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Development of Amphibious Mobile Solar Power Generator with Ultra Water Filtration System for Disaster Relief

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ABSTRACT

During severe flood and natural disaster scenarios, electricity power becomes an essential and critical element to ensure the operation of medical services, equipment and communication systems as the power stations will most likely be shut down. Delivering power source and potable water to disaster areas becomes a major obstacle during severe flooding following the rise of water level causing road transportation becomes inaccessible. Therefore, an amphibian trailer equipped with a hybrid solar photovoltaic (PV) and an ultra-water filtration system is a good solution as it can be deployed or towed to the disaster areas by either a boat or a pickup truck. The amphibian trailer is equipped with a hybrid standalone solar PV system with battery storage and a generator set that can supply approximately 25 kWh of electric power per day. An ultra-water filtration system is also installed on the trailer, and it is powered by the hybrid solar PV system. Aluminium is used to construct the chassis of the trailer to ensure that the trailer is lightweight, strong, durable, and anti-corrosion. The wheeled trailer is integrated with a fiberglass floatable pontoon to allow it to operate on land and water. More importantly, the amphibious trailer can be relocated easily based on the situation and needs. This paper describes comprehensively the design and development process of the solar amphibious trailer.

Keywords: Amphibious, flooding, natural disaster, solar photovoltaic, water filtration

INTRODUCTION

Electricity power cuts in disaster areas in unavoidable especially when natural disasters such as hurricanes and floods take place. The nearby power stations are shut down during floods to avoid any power leakage and electrocution to disaster victims. A devastating disaster will most likely wipe off the power stations at the disaster site. Furthermore, delivering electrical power to disaster sites becomes a major problem especially when roads become inaccessible due to the road being badly damaged or the rise of water levels during a flood. In response to this problem, an off-grid solar PV system can be utilized to provide green and sustainable electrical energy to disaster areas. This is important to ensure necessities such as medical needs can be provided to the victims when facing a disaster.

Apart from supplying electricity, supplying clean potable water is also another major problem when a natural disaster takes place. Generally, flooding disrupts the resources of clean water. In most cases, extreme flooding causes rivers and streams murky as the water is contaminated by suspended solids and sediments. This problem worsens when the flooding prolongs as the number of victims increases which leads to higher demand for clean water. Besides that, prolonged flooding will also disrupt and damage the water treatment facilities, and thus, longer maintenance time is needed to restore and repair the water supply facilities. Furthermore, road damage and high-water level are the main causes of clean water supply disruption as the roads in flooding areas have become inaccessible (See, Nayan, and Rahaman 2017).

The increasing occurrence of disasters throughout the world is a commonly identified indicator of non-sustainable development (Burton, W.Kates, and F.White 1993). There is mounting concern about the impacts of disasters related to climate change. Climate change causes shifts in weather conditions and increases the frequency and severity of extreme disaster events (O'brien et al. 2006). The most severe disaster that is frequently taken place in Malaysia is flooding, which usually occurs during Monsson season. In Malaysia, 9% or 29,720 km^2 of the country is located in flood-prone regions with a total of 4.915 million people affected by floods (D/iya et al. 2014). Furthermore, Malaysia experiences a high amount of rainfall throughout the year ranging between 2000 mm and 3000 mm in a year (Nazri et al. 2018; Ishaka, Ahmada, and Singha 2021).

In December 2014, a massive flood happened in the state of Kelantan, northeast of the Malaysian peninsular. It was recorded as the most disastrous flood in Kelantan. The government estimated around 200,000 people were affected (Baharuddin et al. 2015). Penang and Kedah were also affected by the flood which caused significant damage to residential homes, roads, ports, and other infrastructure facilities (Shafiai et al. 2016).

Between the urbanized infrastructures, the electricity infrastructure is the fundamental facility for the development of each country. With the increase in demand for electricity, the safety and continuous supply of electrical energy have become a problem (Rostam, Sidek, and Basri 2016). During the flood, the electricity supply was cut off due to safety reasons. It has been reported, that during the extreme flood events in Kelantan, a number of the main power stations were shut down (Berita Harian Online 2014). The electricity can be supplied using generators, but the access to fuel supply is quite limited. Furthermore, generators that run on fossil fuels such as gasoline and diesel oil have problems on their own as well (U. S. Department of Energy 1999). Without electricity, the telecommunication system would not be functioning, the medicine that requires controlled temperature storage cannot be preserved, and there will be no power to light up the nights (Young 1995). To sustain life and safety in emergencies, backup power for critical equipment should be available for a minimum of 3 days after a disaster takes place (City 2009). When Hurricane Hugo took place in Puerto Rico and the Southeast United States in 1989, mobile PV generator systems were used to supply electrical power to a community center for six weeks after a storm (Qazi and Qazi 2014). The PV systems were also used to power up Haiti during a disaster that took place in 2010. It was used to provide low-cost and reliable electricity to poor rural areas for schools, community centers, small businesses, and homes. The PV system was also used to power up the lights, run the radio and charge mobile phones (Yago 2007). The PV panels in the trailer charge four large station batteries which the smaller home packs are charged. In Malaysia, there is no mobile application that is available to supply electrical energy and clean water to disaster victims

USE OF RENEWABLE TECHNOLOGIES IN PAST DISASTER RELIEF MISSIONS

In September 2017, Puerto Rico was hit by Hurricane Maria which was labeled to be the worst natural disaster that the region has ever suffered in 85 years, with a record of 3,057 fatalities from the disaster. The emergency responders and relief workers struggled to provide aid due to the electricity cut-off, which was not fully corrected until August 2018. This hindered the relief process and caused millions of victims without necessities. Throughout the 11 months, plenty of renewable energy companies worked to provide electricity to the victims. The best option available was to use portable renewable energy storage systems as they can provide off-grid electrical energy and allows the victims to have access to necessities (Keller 2019). One of the companies that contributed to disaster relief was EnerDynamic Hybrid Technologies, a Canadian company that developed portable renewable energy systems for disaster relief. One of the products of the company is the Power Wagon, a trailer with a solar PV system providing up to 10 kWh of energy and storing 40kWh of battery power. It can act as a portable charger or mobile power station for the lighting system, mobile devices, and medical devices. The company has been providing relief to the Hurricane Maria victims in Puerto Rico since January 2018.

FIGURE 1. 5 kW Power Wagon of EnerDynamic (EnerDynamic Hybrid Technologies 2020)

Another example of the use of renewable technology for disaster relief was when Hurricane Dorian hit the Bahamas in September 2019, the most disastrous storm ever hit the country with a total of 74 fatalities, and over 70,000 were left homeless. In response to the disaster, renewable energy company ReVision Energy worked together with engineers from AMICUS Solar National Co-op and developed and sent emergency relief trailers to provide electrical energy for lighting, medication, cell phones, and other emergency needs (Avila et al. 2020).

FIGURE 2. Emergency solar trailers for disaster relief (Scribner 2019)

The trailers were fitted with six solar panels and eight deep cycle batteries that cater to up to 30 electrical outlets installed on the exterior of the trailers. The users can plug in their devices and appliances that require electrical power including refrigerators and water filters (Scribner 2019). The same emergency solar trailers concept was used to provide electrical power to Puerto Rico. This has sparked more renewable energy companies to venture into manufacturing renewable technologies for disaster relief purposes. In

November 2017, ReVision plans to build 100 units of solar trailers to be sent to Puerto Rico to continue the disaster relief mission (Chow 2017).

A UK-based company Renovagen introduced a new patented technology called Rapid Roll which is a flexible, rollable solar PV as a single sheet of mattress. It is built with strong structural support and electronic cabling for power transmission embedded throughout the system. The major advantage of this technology is that it can provide off-grid electrical power in remote areas as well as serves well for disaster relief purposes. The solar PV is assembled on-site by being rolled out of a trailer and switched on immediately without cable connections required as everything is built in permanently. This technology is becoming favorable as it can deploy as much as 11 kWp of electrical power within 2 minutes (Renovagen 2018).

FIGURE 3. Rapid Roll is being rolled out of a trailer on site (Renovagen 2018)

In light of the recent Covid-19 pandemic, Renovagen worked together with First Aid Africa to accelerate the COVID-19 testing in Zambia by deploying one of Renovagen's portable solar power systems, FAST FOLD. A stable power was to be supplied to Mbereshi Mission Hospital as the hospital needed to be struggling to conduct the COVID-19 test efficiently as the hospital only has 6 hours of power and it was very unreliable. This shows that an off-grid and reliable portable energy system is crucial during emergencies whether it's a global pandemic or natural disasters. FAST FOLD was deployed on the site within minutes and provided 100% self-sustaining power for all of the medical purposes to combat COVID-19 in Zambia (Renovagen 2020). These examples perfectly showed how important it is to utilize mobile and portable renewable energy for emergency and disaster relief purposes.

Important aspects of renewable technology for disaster relief missions:

1. The use of PV systems on trailers must comply with the country's Department of Transport for use on road.
2. The trailer must provide strong support and stability to the PV system for it to be transported and deployed safely.
3. The size of the trailer must be large enough to accommodate the entire PV system. A larger surface area allows more space for solar panels.
4. Requires a short time for it to be deployed and perhaps can start operating without complicated procedure

DESIGN AND DEVELOPMENT OF THE AMPHIBIOUS MOBILE SOLAR PV

The amphibious chassis has floatable pontoon boxes installed in the chassis to allow the trailer to maneuver on the road and water. It is designed to be amphibiously mobile so that it can be deployed or towed to the disaster site by a boat or a pickup truck. This will allow the amphibious trailer to supply/deliver electricity to the victims during disasters in which roads become inaccessible such as flooding. The trailer is also equipped with a hybrid PV system as this will help to generate green and sustainable electric power. The main purpose of the amphibious trailer is to generate clean electrical power and power up the disaster site. This is very useful during a disaster relief mission as electric power is likely to be unavailable during this disastrous situation. During disasters such as severe flooding, electricity becomes an essential and critical element due to the shutdown of power stations. It is important to have an off-grid electrical supply to ensure the operation of medical services, equipment and communication system.

THE CHASSIS

The main body is shaped like a cage, made out of lightweight aluminium material which is fully fabricated locally. The dimension of the body is 5 x 2 x 0.8 m. The body is used to accommodate 40 pieces of pontoon floatable boxes. The dimension of each floatable pontoon box is 500 mm x 500 mm x 400 mm and provides an upwards buoyance force of as much as 350kg/m^2. The floating pontoon box is made from High-Density Polyethylene (HDPE), which is lightweight and has high tensile strength.

FIGURE 4. High-Density Polyethylene (HDPE) Floating Pontoon

The trailer is also fixed with two sets of 13-inch tires. The frontal part of the trailer is equipped with a tow hitch, which enables the trailer to be towed by a pickup truck or a boat. Aluminium mounting frame is built on the main body to secure the PV panels on the main body. The mounting frame is designed in such a way that it can rotate as much as

45°, which allows the PV panels to be ‘opened’ and ‘closed’ positions. When the panels are required to be fully operated, the PV mounting frame will rotate to 0°, which makes the PV panels horizontal, and this maximizes the harnessing of incoming solar radiation. When it is not required to be fully operated or in an idle state, the PV mounting frame will be tilted to 45° from the horizontal position. The rear section of the trailer can be mounted with an outboard motor as a secondary method for the trailer to maneuver on the water.

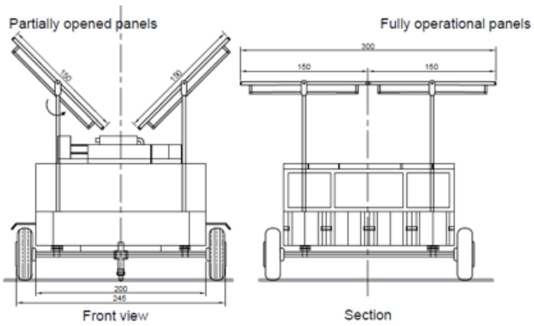

FIGURE 5. (a) partially opened panels (b) fully operational panels (dimensions in centimeter)

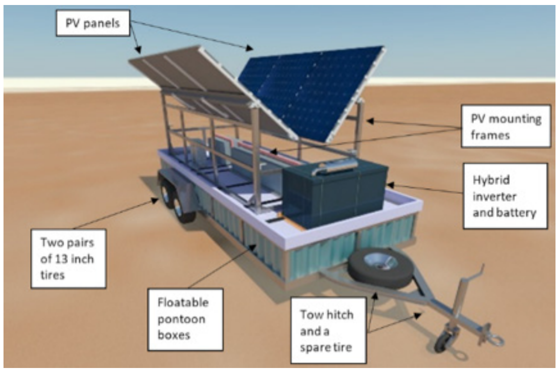

FIGURE 6. Components of the amphibious trailer

FIGURE 7. The amphibious trailer being towed on the road

FIGURE 8. The amphibious trailer floating on the water

TABLE 1. Summary of the trailer’s chassis component

Component	Functionality
Aluminium Chassis	The structure of the main body. The aluminium material ensures that it is lightweight, anti-corrosion, durable and strong.
Two pairs of 13-inch tires, plus one for emergency	Allows the trailer to maneuver on land.
PV mounting structure	Allows the remote-controlled operable solar PV mounting frame to open and close. During the transportation of the trailer, the solar PV mounting is in closed form. Once the trailer has reached the site, the solar PV mounting is opened to allow it to harness the solar energy.
Floatable pontoon boxes	Allows the trailer to float and maneuver on the water. The design of the chassis allows the floatable pontoon boxes to be replaced in case it is damaged as it is installed in a ‘cage-like’ structure.
Tow hitch	Allows the trailer to be towed by either a boat or four-wheeled drive (4x4) vehicle.
Outboard motor	Allows the trailer to maneuver on the water by itself without the need for it to be towed by a boat.

DESIGN OF THE HYBRID PV SYSTEM

The hybrid PV system comprises 12 sets of solar panels connected in series which was customized for the trailer. Each solar panel has an expected output of 240 Wp. Hence the estimated total electrical output that can be obtained by the entire solar panel system is 2.88 kW. The hybrid PV system is installed with a hybrid inverter, batteries, and generator as a standby.

MODULAR SYSTEM

The Hybrid Solar Power System is designed as a modular system whereby it can be scaled up for a bigger power supply when it is required. The modular system allows two or more units of the solar amphibious trailer to be interconnected with each other to scale up the power supply. Figure 9 shows the schematic diagram of the modular system.

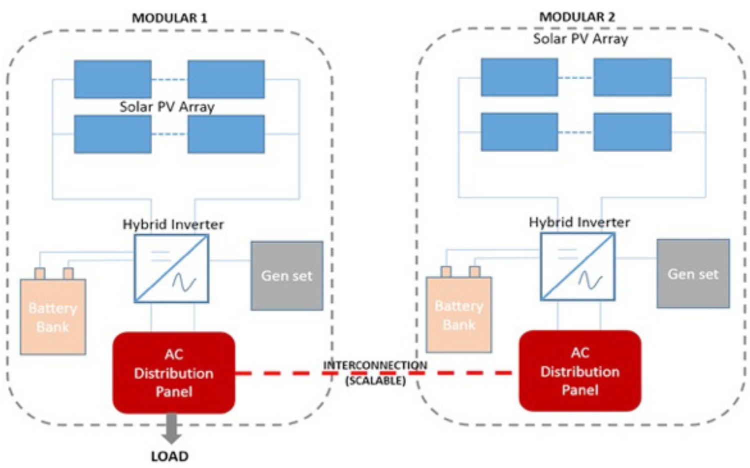

FIGURE 9. Schematic diagram of a modular concept hybrid PV system and the interconnection for a scalable power supply

TABLE 2. Summary of the hybrid PV system components

Component	Functionality
Solar Panels	Collect and supply green and sustainable energy to the victims or disaster sites. Expected output per panel 240 Wp
Hybrid inverter (inverter + charge controller)	To convert the DC to AC and vice versa, and also to charge the battery.
Battery	To store the electrical power.
Generator set	Act as a standby power generator. To provide an uninterrupted power supply in case of low solar radiation during rainy days. The expected output is 7 kW.

SOLAR PANELS

The type of solar panel used for this project is Panasonic VBHN240SJ25 photovoltaic module. This model uses HIT solar cell technology which is made of a thin monocrystalline silicon wafer surrounded by ultra-thin amorphous silicon layers. HIT solar cells are high-efficiency solar cells with a higher tolerance to high ambient temperature and can produce high energy production in hot and humid climate conditions like Malaysia.

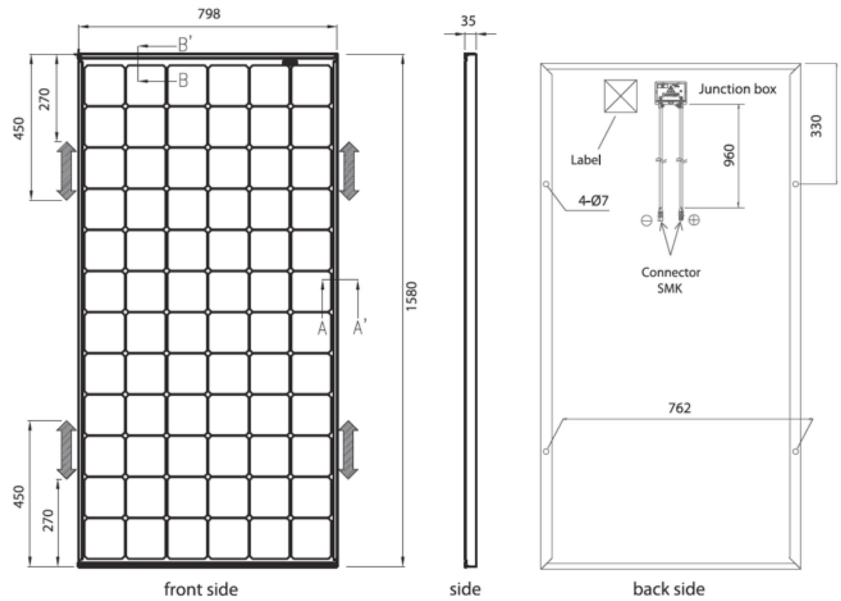

FIGURE 10. Engineering drawing of Panasonic VBHN240SJ25 solar panel

TABLE 3. Mechanical and technical specification of Panasonic VBHN240SJ25 (Panasonic 2013)

Specification	Unit	Value
Cell type and thickness		HIT cells / 5 inch
No of cells		72 (6 x 12)
Dimension	mm	1580 x 798 x 35
Weight	kg	15
Front type		AR coated tempered glass
Tolerance	%	+10/-5
The maximum value of Pmax	W	240
Open circuit voltage (Voc)	V	52.4
Short circuit current (Isc)	A	5.85
The voltage at Pmax (Vmp)	V	43.6
Current at Pmax (Imp)	A	5.51
Module Efficiency	%	19.4

BATTERY

The model of the battery is LDC12-150-GC12 by Leoch Battery as shown in Figure 11 below. Each of the battery voltage is 12V, 150Ah, and a total of 8 batteries are used which equals to 600Ah capacity and supply voltage of 24V for the entire system to supply sufficient current. This type of battery was chosen due to the following features and benefits:

1. Uses deep cycle AGM technology which is a green solution
2. Over 99.99% virgin lead for grid plate and active material
3. Heavy duty
4. Maintenance free
5. Longer shelf life

FIGURE 11. LDC12-150-GC12 by Leoch Battery

TABLE 4. Electrical and physical specification of LDC12-150-GC12 by Leoch Battery (Leoch Battery 2018)

Specification	Unit	Value
Voltage	V	12
Dimension	mm	180 x 274 x 274
Weight	kg	42.2
Case material		ABS

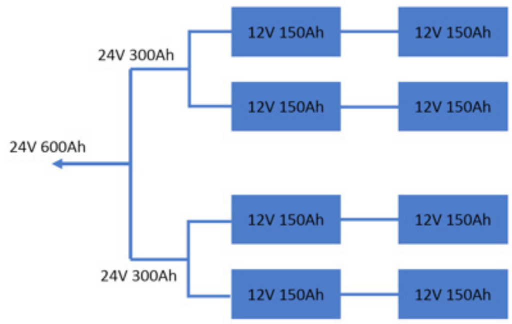

FIGURE 12. Battery layout diagram

HYBRID INVERTER

The model of the hybrid inverter used in this project is PV1800 by MUST. It is a hybrid and multifunctional inverter which combines the functions of an inverter, MPPT solar charger, and battery charger which is capable to supply uninterruptable power support. The maximum PV array open circuit voltage can reach up to 450V and MPP voltage is between 150Vac and 450Vac, and this allows maximum use of the solar energy.

FIGURE 13. Hybrid inverter PV1800 by MUST (MUST, n.d.)

TABLE 5. Specifications of the hybrid inverter

Specification	Value
Nominal system voltage	24 VDC
Rated power	3000VA / 3000W
Surge power	6 KVA
Waveform	Pure sine wave
AC Voltage regulation	230AC ±5%
Inverter efficiency	90% ~ 93%

Generator set

A generator is required in a stand-alone system as a backup energy source in case the solar panels could not harness sufficient energy due to external factors such as weather. In this project, an open frame type gasoline generator model SEB7000HSa by Daishin Industries Ltd. was chosen as shown in Figure 14 below. The technical specification is detailed in Table 6.

FIGURE 14. SEB7000 HSa generator by Daishin Industries Ltd

TABLE 6. Technical specification of SEB7000 HSa generator by Daishin Industries Ltd (Daishin Industries Ltd. 2009)

Specification	Unit	Value
AC Max output (50 Hz)	kVa	5.5
AC Max output (60 Hz)	kVa	7.2
AC Rated output (50 Hz)	kVa	5
AC Rated output (60 Hz)	kVa	6.1
Rated voltage (50 Hz)	V	220
Rated voltage (60 Hz)	V	110/220
DC output		12V/8.3A
Dimension	mm	682 x 534 x 509
Weight	kg	85

CHARGING POINTS

The trailer also comes with charging points powered by solar PV which can be used for various purposes during the rescue mission such as powering up the electrical needs at the site.

FIGURE 15. Charging points on the trailer

ULTRA-WATER FILTRATION SYSTEM

The amphibious trailer is also equipped with an ultra-water filtration system powered by the solar PV system, which was customized specifically for this trailer. The purpose of the water filtration system is to filter, store and deliver clean water to the disaster relief site. The ultra-water filtration system is powered by the PV system and can filter flood water into clean and potable water. Furthermore, the tanks can contain up to 300 L of filtered and potable water.

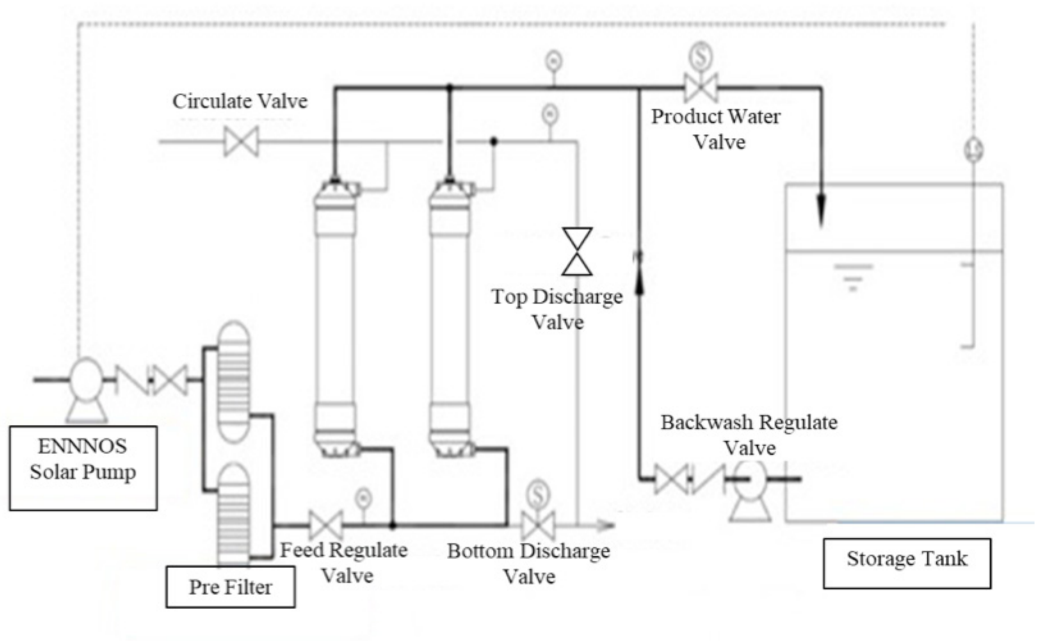

FIGURE 16. Schematic diagram of the ultra-water filtration system

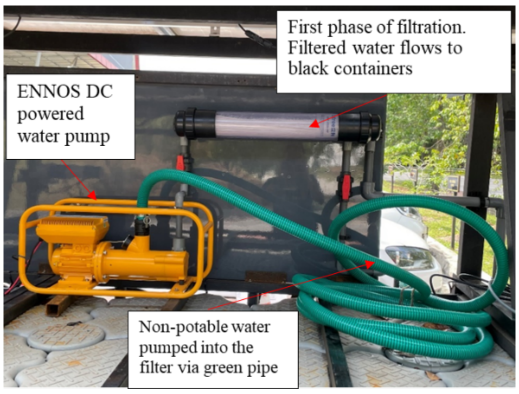

FIGURE 17. Ultra-water filtration system from a non-potable water source

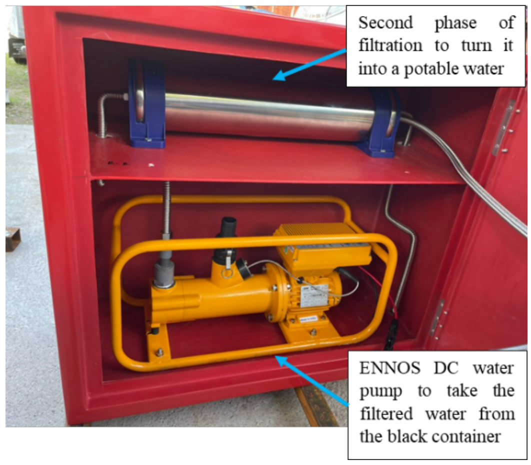

FIGURE 19. Second phase of filtration - water taken from the black containers

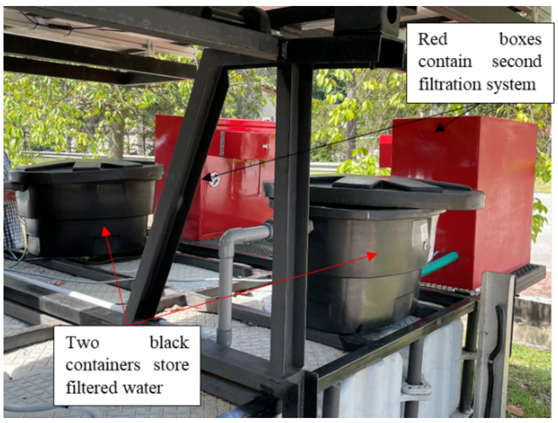

FIGURE 18. Second phase of filtration - water taken from the black containers

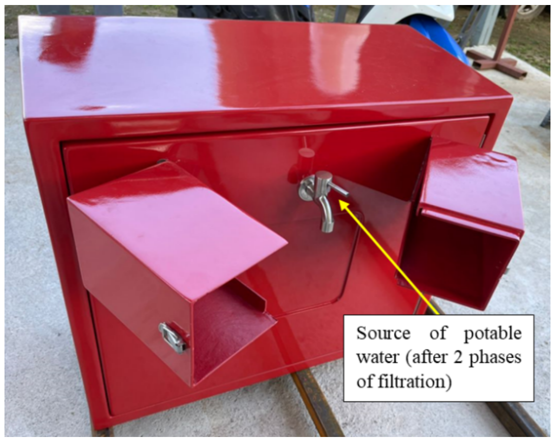

FIGURE 20. Source of potable water after two phases of filtration

The amphibious trailer is equipped with a solar power monitoring system called Solar Must. The monitoring allows users to monitor real-time data on the amount of electricity produced by the solar panels and the amount of electricity used via mobile phones application or internet portals. Besides that, the monitoring system also tracks historical data such as the monthly and yearly electricity production by the solar panels and the consumption by the users. Some of the daily and monthly electricity production can be seen in Figure 21 and Figure 22 below.

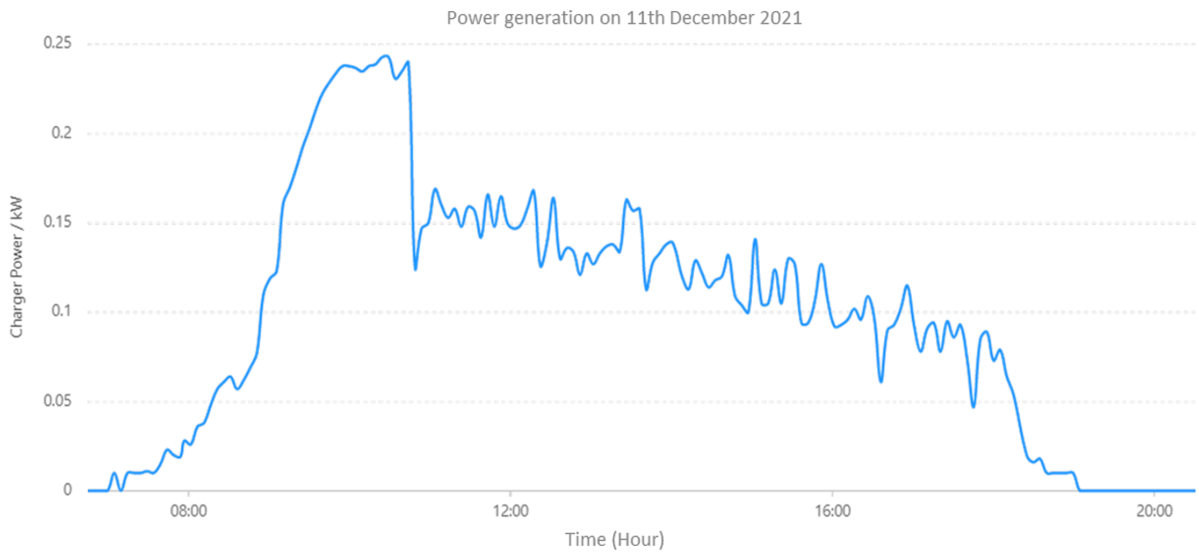

FIGURE 21. Power generation on 11th December 2021

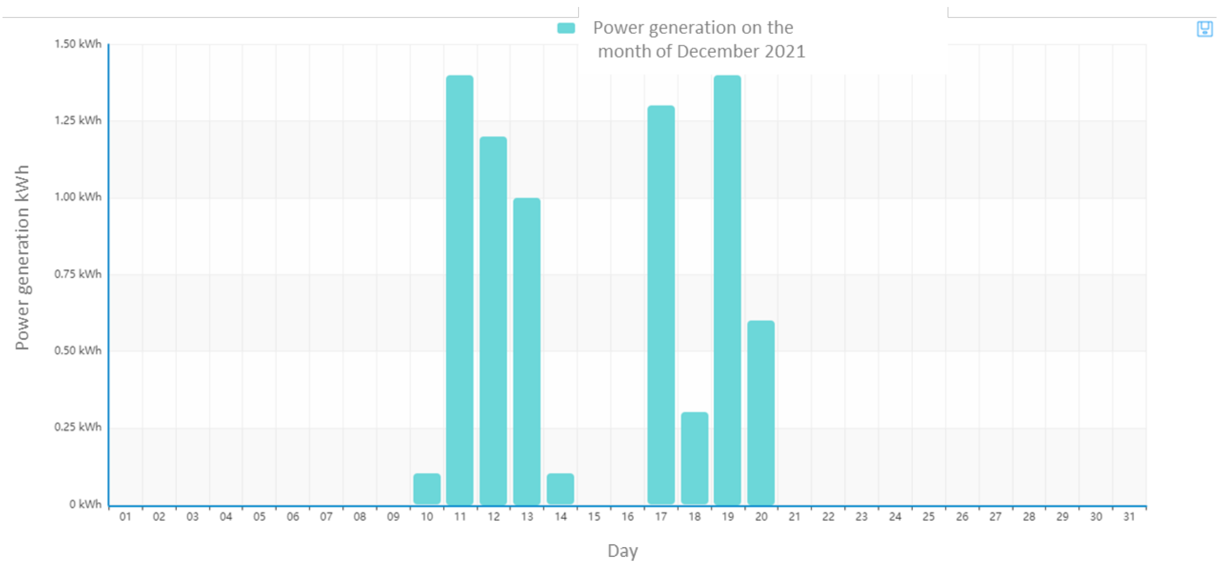

FIGURE 22. Power generation in December 2021

SOLAR PV SYSTEM SIMULATION USING PVsyst PHOTOVOLTAIC SOFTWARE

PVsyst is software designed for architects, engineers, and researchers to perform simulation and estimation of PV production in an early stage of PV installation. The users get to set the meteorological data, choice of solar panels, inverters, possible shadings, geometrical layout, electrical connection, user needs, and economic scenarios. Some of the outcomes from the simulation are the available energy, used energy, excess energy, performance ratio, solar fraction, yearly consumption, and energy losses.

INPUT PARAMETERS

The input parameters are to replicate the actual situation of the amphibious trailer during a disaster rescue mission in the PVsyst software. Table 7 below details the input parameters for the geographical site, the PV array, battery, and backup generator characteristics as well as the household user needs.

TABLE 7. The input parameters in PVsyst

Geographical site	
Location	Kuala Lumpur, Malaysia
	Latitude 3.1°N and Longitude 101.5°E
PV array characteristics	
Collector plane orientation	Tilt 5°
PV module	HIT
PV model	VBHN240SE10
Manufacturer	Panasonic
Total number of PV modules	12 (In series)
Total module area	15.1 m²
Thermal loss factor	2.0 W/m²K
System type	Stand alone with a backup generator system
Battery	
Model	Leoch Battery
Manufacturer	LEOCH International Technology Limited
Voltage	24 V
Nominal capacity	600 Ah
Number of units	2 in series, 4 in parallel
Backup generator	
Model	3 kW
Nominal Power	5.8 kW
Household user needs	
Daily household consumer	Constant over the year
Average usage	8.9 kWh/day

Table 8 below details the energy usage by the appliances of a household. The appliances are assumed to be the basic needs for a household during disaster relief. Figure 23 shows the estimated fraction of daily energy usage where the highest fraction of daily energy is used between 6 pm and 9 pm followed by 11 am to 8 pm, and 9 pm to midnight. The morning hour is estimated to use the least amount of energy.

TABLE 8. The appliance used in a household

Appliance	Number	Power	Use	Energy
LED long	8	14 W/lamp	6 h/day	672 Wh/day
LED short	1	7 W/app	6 h/day	42 Wh/day
Ceiling fan	3	80 W/app	10 h/day	2400 Wh/day
Fridge	1	240 W/app	24 h/day	5760 Wh/day
Total daily energy				8874 Wh/day

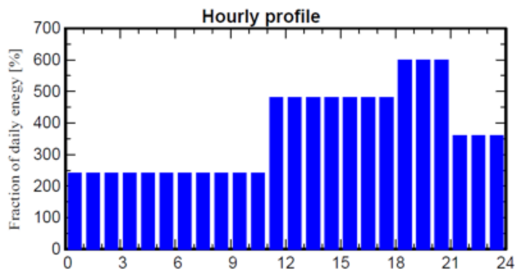

FIGURE 23. The fraction of daily energy hourly profile

SIMULATION MAIN RESULTS

This section details the results obtained by the PVsyst simulation. From the results in Table 8 below, it can be seen that the available energy that the PV system can provide is 3840 kWh/year, which is equal to 10520 Wh/day. This shows that the PV system installed on the amphibious trailer is sufficient to provide electrical energy for basic needs in a household. On top of that, there is backup electrical energy from the generator that could supply 534.2 Wh/day of energy. Hence, during the worst-case scenario i.e., rainy days with no sunshine, the amphibious trailer is still able to provide sufficient electrical energy

TABLE 9. Results obtained by the PVsyst simulation

System Production	Value
Available energy	3840 kWh/year
Specific production	1334 kWh/KWp/year
Used energy	3237 kWh/year
Excess energy (unused)	691 kWh/year
Performance ratio	64%
Solar fraction	93.90%
Back up energy from the gen set	195 kWh/year
Fuel consumption	97/year

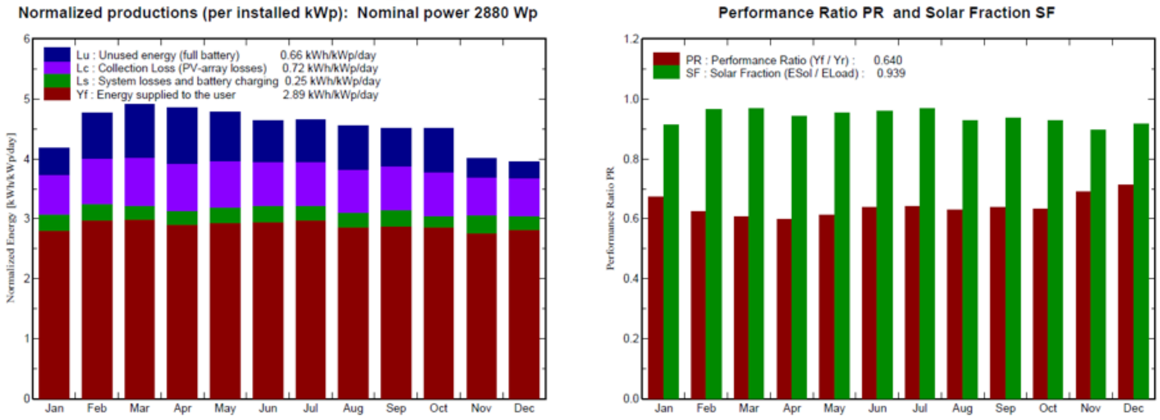

FIGURE 24. Normalized production (b) Performance ratio and solar fraction

CONCLUSION

An unavoidable natural disaster such as flooding has been a reoccurring unfortunate event that takes place in Malaysia, especially during monsoon season. Past events have shown that delivering electrical energy and clean potable water are the major problems during a natural disaster. The literature review has shown that off-grid electrical energy via solar PV is one of the effective methods to supply electrical energy to the disaster site. This is important to ensure that basic needs such as lights and fridges can be functioning when a relief mission takes place. This paper details the design, development, and simulation of the electrical energy production of the amphibious trailer. Preliminary results via PVsyst simulation showed that the PV system can produce 10520 Wh/day of electrical energy, which is sufficient to power up a household's basic electricity needs such as lights and fridges. In the event of insufficient sunlight and electricity production by the PV system, a backup generator set can produce up to 534.2 Wh/day of electrical energy.

Currently, the amphibious mobile solar power generator with an ultra-water filtration system has yet to be deployed to a disaster site. However, it is now on standby mode and ready to be deployed whenever it is necessary

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DECLARATION OF COMPETING INTEREST

None.

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