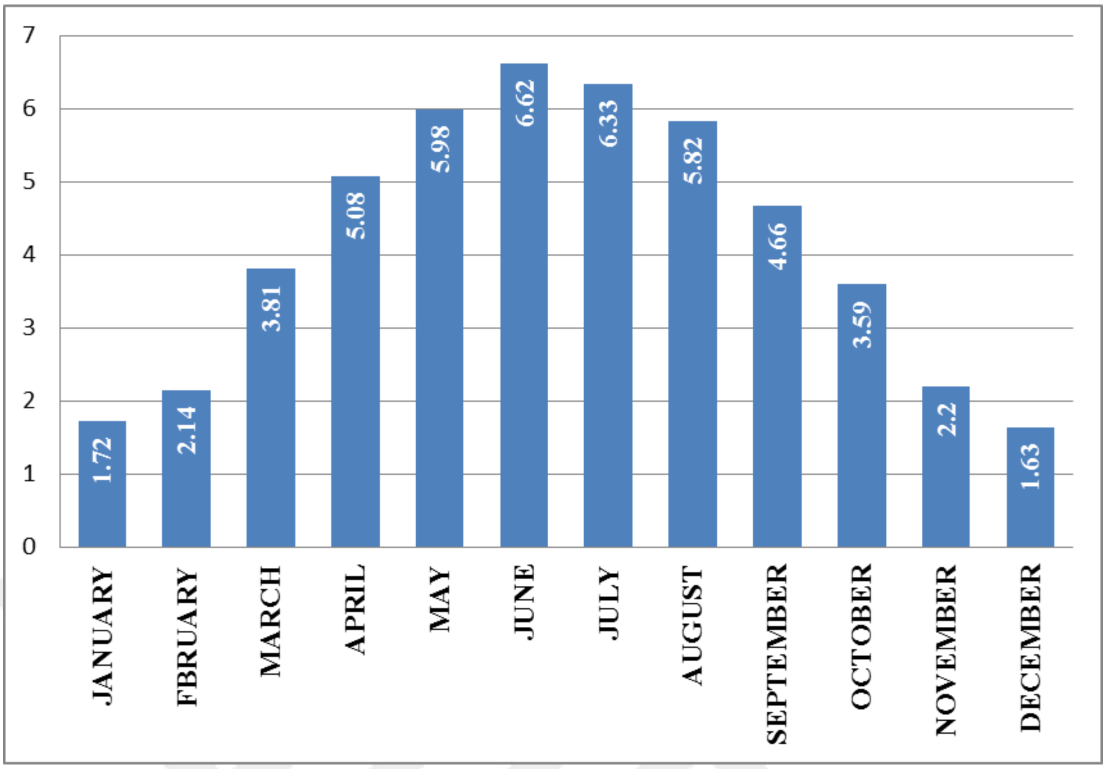


Figure 3.6 Urla global radiation values (KWh/m²-day)

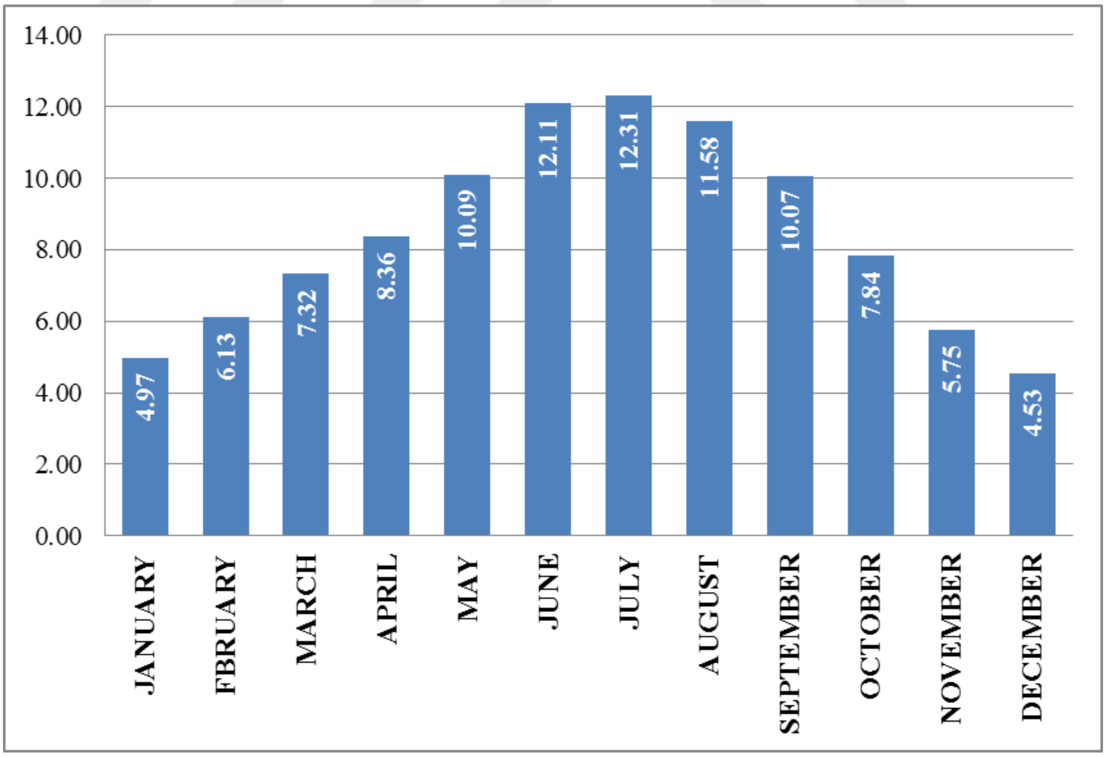


Figure 3.7 Urla hours of sunshine (hour)

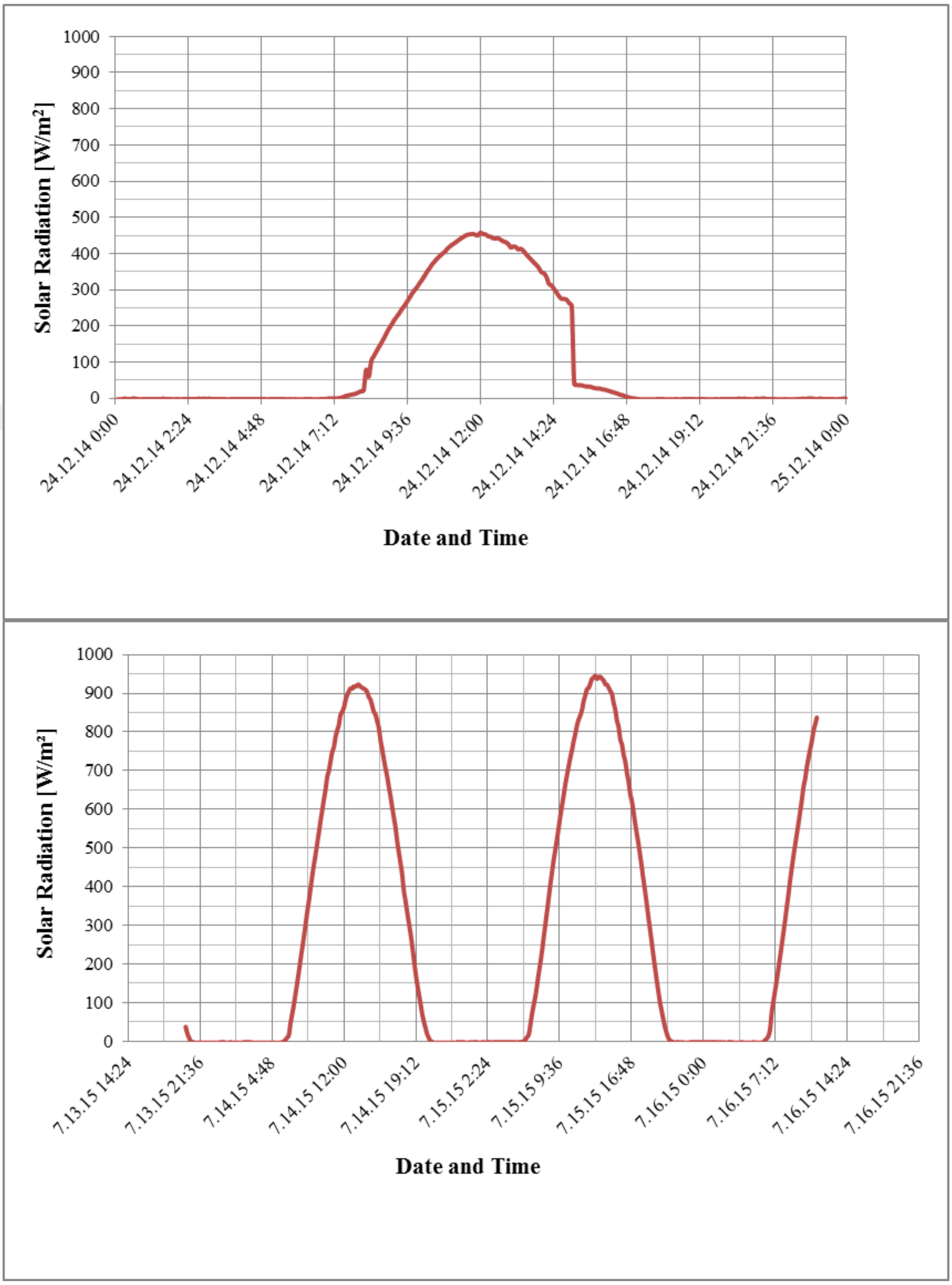


Figure 3.8 Solar radiation levels at Solar Charging Station 1 (Deşarj1@Tinaztepe) on 24/12/2014 and 15/07/2015

CHAPTER FOUR
EXPERIMENTS AND OPTIMIZATION

First scenario is created according to the information received from people who are handline fishermen. The handline fishermen sail before the sunrise and they spend only four hours including sailing to fishing area and sailing back to shore. According to this information and the data taken from sea trail results On 9th of July (Table 4.1) and pyranometer the steps are followed as below. On 5th speed forward the slowest speed is 5.47 km/h. This velocity and related data (the current and voltage) is chosen because this is the most pessimist scenario.

Second scenario is also created according to the information which mentioned before. According to this information and the data taken from sea trail results On 20th of August (Table 4.2) and pyranometer the steps are followed as below. And the speed is taken as average speed.

Table 4.1 Sea trial results On 9th of July

	Velocity [mile/h]	Velocity [km/h]	Voltage [V]	Current [A]	Duration	Power (Watt)
1st gear (forward)	1.7	2.74	12.5	7.3	00:42	91.25
3rd gear (forward)	2.5	4.02	12.1	16	02:32	193.6
5th gear (forward)	3.6	5.79	11.8	34.4	04:00	405.92
	3.5	5.63	11.7	33.5	05:24	391.95
	3.5	5.63	11.8	34.2	06:24	403.56
	3.4	5.47	11.7	34	07:24	397.8
	3.8	6.12	11.7	33.5	08:24	391.95
	3.6	5.79	11.7	33.3	09:24	389.61
	3.5	5.63	11.6	33.8	10:24	392.08
	3.6	5.79	11.6	33.5	11:24	388.6
	3.8	6.12	11.6	33.3	12:24	386.28
	3.6	5.79	11.6	33.3	13:24	386.28

The discharges graphs of batteries are shown in Figure 4.1 and Figure 4.2.

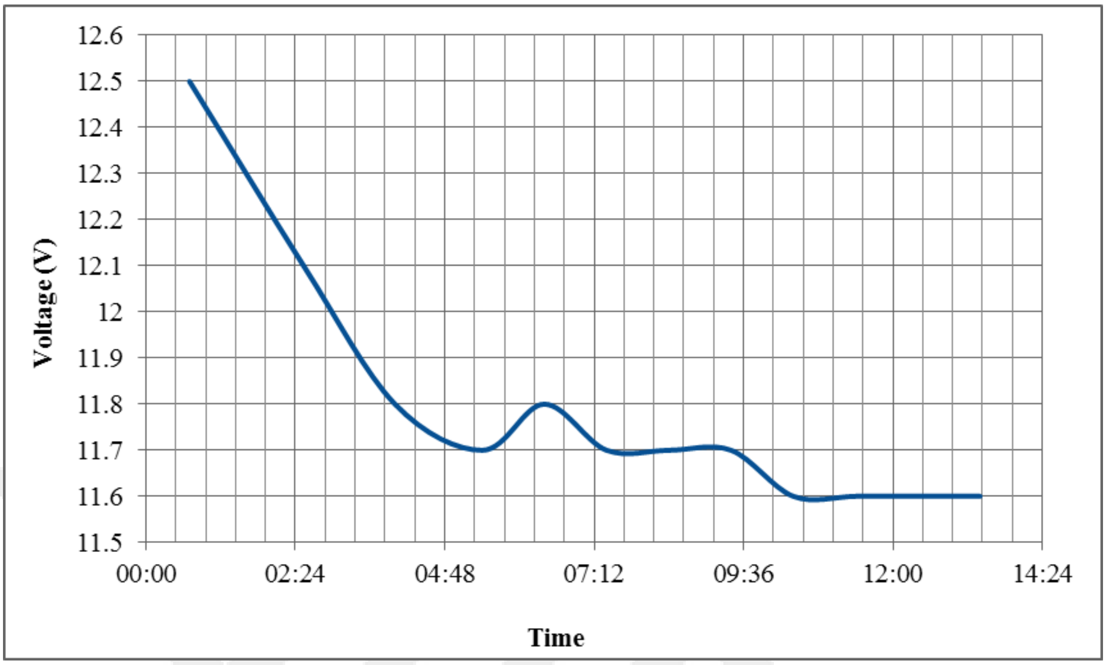


Figure 4.1 Discharge graphic of Eurostar batarries on 9th of July

Table 4.2 Sea trial results On 20th of August

	Speed [km/h]	Voltage [V]	Current [A]	Time	Power (Watt)
5th gear (forward)		11.9	30.5	11:57	362.95
		11.8	30.3	12:02	357.54
	5.7	11.4	27.7	12:07	315.78
3rd gear (forward)	3.9	11.6	17.7	12:10	205.32
		12	12.4	12:23	148.8
		11.9	11.3	12:28	134.47
		11.4	17.2	12:33	196.08
	3.8	11.3	16.9	12:38	190.97
		11.1	16.2	12:43	179.82
		10.9	16.2	12:46	176.58
	3.2	10.8	16.1	12:48	173.88
	3.4	10.6	15.7	12:50	166.42
		10.5	15.8	12:52	165.9
		10.4	15.3	12:53	159.12
		10.3	15.1	12:54	155.53
		10.2	15	12:55	153
		10.1	14.7	12:56	148.47

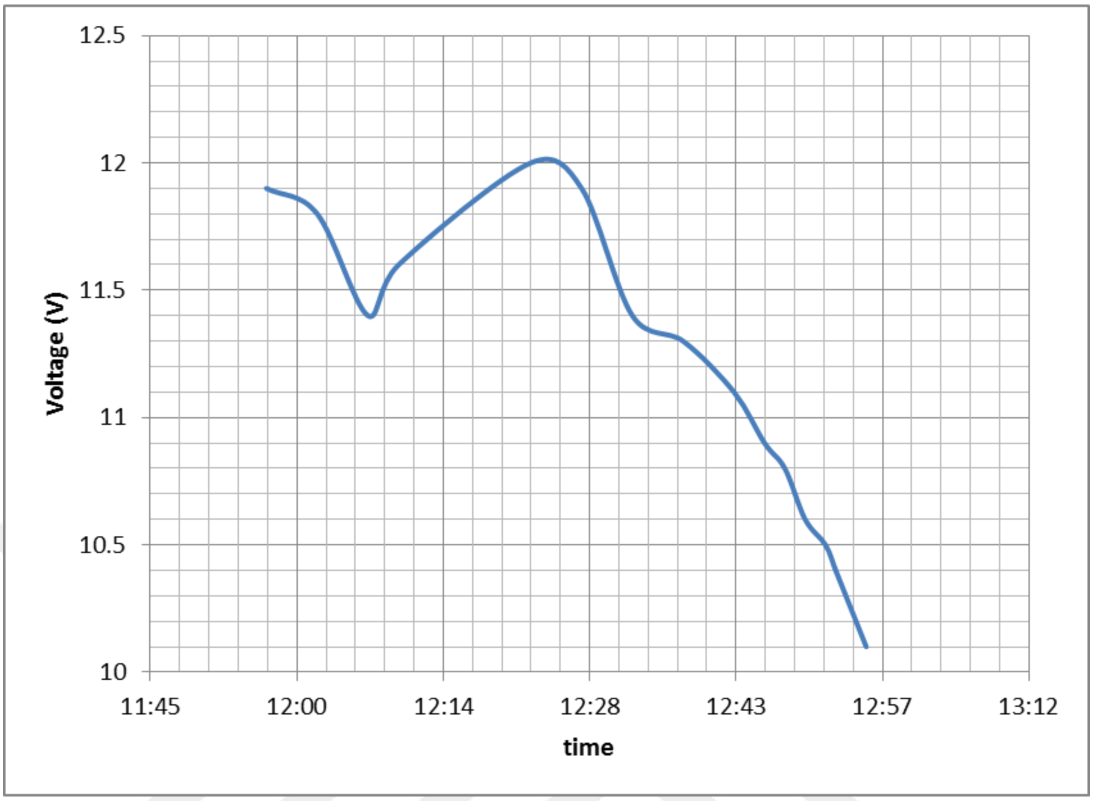


Figure 4.2 Discharge graphic of Eurostar batarries on the 20th of August

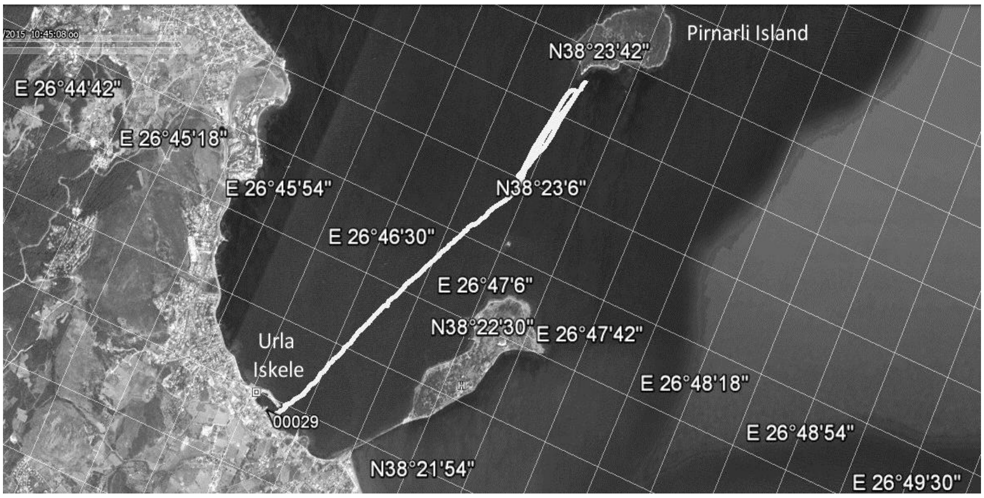


Figure 4.2 Route

Comparison of sea trial results is shown in Table 4.3.

Table 4.3 Comparison of sea trial results

	On 24th of December 2014 (based on pyranometre data)	**On 15th of July 2015 (based on pyranometre data)**	**On 9th of July 2015 (based on test result)**	**On 20th of August 2015 (based test result)**
Energy ganerated from Pv [Watt]	38.82	40.46	104.58	120.96
Energy need to propel the boat [Watt]	397.8	397.8	397.8	168.17
Battery capacity [Wh]	318.24	318.24	318.24	318.24
Duration [h]	0.64	0.64	0.64	0.98
Energy need to propel the boat to Pirnarli Island [Wh]	254.53	254.53	254.53	164.41
The possible energy usage from PV during the sailing [Wh]	24.84	25.89	66.91	118.26
Energy drawn from batteries (in 0.64 hour) [Wh]	229.7	228.65	187.62	46.15
The amount of energy left in the battery (if only energy drawn from batteries)	63.71	63.71	63.71	153.83
Stored energy in batteries during the hole experiment [W]	135.86	161.83	418.3	483.84

CHAPTER FIVE
CONCLUSION

In this research, a handline fishing solar boat is designed, manufactured, energy needs of the system is determined and optimized for Izmir Coast handline fishermen fishing characteristics. Two experimental cases are obtained for a travel of eight kms and four kms those are based on sailing before sunrise and after sunset, fishing in daytime or at night. The handline fishermen sail before the sunrise and they spend only four hours including sailing to fishing region and sail back to shore. Calculations are realized due to this information, the data taken from sea trial and measuring devices. Even the conditions are evaluated for the pessimist scenario, the results of the sea trial, energy capacity determination study and the solar boat itself were very satisfactory.

As a future work, it is planned to expand the research area to Egean Sea costal in Turkey. The study could be more realistic by gathering information, which is taken by the researchers in this study, from the handline fishermen. Furthermore, the composite plate, on which solar panels are mounted, could be improved to open close system as a cover for solar boat equipment. Hence the improved plate could be made functional.

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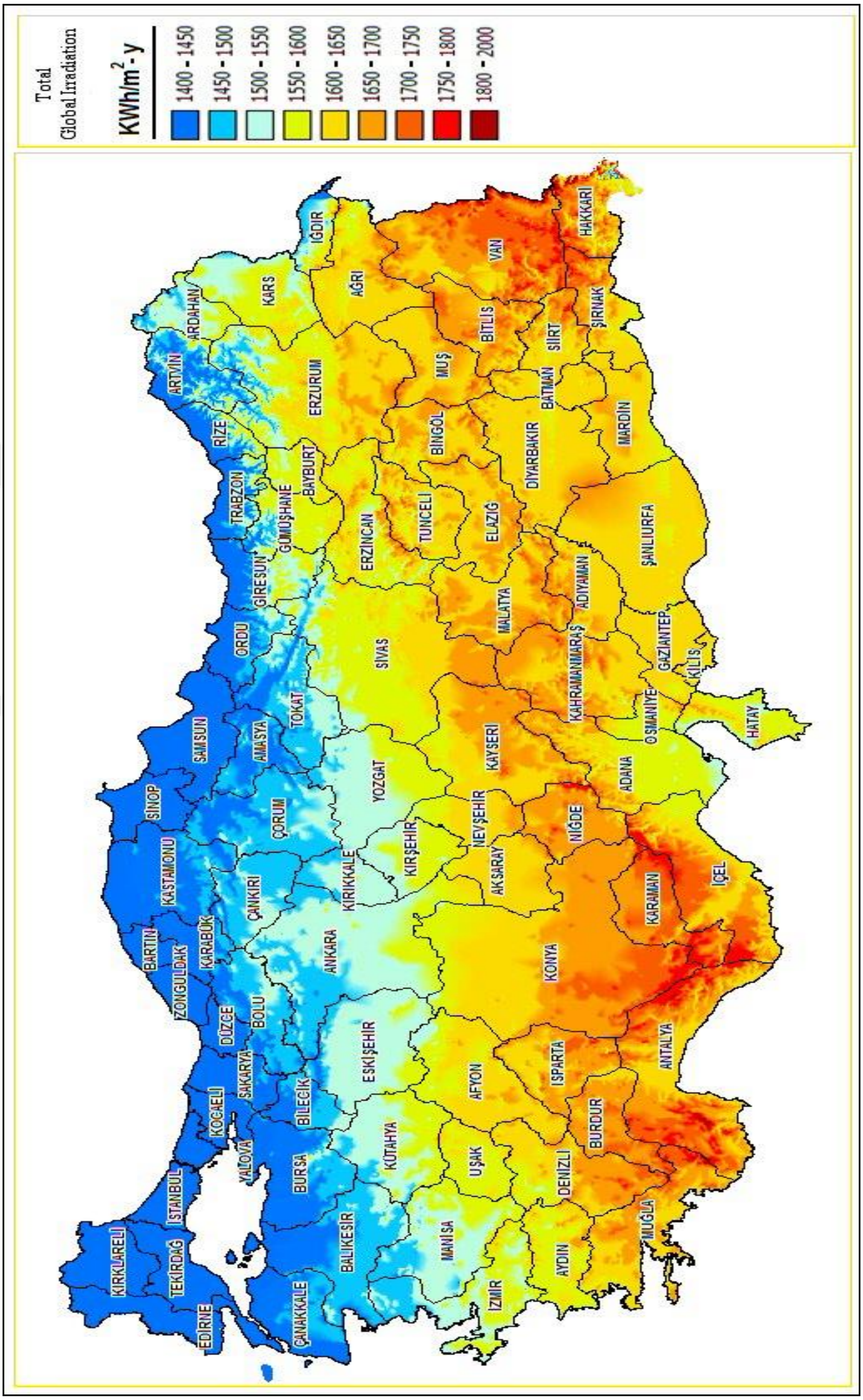
APPENDICES

A.1 Total Global Radiation for Turkey



A.2 Beaufort Scale

Beaufort number	Description	Wind speed		Sea conditions	Land conditions
		kts	km/h		
0	Calm	< 1	< 1	Flat.	Calm. Smoke rises vertically.
1	Light air	1 – 2	1 – 5	Ripples without crests.	Wind motion visible in smoke.
2	Light breeze	3 – 6	6 – 11	Small wavelets. Crests of glassy appearance, not breaking	Wind felt on exposed skin. Leaves rustle.
3	Gentle breeze	7 – 10	12 – 19	Large wavelets. Crests begin to break; scattered whitecaps	Leaves and smaller twigs in constant motion.
4	Moderate breeze	11 – 15	20 – 28	Small waves with breaking crests. Fairly frequent white horses.	Dust and loose paper raised. Small branches begin to move.
5	Fresh breeze	16 – 20	29 – 38	Moderate waves of some length. Many white horses. Small amounts of spray.	Branches of a moderate size move. Small trees begin to sway.
6	Strong breeze	21 – 26	39 – 49	Long waves begin to form. White foam crests are very frequent. Some airborne spray is present.	Large branches in motion. Whistling heard in overhead wires. Umbrella use becomes difficult. Empty plastic garbage cans tip over.
7	High wind, Moderate gale, Near gale	27 – 33	50 – 61	Sea heaps up. Some foam from breaking waves is blown into streaks along wind direction. Moderate amounts of airborne spray.	Whole trees in motion. Effort needed to walk against the wind. Swaying of skyscrapers may be felt, especially by people on upper floors.
8	Gale, Fresh gale	34 – 40	62 – 74	Moderately high waves with breaking crests forming spindrift. Well-marked streaks of foam are blown along wind direction. Considerable airborne spray.	Some twigs broken from trees. Cars veer on road. Progress on foot is seriously impeded.
9	Strong gale	41 – 47	75 – 88	High waves whose crests sometimes roll over. Dense foam is blown along wind direction. Large amounts of airborne spray may begin to reduce visibility.	Some branches break off trees, and some small trees blow over. Construction/temporary signs and barricades blow over. Damage to circus tents and canopies.
10	Storm, Whole gale	48 – 55	89 – 102	Very high waves with overhanging crests. Large patches of foam from wave crests give the sea a white appearance. Considerable tumbling of waves with heavy impact. Large amounts of airborne spray reduce visibility.	Trees are broken off or uprooted, saplings bent and deformed. Poorly attached asphalt shingles and shingles in poor condition peel off roofs.
11	Violent storm	56 – 63	103 – 117	Exceptionally high waves. Very large patches of foam, driven before the wind, cover much of the sea surface. Very large amounts of airborne spray severely reduce visibility.	Widespread vegetation damage. Many roofing surfaces are damaged; asphalt tiles that have curled up and/or fractured due to age may break away completely.
12	Hurricane	≥ 64	≥ 118	Huge waves. Sea is completely white with foam and spray. Air is filled with driving spray, greatly reducing visibility.	Very widespread damage to vegetation. Some windows may break; mobile homes and poorly constructed sheds and barns are damaged. Debris may be hurled about.