Development and Evaluation of Solar Powered Catamaran for Sustainable Tourism in Southeast of the Gulf of Thailand

Gunn Panprayun*‡, Suwan Pitaksintorn**

* Faculty of Environment and Resource Studies, Mahidol University, Nakhon Pathom 73170, Thailand

** Department of National Parks, Wildlife, and Plant Conservation,

Ministry of National Resources and Environment, Bangkok 10900, Thailand

(gunn.pan@mahidol.edu, suwanpita@hotmail.com)

‡ Corresponding Author; Gunn Panprayun, 999 Mahidol University, Nakhon Pathom, Thailand, 73170,

Tel: +66 2 441 5000, Fax: +66 2 441 9509, gunn.pan@mahidol.edu

Received: 03.09.2017 Accepted:12.12.2017

Abstract- The aim of this research is to develop and evaluate the solar powered catamaran for a response to low carbon destination and sustainable tourism for Ko Mak Island, Thailand. The development process includes ship design, PV system design and shipbuilding. Thus, it has designed that are the length with 7.5 Meters and the width with 3.5 meters. Similarly, it has installed 1.8 kWp photovoltaic generation system and 2 units of 3-hp induction motors. The performance evaluations have been accomplished in the open water in the designated route. The result showed that the uppermost speed of the catamaran was 9.18 km/h at 4,500 W. At normal cruise speed of 2,000 W, the catamaran speed was 7.77 km/h and maximum travel distance without charging at depth of discharge equally to 0.6 is 41.96 km. Therefore, the catamaran cruise distance would cover any common travel route of Ko Mak Island. Furthermore, the 19-km extended travel route has been guided for the boat cruise and monitoring. The cruise has been performed in calm weather condition, which insolation of the cruise was 27.18 kWh. The PV system could generate electricity equally to 4.1 kWh or with efficiency of 15.08 percent. However the total consumption was 5.7 kWh. The average cruise speed was 6.26 km/h and the average motors consumption was 1,889.37 W. Finally it turned out that the boat has good maneuver response and good throttle response, passengers can walk to several parts for doing activities conveniently.

Keywords solar powered, solar boat, photovoltaic boat, electric boat.

1. Introduction

Many marine coastal areas around the world are facing the growth of tourism pressure, especially cruising along coral reef areas. Almost of boats related in the seaside tourism are fuel and oil based vehicles, which internal combustion engine is main compartment. These boats cause much oil contamination into the sea. Apart from the oil strain and soot affecting to the coral reef in the direct way, it makes the sound, vibration, smoke to annoy the tourists as well as releasing carbon to the atmosphere. These released carbon is one of the reasons causes the global warming [1]. Moreover, boat noise is an important source of marine pollution that can mask biotic sounds, disrupting the successful transmission between caller and receiver, and can cause physical, physiological and behavioral changes in some marine species [2]. Thus, the using of EV boat replacing for the internal combustion boat is another friendly opportunity to the environments for applying the electric motor work with energy effectiveness in most ways with 85.5-96.2 percentage [3]. Consequently, there are several electric motors in tourist destination areas of naturalistic interest, especially in the lakes which cause to the zero exhaust while, the sound and the vibration as the lower level than in the internal combustion engine [4, 5].

In addition, the environmental problem related to tourism in previous paragraph occurs in Ko Mak, which is an island located in Trat province, Thailand. Ko Mak is well known as

its clear water, white sand beach, beautiful coral reef, and plentiful of marine life, even rare species such as dugongs are encountered by villagers. On the other hand, there is a barrier to apply EV boat to the area since electricity on the island is limited by diesel engine generation. So, solar powered generation boat is proposed. Likewise, the performance of a solar powered boat in marine water for tourism is a question. So, this paper wants to represent solar powered boat development for Ko Mak tourism and evaluation of its performance in the open water.

2. Study Area

Ko Mak island was selected as the study area. Moreover, is the large island located between the Ko Chang Island and the Ko Kood Island with the distances from the coast approximately 38 km. It has the accommodations for the tourists as one of all large-scale islands in Trat province following by Ko Chang Island and Ko Kood Island. Besides, its shape looks like the four point stars, and most area is the plain with coconut garden. Fortunately, the natural condition is still quite abundant with beautiful beach line, peaceful atmosphere and simple and friendly lifestyle of people in the islands including of not far away of the bend of the bay and the streets on the island around 27 km. As the result, the tourists could travel conveniently. Additionally, the tourist season begins from October to May. The study route is from Ko Mak to Ko Kradat, the most popular tourism route. The map of Ko Mak is shown as the figure 1.

Fig. 1. Ko Mak map

3. Ship Development

3.1 Ship design

The modern concepts in ship design which based on efficiency and economic [6] has been selected as a major principle for the ship development process. The first step of the ship design spiral is to clarify mission requirements, which have been collected from the previous study [7]. Therefore the previous study based on tourists and entrepreneur expectations, which could be concluded as following: tourist expectations 1) privacy cruise for 4-7 persons without exceeding to 10 persons 2) environmental friendly atmosphere 3) safety for cruise, especially for children fall off 4) speed was insignificant for western travelers; entrepreneur expectations 1) charter boat fits for 6-10 persons 2) area for activities includes sun bathing, fishing, diving deck 3) Latest ship design with modern style 4) Recommended speed was about 10 km/h 5) a single trip should finished in 30-45 minutes 6) safety for cruise and passengers includes good drainage, non-slip surface, curved decoration 7) budget for a recent boat should be less than 400,000 Baht or 12 thousands USD (33.33 Baht per 1 USD) 8) easy to maintain for local mechanics.

According to the expectation from the tourists and the entrepreneur opinions as the above information, this project has made a conclusion that the ship type should be a catamaran because it has the specialty with two bilges to be assembled in the parallel way. Then, in overall the catamaran has much wideness with good stabilization not the same as the ship with only one bilge. Thus, it is fitted in the tourists who satisfied with the safe ship. Similarly, the installing of heavy and large solar cell on the roof of catamaran and the slender bilge have the good advantages with the non-resistance of water and the strong effectiveness on using of drive power. In addition, it has designed for the driving unit by placing the motors at the center of the ship. Besides, the power will be sent through the driveshaft and the propellers at the tail of the catamaran in the similar form of the long tail boat. However, it has the good advantage with the easy maintenance managed by the local mechanics. On the other hand, it has the disadvantages with the lower power transmission basing on the increased angle of driveshaft. The ship design point out the main compartments and their bilges in cross section are shown in the figure 2.

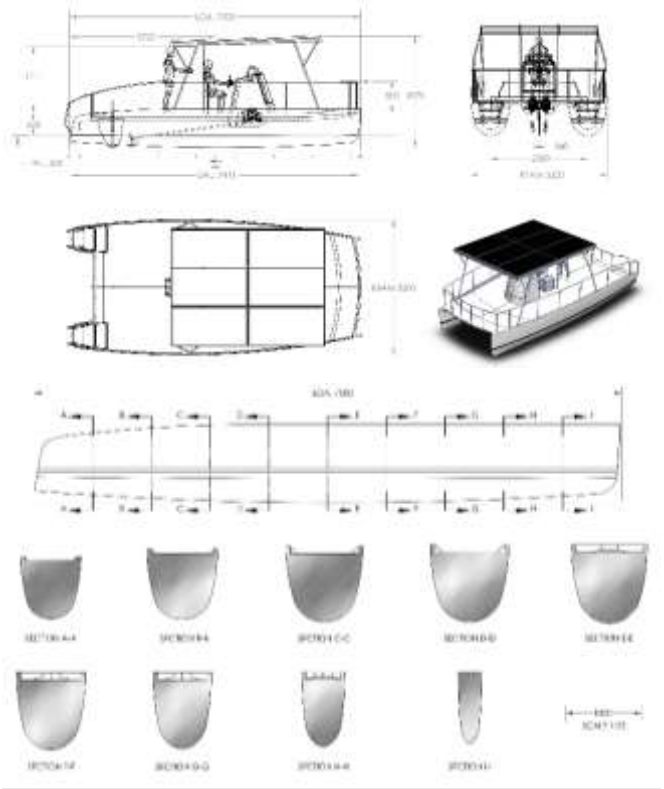

Fig. 2. Ship design and cross section

The ship design has been simulated at speed of -3 m/s. The result shows no severed drag as the show in the figure 3. While the thrust required for cruising speed of 10 km/h is 0.76 kN which equal to 2.15 kW. However, the project considered to double motor power to 4.3 kW due to driveshaft angle loses compensation. So, double 3-hp motors which equal to 4,476 W have been selected.

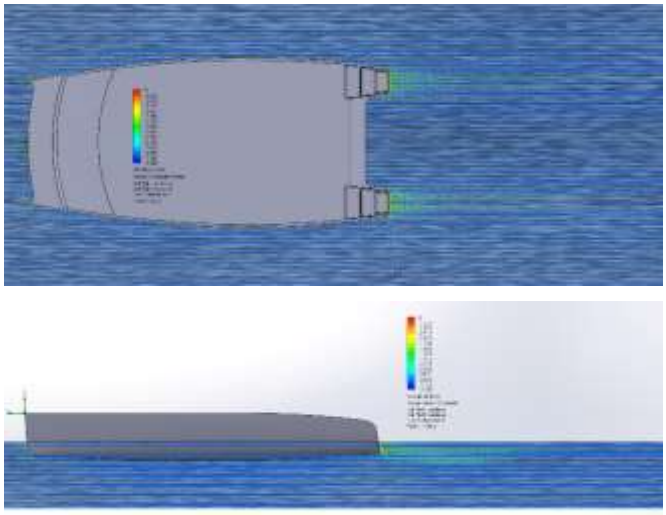

Fig. 3. Ship simulation with current speeds of -3 m/s

3.2 Photovoltaic system

Since 4.3 kW is load demand for desired cruising speed and cruising length is 2 hours, so the total energy require for a single trip is 8.6 kWh. The battery capacity is equal to energy demand divide by battery voltage, depth of discharge, and battery charging efficiency, which is 48 V, 0.6, and 0.9 in the order. So, the required capacity of the ship is 331.79 Ah. In this case, 125 Ah, 12 V deep cycle batteries is selected and apply twelve batteries by connect to four serial circuits and three series of parallel circuits. The installed capacity is up to 375 Ah. Thus, they have been installed at the bilge with the waterproof cover on the battery storage including of the vents to protect from the contamination of gas inside the bilge.

For PV design, the area irradiation from NASA Surface Meteorology and Solar Energy data set at the latitude position of 11.820 N and the longitude position of 102.484 E has been considered. It was found that since October to May it is in the high season of traveling with having a calm wave as the averages of solar irradiance similarly to 5.519 kWh/m^2.d, it should specify for the efficiency of polycrystalline panel with equally to 0.163. While, typical polycrystalline module efficiency ranged from 15.3 to 16.51 [8], battery efficiency of 0.9, and invertor efficiency of 0.95. Thus, it has represented that the effectiveness of system efficiency is likewise with 0.1296. So, PV installing required area is 11.8 m^2 or equal to 6 panels of the 72-cell type panel. Then, it has the advantage with installing of solar cell replacing of the roof that is to be consisted of the great vents to take the heat from the panels to the environment with the sea breeze. It should be noted that the maximum available area for PV panel is 18 square meters, but trade off 6 square meters for sun deck. The PV generation system is shown as the figure 4.

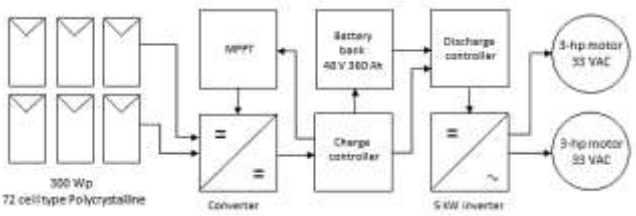

Fig. 4. Single line diagram of photovoltaic generation system

3.3 Shipbuilding

In this case, has been built at Navalian Shipyard, Pattaya, Thailand. The ship hull is made of fiberglass, while the support structures are made of stainless steel. The control unit includes ship's wheel, compass, electrical control switches, and is installed in the motors room as shown in the figure 5 and figure 6. The ship has been named Sang Suwan.

Fig. 5. Ship overview

Fig. 6. Ship control unit

Taking into thoughtfulness the budget of the ship, it has the higher costs than the expectation of the entrepreneurs due to the lacking of the fiberglass molding of the ship hull. So, it must have the higher level of the expenditures than usual. Then, in the future it can reduce times and the expenditures in this part for 10-20 percent from using a molding. The expenditure is shown as the table 1. It should be noted that a BLDC motor is more capable for electric vehicle comparing to an AC induction motor due to compactness, cooling, and energy consumption. Typically, the BLDC motor has a few

percentage point of efficiency higher than the AC induction motor [9, 10]. However, in this study, the AC induction drive has been selected considering with low cost, simplicity, and familiarity to users.

Table 1. Ship building expenditure

Equipment	Unit	Cost THB (USD)
1. Hull	7.5 × 3.5 Meters	230,000 (6,900)
2. Electric Motor with Controller	3-HP Motor 2 units	60,000 (1,800)
3. Transmission unit	1 unit	20,000 (600)
4. Photovoltaic Panels	300 Wp 6 panels	60,000 (1,800)
5. Battery	12V 125 Ah 12 units	72,000 (2,160)
6. Invertor	5 Kilowatts	50,000 (1,500)
7. Other Equipment		20,000 (600)
Total		512,000 (15,360)

4. Ship Evaluation

4.1 Open water performance test

Throughout during the cruise, the boat has been tested to find the relationship between power and speed. Thus, set the specified motor power at 500, 1,000, 1,500, 2,000, 2,500, 3,000, 3,500, 4,000, and 4,500 W then speeds were measured using a GPS instrument and retrieved data from the charge controller/inverter unit. The data set is shown in the figure 7.

Fig. 7. Charge controller and inverter unit

In addition, the cruise testing was performed in Laemngob Cape, which located in the latitude positions of 12.177840 N and 102.385357 E. The ship cruised for each specified power for 1,000 meters in the return route from Sapanphla Chalermphon Pier to Laemngob Pier. The route is shown in the figure 8.

Fig. 8. Cruise testing area

Therefore, according to the weather during the test from Thai Marine Meteorological Center, it was found that there is the North East wind speed with 13-15 knots and high wave with 0.3 - 0.6 meters conforming to the real test condition with three passengers and the average weight of 80 kg. Besides, according to the test result, it was found that the Catamaran Solar cell has the most speed at 9.18 km/h with 4,500 W. However, it was found that the effectiveness to use the energy is in reducing way with the increasing with the speed as the result is shown in the figure 9 as the performance curves of the boat.

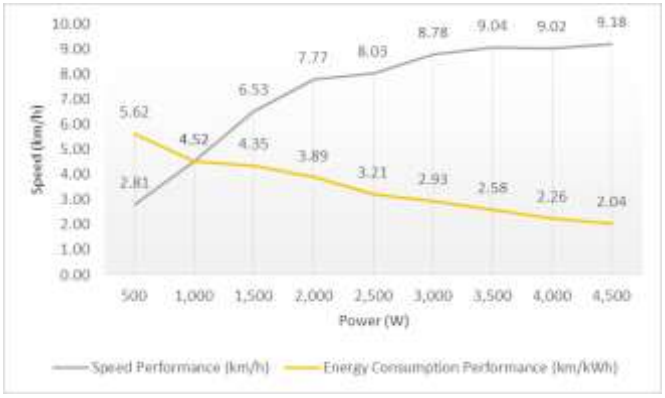

Fig. 9. Performance curves

Then, if it has considered about the capacity of the designed battery, it will see that the battery can discharge the power up to 10.8 kWh at depth of discharge equally to 0.6. Similarly, if it has setup for the motor power with 2,000 W, it will assist to use the solar powered catamaran with 5.4 hours as well as traveling with the distances of 41.96 km. Thus, it can make the table summary for selecting the suitable speed with the tourism routes as the designing with these ways:

Table 2. Ship performance for tourism route planning

Power (W)	Averages of Speed (km/h)	Cruise Length)hour(	Max. Distance (km)
500	2.81	21.60	60.70
1,000	4.52	10.80	48.82
1,500	6.53	7.20	47.02
2,000	7.77	5.40	41.96
2,500	8.03	4.32	34.69
3,000	8.78	3.60	31.61
3,500	9.04	3.09	27.89
4,000	9.02	2.70	24.35
4,500	9.18	2.40	22.03

4.2 Cruise performance

In this case, Ko Kradat is selected as a destination since it is the most popular destination for traveling from Ko Mak. The solar powered catamaran has sailed from Ao Nid Bay to Ko Kradat, around Ko Kradat, and going back to Ao Nid Pier with whole distances of 19.188 km by classifying into 3 parts: 1) from Ao Nid Bay Pier to the South Cape of Ko Kradat (green line) with total distances of 4.897 km 2) the route around Ko Kradat (yellow line) with total distances of 9.743 km. Moreover, 3) the distances for the Southern of the Cape in Ko Kradat back to Ao Nid Bay Pier (red dashed line) with a total of 4.548 km. The cruising is shown in the figure 10. During the time of cruise, solar insolation, solar output, motor input, global position, and speed has been recorded. By the way, the part around Ko Kradat is an extended distance. The ordinary route for tourism is from Ko Mak to Ko Kradat pier, which located in the south Cape of the island.

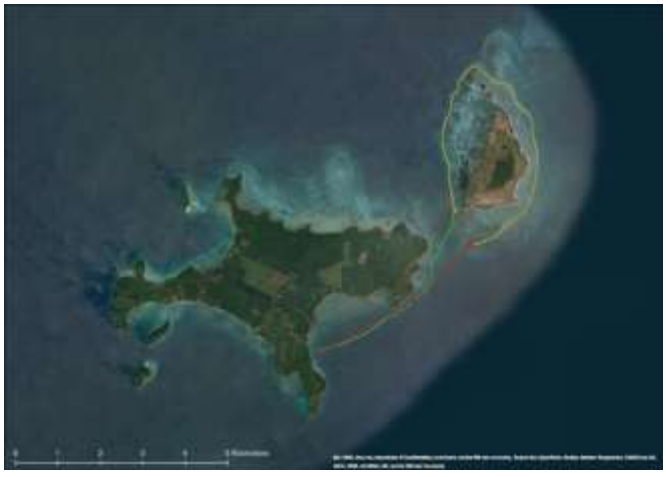

Fig. 10. Cruising route

Therefore, according to the weather condition during the test of Marine Meteorological Center in Thailand it was found that there is the North East wind speed approximately for 7-9 knots and the high wave less than 0.3 Meters conforming to the real test condition with three passengers and the average weight of 80 kg. Similarly, it can charge with full battery that has the voltages of 51 V from sailing in the designated route. Additionally, the first period of time to use the Catamaran Solar Cell is at Ao Nid Pier to the southern Cape of Ko Kradat island between 0.10 - 0.39 p.m. while the second period of time to travel around Ko Kradat and the third period of time to go out from Ko Kradat back to Ao Nid Pier begin from 0.40 - 1.19 p.m. and 1.20 - 3.10 p.m., respectively. On the same way, during the trip it was found that the catamaran has the good balancing with the subtle design to allow for the passengers to walk around and doing activities conveniently. What's more, in the common case it has shown of no problem about the winds and the waves except for the cruising against the strong wind will greatly reduce the speed. Besides, the catamaran has a good performance for cruising against or along the wave and no severe drag as simulation and as the figure 11. However, the weakness of the catamaran boat is when the wave came against besides hulls, the boat rolls twice due to double bilge design.

Fig. 11. Low water drag at boat tail

Then, the average insolation during the test is equally to 750.75 W/m^2. Thus, if it has calculated with the installed area of 12 square meters, it will gain the insolation values in the same way with 27.18 kWh as the representation of the figure 12 with other parameters.

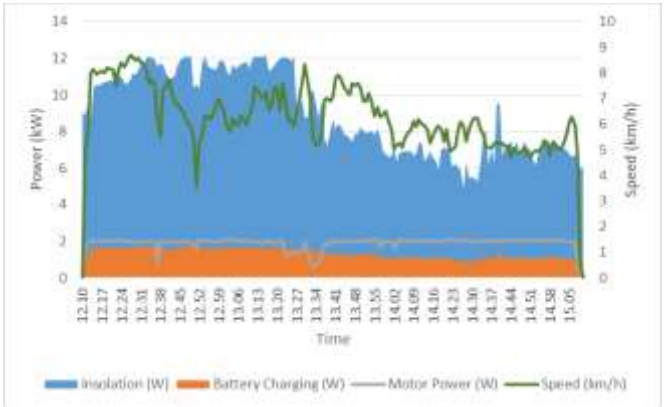

Fig. 12. Cruising summary

According to the analyzing of data, it was found that the solar energy input to the PV panels is likewise to 27.18 kWh.

Then, the system can transform the solar energy to battery with equally to 4.1 kWh or 15.08 percent. Similarly, along the testing cruise the energy has been consumed by motors with equally to 5.7 kWh with the motor power in mean of 1,889.37 W, and with average speed for 6.26 km/h. However, apart from the periods of time to go inside and outside of the pier as well as the periods of time to use the catamaran forced through the underwater rocks, this ship can make the higher speed. Thus, in this subject it should make the realization in the special way with using the navigation plan if it has the requirement to sail the catamaran in 2 consecutive days. On the other hand, although it can end the trip on the second day, there may have the problem in using of energy as the overuse of battery more than the design of depth of discharge. In this case, it may affect to the duration of the battery in overall, so it should prepare for the alternative battery with having the charging station to be placed in. What's more, this research uses normal propellers which available in the study area. So, there are some potentials for development of an impeller unit with the suitable size for the catamaran.

5. Conclusion

The catamaran solar cell was designed as the tool for promoting the low carbon destination and sustainable tourism in Ko Mak Island, Trat Province, Thailand. Besides, it has come from the listening to the opinions for the users and the tourists until gaining the conclusion in design and building for solar powered catamaran with the length of 7.5 meters, the width of 3.5 meters. The catamaran has installed 6 panels of 300-Wp photovoltaic modules which equally to 12 square meters. On the same way, it has applied the charge controller with MPPT and inverter unit with the size of 5 kW, Deep cycle lead acid battery has been chosen and installed for total capacity similar to 18 kWh, the system voltage is 48 V. Therefore, it can discharge the energy up to 10.8 kWh at depth of discharge of 0.6 for 2 of 33 VAC 3-HP induction motors. Furthermore, the motor has been installed in the center of the catamaran as well as the installing of the shaft to send the power to the impeller of the long tail ship to be easily for maintenance. Therefore, the solar powered catamaran can increase the speed to 9.18 km/h at 4,500 W. Then, if it has applied the motor power with 2,000 W the speed of it will be 7.77 km/h in order to use with the solar powered catamaran for 5.40 hours. Then, this type of ship can make the most distance with 41.96 km. In this case, according to the result of the ship run test in the distance of 19.19 km under the calm weather suitably for traveling it was found that the catamaran has efficient maneuver response, good throttle response, passengers can walk to several parts for doing activities conveniently. Then, in the common case it has shown of no problem about the winds and the waves. As the result, during the test, the insolation value is likewise to 27.18 kWh while the Solar cell system can produce the power energy and charge to battery with 4.1 kWh or with the effectiveness with equally to 15.08% and the average speed with 6.26 km/h.

References

[1] J. O. Amaechi, T. C. Godstime, Automotive Exhausts Emissions and Its Implications for Environmental Sustainability, International of Advanced Academic Research - Engineering, Vol. 1 (2), November 2015, pp. 1-11.

[2] L. J. Holmes, J. McWilliam, M. C. O. Ferrari, and M. I. Maccormick, "Juvenile damselfish are affected but desensitize to small motor boat noise", *Journal of Experimental Marine Biology and Ecology*, Vol. 494, pp. 63-68, September 2017.

[3] C. Burt, X. Piao, F. Gaudi, B. Busch, and NFN. Taufik, *Electric Motor Efficiency under Variable Frequencies and Loads*. ITRC Report No.R06-004, California Polytechnic State University, 2006, pp. 2.

[4] S. Minami, T. Hanada, N. Matsuda, K. Ishizu, J. Nishi, and T. Fujiwara, Performance of a Newly Developed Plug-in Hybrid Boat, *Journal of Asian Electric Vehicles*, Vol. 11(2), pp. 1653-1657, 2013.

[5] G. S. Spagnolo, D. Papalillo, A. Martocchia, and G. Makary, Solar-Electric Boat, *Journal of Transportation Technologies*, Vol.2, pp. 144-149, 2012

[6] H. Schneekluth and V. Bertram, *Ship Design for Efficiency and Economy*, 2nd ed., Butterworth-Heinemann, 1998.

[7] R. Lukkanaworakul, M. Yutithum, T. Piekkoontod, and A. Satayavibul, and S. Tohmad, *Study on Potential of Using Solar Powered Catamaran for Coral Reef Tourism*, Report No.RDG5650017, The Thailand Research Fund, May 2016.

[8] A. Rios, J. Guaman, C. Vargas, and M. Garcia, Design, Dimensioning, and Installation of Isolated Photovoltaic Solar Charging Station in Tungurahua, Ecuador, *International Journal of Renewable Energy Research*, Vol.7, No.1, pp. 234-242, 2017.

[9] I. Alphonse, S. H. Thilagar, F. B. Singh, Design of Solar Powered BLDC Motor Driven Electric Vehicle, *International Journal of Renewable Energy Research*, Vol.2, No.3, pp. 456-462, 2012.

[10] S. Tsotoulidis, A. Safacas, Analysis of a Drive System in a Fuel Cell and Battery powered Electric Vehicle, International Journal of Renewable Energy Research, Vol.1, No.3, pp. 31-42, 2011.