Design and Development of the Electrical Energy Administration and Energy Management System in Nile Tilapia fish pond: A Case Study of the Nile Tilapia Farming Community, San Sai District, Chiang Mai, Thailand

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ABSTRACT

Dissolved oxygen (DO) is an important factor for the cultivation of Nile Tilapia fish. Traditional cultivation utilizes the utility grid to supply the air blower motor to manage the DO level in the pond. However, common issues include dropping voltages or utility grid failure. Hence, the main objective of the present study is to design and develop an electrical energy administration and energy management system which can be applied in a Nile Tilapia fishpond. Solar hybrid system has already been implemented in the fishpond and functions using three electrical energy sources, including solar panels (10 panels, 325 W polycrystalline), the utility grid, and battery modules (24 pieces, 20 Ah 12 V). The controller administers and manages the electrical energy sources to supply the aerator. The new operational plan is an improvement and replacement for the previous operational plan and is embedded into the MCU core (ESP8266) to evaluate and display parameters via an online server (Blynk). The administrator can adjust the events using a smart device to test each function and check the system's responses. The reserve energy source is focused on the battery module and is tested to determine its feasibility and potential. The experimental results are divided into three sections. The first result showed that the aeration system is able to use a three-phase air blower motor using the solar hybrid system and three electrical energy sources. The second result demonstrated a relatively good reaction to the new operation plan in each event in the fishpond. The third results showed the feasibility and potential of the battery module component of the system under various operations and varying electrical energy sources. The battery module can store up to 5,509.4 Whr of reserve energy and supply the air blower motor for 2.4 hours. Finally, this system had an investment budget of 127,575 Thai baht and a payback period at 10.48 years.

Keywords: Electrical energy administration system, energy management system, *Nile Tilapia* fishpond, solar hybrid inverter.

1. INTRODUCTION

In Thailand, *Nile Tilapia* are cultivated intensively which requires the use of electrical energy for fishpond aeration systems to increase or maintain dissolved oxygen (DO) levels. Most farmers prefer to use the utility grid, but this often encounters problems. The first issue is the lack of an electrical energy backup to supply electricity in the event of an aquaculture emergency or a utility grid failure. The second issue was the lack of administration and management for both the use of the electrical energy for aeration

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system and maintaining the DO level. Agriculturists had no exact plans or schedules to switch the aeration system on or off, or to solve problems in the event of utility grid failures or a DO level.

The appropriate DO and pH for *Nile Tilapia* fish cultivation is 4 mg/L and 6.8-8.0, respectively [1]. However, this paper focuses on DO as an important factor since it clearly affects *Nile Tilapia* fish in fishponds more than pH. The use of solar cells within the agricultural and aquaculture sectors is increasing. In particular, these sectors use solar cells as a supplementary electrical energy source due to increasing electricity costs, pollution from mechanical engines, and high production costs. It is therefore reasonable to apply solar energy in the agricultural and aquaculture sectors. Several researchers have demonstrated the feasibility of using solar energy for aquaculture which are described as follows. Gokay [2] used solar panels as an electrical energy source to supply the electrical motor of a water pump and charge the battery. This system maintained the aquatic pond temperature at 17°C to support the survival, growth, and increase productivity of the fish in the pond over the course of the year. Meanwhile, Tamal et al. [3] designed a solar energy system for a small aquatic pond in Bangladesh using HOMER Pro software. The system consisted of a 2kW of solar panel, a 400 Ah deep-cycle battery, a 0.2 kW of solar inverter, with the cost of energy (COE) of this system being 0.463 $/kWh. Furthermore, Ail et al. [4] designed and evaluated an optimum solar water pumping system for rural areas using a PV-powered water pumping system (PVWPS) to study the economics of both PV and diesel pumping solutions. The PVWPS was shown to be more cost-effective than the diesel generator over the lifetime.

Research on the management and control system for aquatic ponds will now be discussed. Moataz and Mohamed [5] designed a fish farm management system based on the microcontroller for an aeration control system that operates a 1hp-3 phase induction motor with a time schedule. Igib et al. [6] designed an optimum sizing of electrical power to support the electricity demand of a fishpond aeration system. This was the most economically feasible and the COE was about 0.769 $/kWh. Similarly, Qorry and Sri Endah [7] studied the energy consumption of the Tilapia fish culture system. A preliminary audit result showed that to produce one a live-weight ton of tilapia consumed 4,821.08 MJ which consisted of electricity (4,576.74 MJ), labor (180.33 MJ), diesel (49.33 MJ), and gasoline (14.68 MJ). Therefore, the primary goal of utilizing solar energy is to reduce fossil fuel dependence, lower the electrical costs, as well as to maintain good electrical supply stability in the system and DO level. Hence, it is desirable to develop an electrical energy administration and management system in a *Nile Tilapia* fishpond. This system device relies on the combination of three power sources, in which electricity supplied by the utility grid is used in combination with a renewable energy power source (electrical energy from solar panels), and an electrical energy backup (battery module). The operation of the system uses a hybrid energy sharing module to distribute energy to the aerator, while the solar charger module is used to store energy in the battery module. The working situations are divided into three events, Situation 1 - in the case of daytime and normal electricity, the system will provide electrical energy where it is used in combination with solar energy and the utility grid to the aerator, but if the aerator stops working the system will bypass the solar energy to a battery to storage. Situation 2 - at night under normal electrical and DO conditions, the system will pay the utility grid to the aerator.

Meanwhile, the electricity will charge the battery until the early morning hours, the system will bring energy from the battery in combination with the utility grid to reduce energy consumption and discharge at the same time. Situation 3 - at night under a utility grid failure and with the DO level entering a crisis event, the control system commands the controller to pay the energy from the battery backup to the hybrid inverter and pass to the aerator to fill air in the *Nile Tilapia* fishpond. This system acts as a substitute for the farmer, thus enabling the farmer to save time and precisely control the aerator. In addition, it also helps to reduce energy consumption and cultivation costs.

2. MATERIALS AND METHODS

The experimental designs are divided into four parts, as follows:

2.1 Project assumption of the electrical energy administration and management system in *Nile Tilapia* fish pond

The design hypothesis is largely based on the farmer's previous operational plan. The previous system is improved with the addition of a solar cell system and a new operational plan to manage the aeration system, which is the main part and consumes most of the electricity in the fishpond. The aerator schedule study found that the operation of aerators depended on the age of fish [8]. In the first month of cultivation the aerator was not turned on. Then, from the second to the final month of cultivation, the aerator was turned on during the day between 9.00 a.m.-11.00 a.m., and then 1.00 p.m. - 6.00 p.m. At night, the aerator was turned on between 8.00 p.m. - 6.00 a.m. The total operational time of the aerator was 17 hours per day. If carefully considered, DO crises typically occur at 4.00 a.m. - 6.00 a.m. On some days, the DO levels at night were below 2.0 mg/L [9]. Hence, the main idea of this system is focused on the operational time of the aerator by developing an electrical energy administration and management system to manage and stabilize the electrical energy sources for the aerator, maintain DO levels, in addition to accumulating solar energy in the battery module.

2.2 Design and development of the electrical energy administration and energy management system in *Nile Tilapia* fishpond

The conceptual framework of the electrical energy administration and energy management system is shown in Figure 1. The system consists of three separate electrical energy sources, the utility grid, solar cells, and the battery module. The controller is the main part which selects the appropriate electrical energy source to supply the aerator. Furthermore, the electrical energy remaining during the day will also charge the battery module. A solar hybrid inverter is an automatic load sharing device that combines utility grid electricity with the solar cell or battery module (depending on the controller selection). A powered electronic switch automatically switches the aerator on or off. The AC power analyzer is connected to the utility grid line to measure and record energy consumption data. The Blynk server is an online server to display and exchange data between the controller and the AC power analyzer to predict and analyze the aerator controller and battery charging. The DO level is sent from the DO measuring system [10]. In the present study, the main controller is the ESP8266 and is used to analyze and manage the system. It is interfaced with the AC power analyzer via MODBUS RTU protocol to receive the energy parameters and send data to cloud servers for recording and monitoring purposes, as well as to verify the electrical stability to support the aerator system in the case of a utility grid failure (Figure 2). Meanwhile, the DO value is also read by the

ESP8266 from the same cloud server to monitor the DO value. The final side of the ESP8266 is connected to the ATmega 328p via the I2C protocol which is the second controller. It functions to control the control circuit. The communication network in the fishpond is based on a 4G cellular network to connect it to the cloud server.

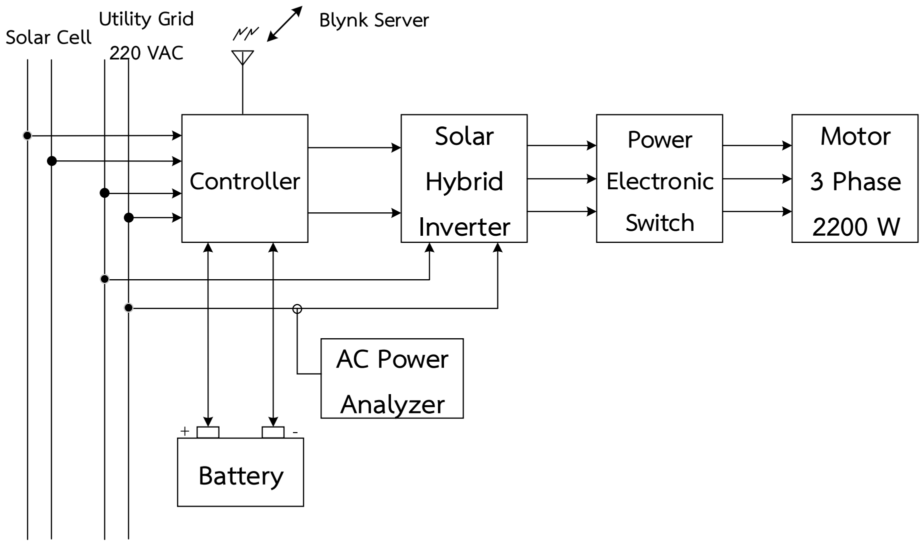


Figure 1. Configurations of the electrical energy administration and energy management system

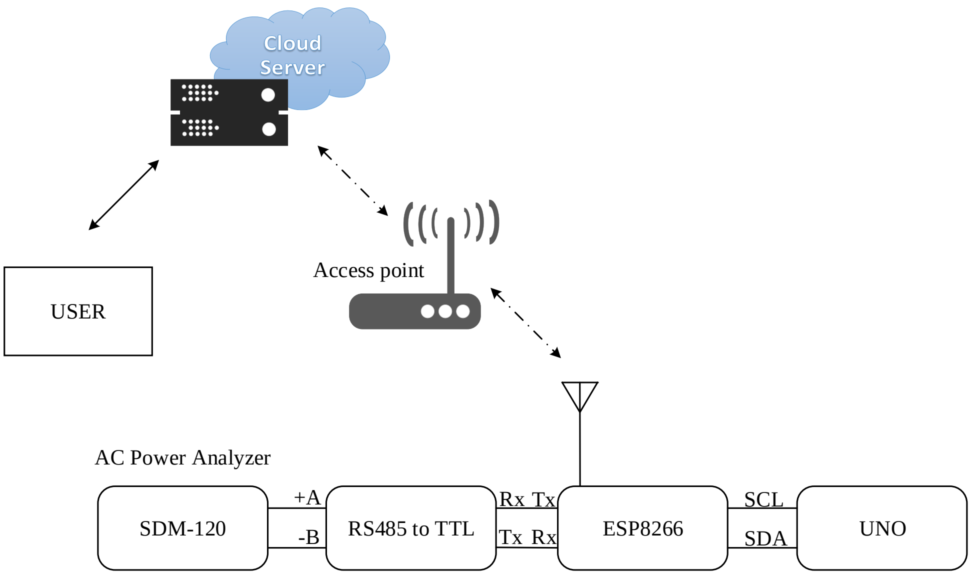


Figure 2. Main controller interfacing

The control circuit configurations consist of the four control circuits, in which each circuit is commanded using the real fishpond environment as a decision-maker. The controller is programmed to receive certain parameters, such as DO level, AC and DC energy consumption, and time. These parameters are evaluated to generate the output control signal for each control circuit. The M1 controls DC energy that is converted from the utility grid with a variac transformer and bridge rectifier with a filter via the DC charger. The M2 controls the DC energy from the battery module which passes to the solar hybrid inverter. The M3 manages DC energy from the solar cell passing to the DC charger, and the M4 manages the DC energy from the solar cell to pass to the solar hybrid inverter, as shown in Figure 3.

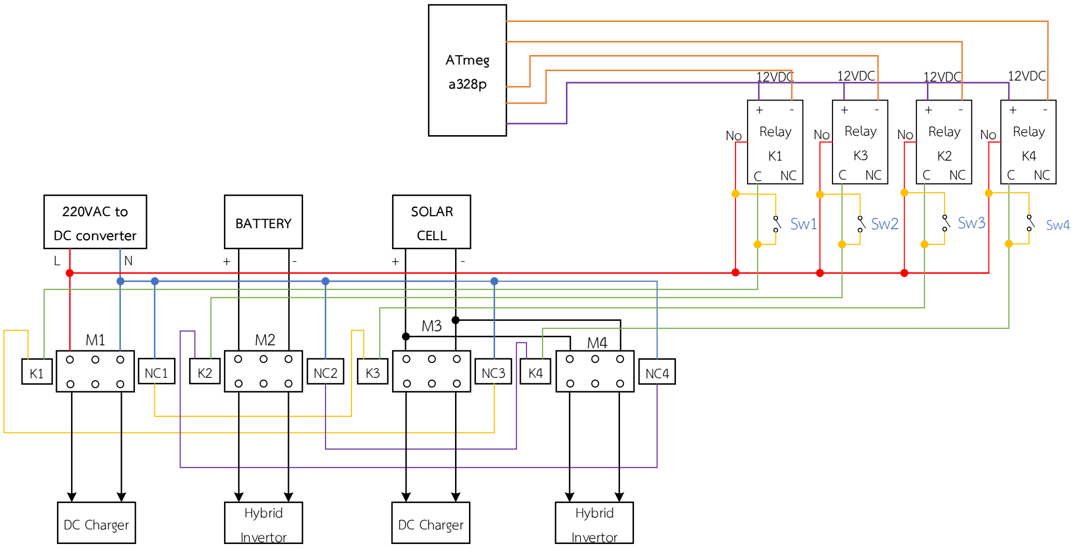


Figure 3. Control circuit diagram

In this system, ten 325 Wp solar panels were connected in a series mode to generate the power at 3.2 kWp and voltage at 340-380 V (depending on solar intensity). This solar panel connects to the controller on the M2 and M3 to distribute to either the DC charger (SC-MH, SC-MH 20A model) or the solar hybrid inverter (Siemens, Sinamics V20 model 2.2kW). After the solar hybrid inverter, the air stone type aerator is connected with an air blower motor that consumes the power by 2.2 kW depending on connected load. Next, the DC charger is the battery module (Chilwee, 6-DZF-22, 12V 20Ah 24 pieces) that is connected in a series mode and has a 5,760 Wh capacity.

New operational plan: Daytime and normal electricity:

The aerator mainly uses electrical energy from the solar cell (M4 turned on) unless electrical energy from the solar cell is insufficient, in which case it will be supplemented by the utility grid. However, if electrical energy from the solar cell is over demand, it will be bypassed to the DC charger to pass to the battery module (M3 turned on). At night under normal electricity and DO conditions, the aerator largely uses electrical energy from the utility grid until the early morning hours (4.00 a.m.), after that it will be supplemented by the battery module (M2 turned on) to discharge the battery and decrease the electrical energy consumption from the utility grid. The off-peak period begins at 10.00 p.m., and the M1 is turned on for additional battery module charging. If the battery module is full, the charger automatically turns off.

Utility grid failure at night and DO levels enter a critical event:

The DO measuring system is designed as a floating buoy [11] and is movable on the water. The fishpond has four specific measurement points, with each point having a distance of 10 meters. The floating buoy moves to the next point every 30 minutes. The direction of movement of the floating buoy is shown in Figure 4, in which it moves from position 1 to 4, before returning from position 4 to 1. Figure 5 depicts the *Nile Tilapia* fishpond studied in this research.

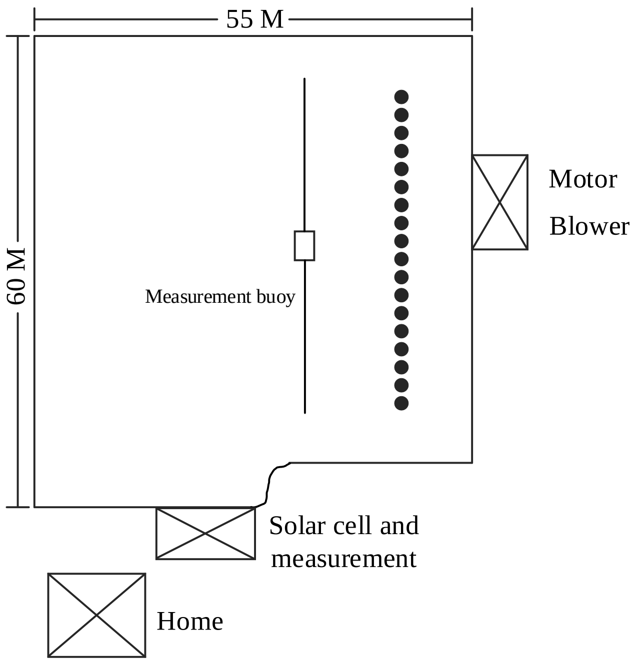


Figure 4. Nile Tilapia fish pond layout

Figure 5. The direction of movement of floating buoy in the fish pond

The DO and energy data is recorded and exchanged on the cloud server, they are the indicators that indicate entering the critical event. The controller will play in the roles as shown in Table 1.

Table1 The role base determination of the events in *Nile Tilapia* fish pond

Daytime	6.00 a.m.-8.59 a.m.	9.00 a.m.-10.59 a.m.	11.00 a.m.-12.59 a.m.	1.00 p.m.-5.59 p.m.
	B(off)+S2H	B(off+S2H)	B(off)+S2Ba	B(on)+S2H
	-	If Po< 100W = S2Ba		
Nighttime	6.00 p.m.-7.59 p.m.	8.00 p.m.-9.59 p.m.	10.00 p.m.-3.59 a.m.	4.00 a.m.-5.59 a.m.
	All off	B(on)+G2H	B(on)+G2HBa	B(on)+GBc2H
	-	-	G2Ba	-
critical event	6.00 p.m.-9.59 p.m.	10.00 p.m.-5.59 a.m.		
			DO>=3.00	DO<3.00
			-	Bc2H

Note: B = Blower, S2Ba= Solar to battery charging, S2H = Solar to hybrid inverter, G2H=Grid to hybrid inverter, G2Ba= Grid to battery charging, G2HBa= Grid to hybrid inverter and battery charging, GBc2H= Grid and battery discharge to hybrid inverter and Bc2H= battery discharge to hybrid inverter.

The designed flowchart procedure consists of reading the energy parameters, including voltage (V), current (I), power (P), and energy (W). The flowchart procedure is developed as a program and run on the ESP-8266 that acts as reader the energy parameters and waits for the command from ATMega328P (Figure 6). It also stores environmental data, such as the DO, critical events, and UNIX time. Meanwhile, the administration and energy management system flowchart is shown in Figures 7 and 8 and are run on ATMega328P that request data from ESP-8266 to analyze and manage the system following the role base.

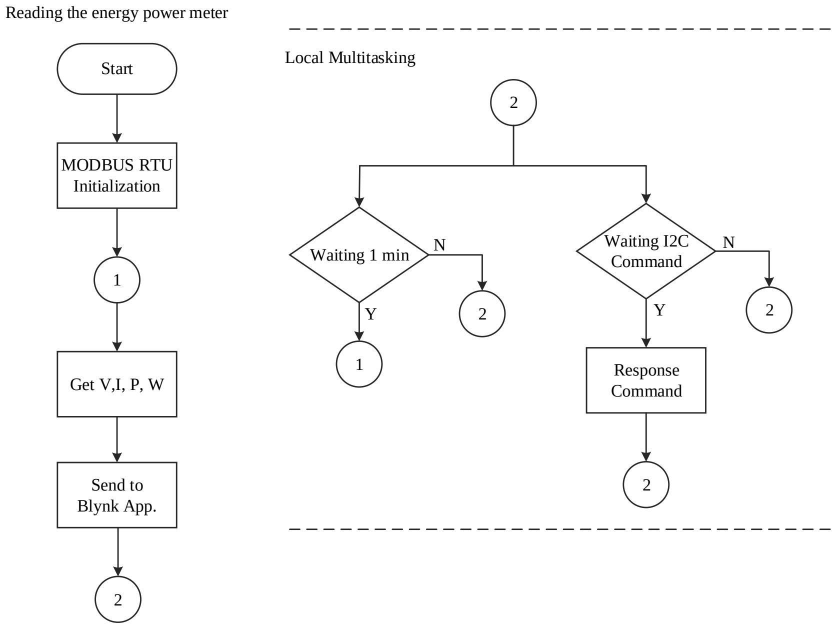


Figure 6. Flowchart of reading the energy parameters

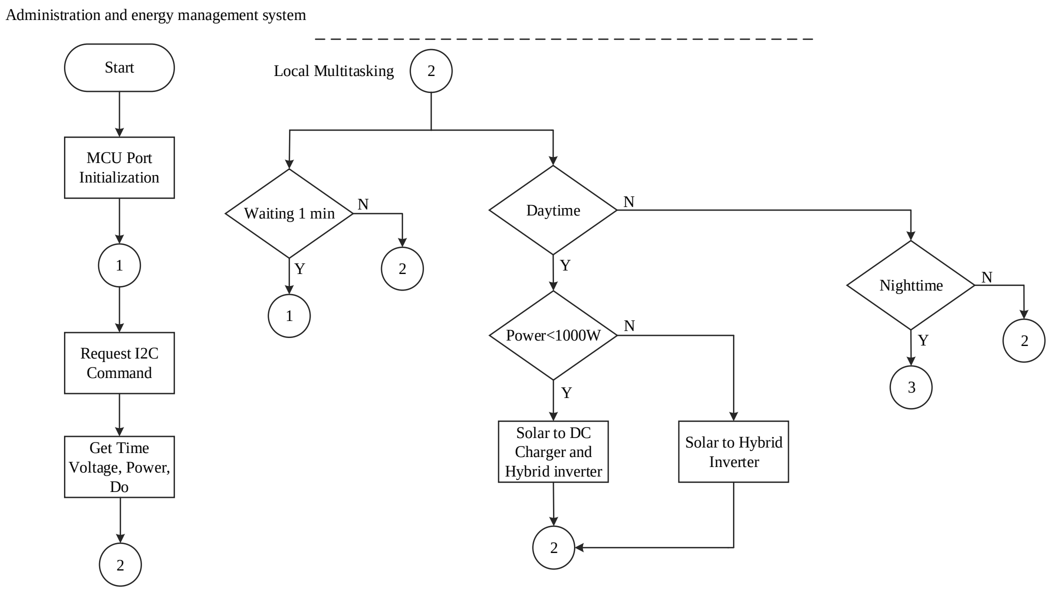


Figure 7. Administration and energy management system page

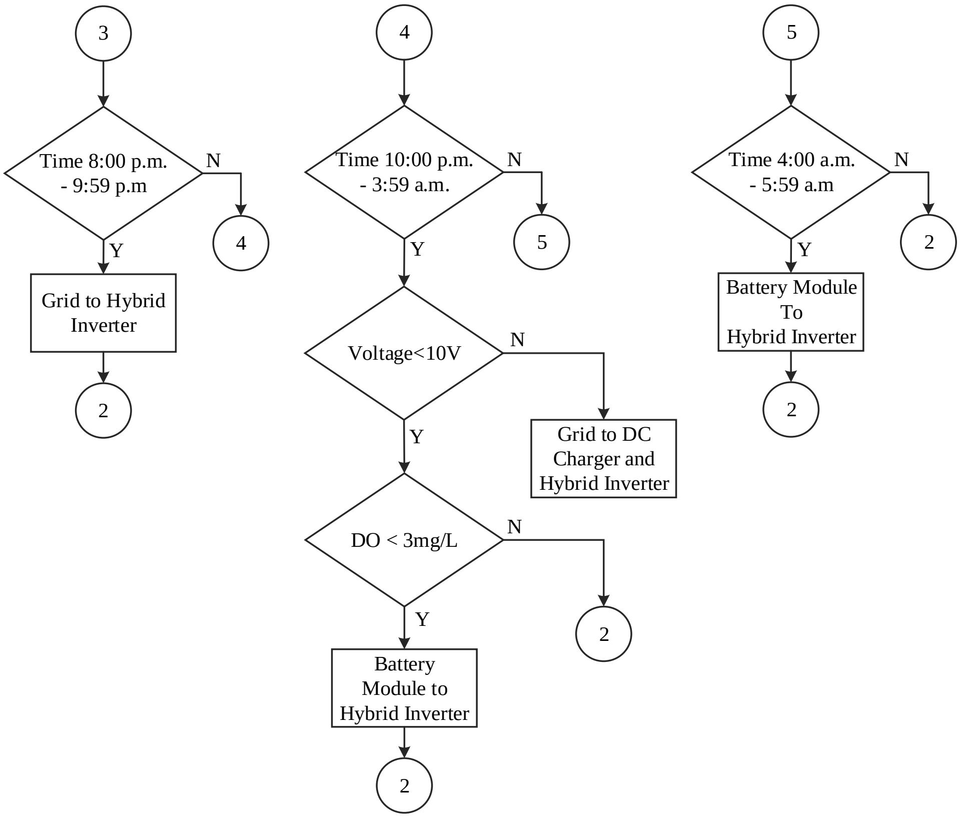


Figure 8. Administration and energy management system page (cont.)

Design of electrical power systems for using in Nile Tilapia fish pond can be designed as follows [12]:

Electrical energy reserve for an aerator system requires 1 hour at power as 2.2 kW and the minimal DC voltage for the solar hybrid inverter needs 288V. While, the specification of the solar panel is 315 Wp, 37.4 V of Vmp and 8.4. A of Imp.

In summary, the solar system is designed by connecting in series with 10 panels that provides the maximum power at 3,150Wp. The solar hybrid inverter is selected by the capacity of the blower at 2.2kW. In the part of the energy backup, the battery module is employed by the local market as 12V and 20Ah that is connected in series amount 24 pieces and provides the maximum energy reserve as 5,760 Wh. While, the battery charger can charge the power at 288 V and 10 Ah (special design for this job).

2.3 Electrical energy administration and energy management system software in the *Nile Tilapia* fishpond

Software was developed to manage the activities or events in the fishpond and to monitor the control system responsiveness. The software runs on the ESP8266 and ATMega328P which are built into the controller system. The monitoring system runs on the online Blynk server. Figure 9 provides details of the monitoring system, as shown on a smartphone. The monitoring system consists of: (1) real-time DO level; (2) date and time; (3) status of control circuits on LED indicator type (M1-M4); (4) real-time graphs of the DO level, AC voltage, and AC power consumption; (5)

temperature and humidity; (6) AC voltage level; (7) AC power consumption; (8) status of control circuits on a real-time graph (M1-M4); and (9) the parameters for critical events, i.e. DO level, AC voltage level, and AC power consumption. The software is always run by the roles of daytime and nighttime (Table. 1) unless the administrator adjusts the parameters for critical events. It will use adjusted parameters for decision together with the previous role.

Figure 9. Monitoring on Blynk application

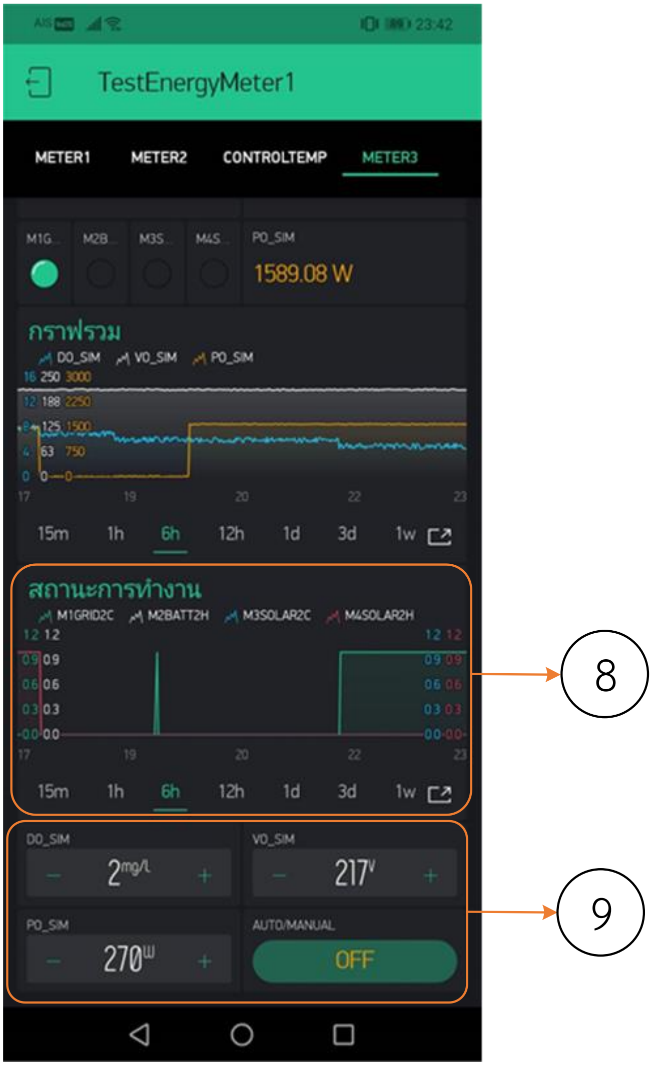


Figure 9. Monitoring on Blynk application (Continue)

2.4 Laboratory-scale testing of the electrical energy administration and energy management system in the *Nile Tilapia* fishpond

The laboratory-scale was undertaken to test the feasibility and potentiality of the devices used in this system prior to onsite installation. The testing largely focused on battery charging using the solar cell and utility grid, as well as how the battery discharged to the aerator.

3. RESULTS AND DISCUSSION

3.1 Design and development results

The *Nile Tilapia* fishpond is located in a 5 rai area in Sansai District, Chiang Mai Province, Thailand. Ten solar panels are built as a roof and the solar hybrid inverter and controller were installed underneath it, as show in Figures 10 (a) and (b)

(a) (b)

Figure 10. (a) *Nile Tilapia* fishpond and (b) solar hybrid inverter

The aeration system uses a three-phase air blower motor (Norvax, NVT-160) which provides the power as three horsepower and are connected to 12 air stone nozzles and are arranged in the pond as shown in Figures 11 (a) and (b), respectively. The battery module (Chilwee, 6- DZF-22) is wired in series mode and connected to the DC charger, as shown in Figures 10 (c) and (d), respectively.

(a) (b)

(c) (d)

Figure 11 (a) and (b) Aeration system with air stone type, (c) Battery module and (d) MPPT solar charger

3.2 Administration and energy management system results

The results of the activities or events in the fish pond that run by the role based in Table 1 as shown in Figure 12. and Figure 13. The parameters in the activities and events in the fishpond consist of measuring the voltage from the utility grid (1), measuring the power of the air stone aerator in event that always occur in the fishpond such as regular event (2), utility grid failure (3) and power sharing (4).

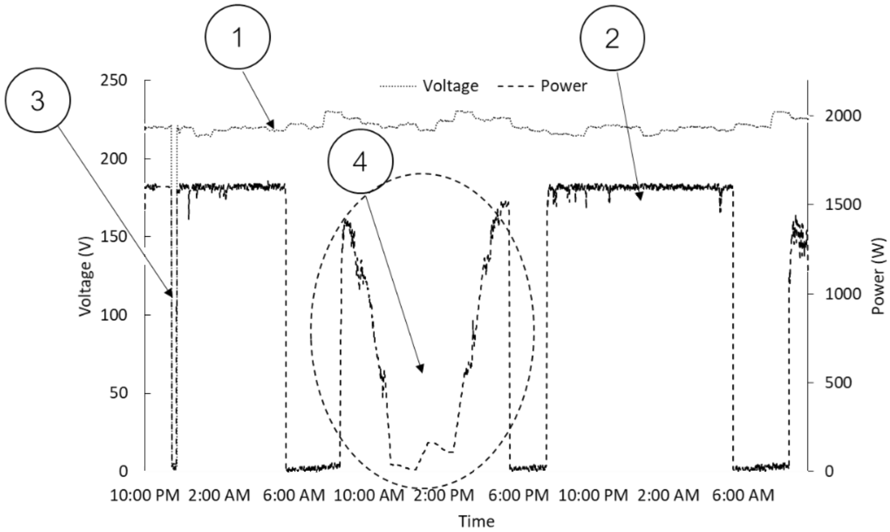


Figure 12. An electrical status in fishpond

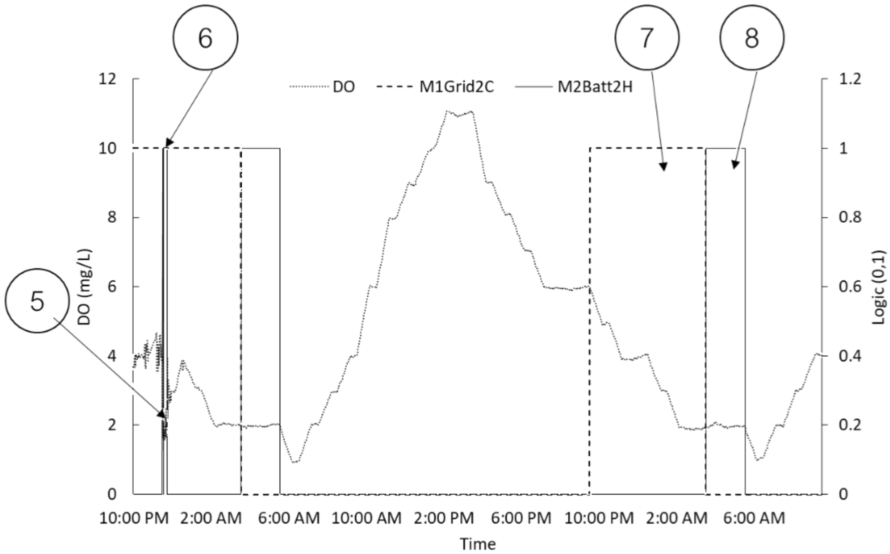


Figure 13. The activities or events in the fishpond run by the role base

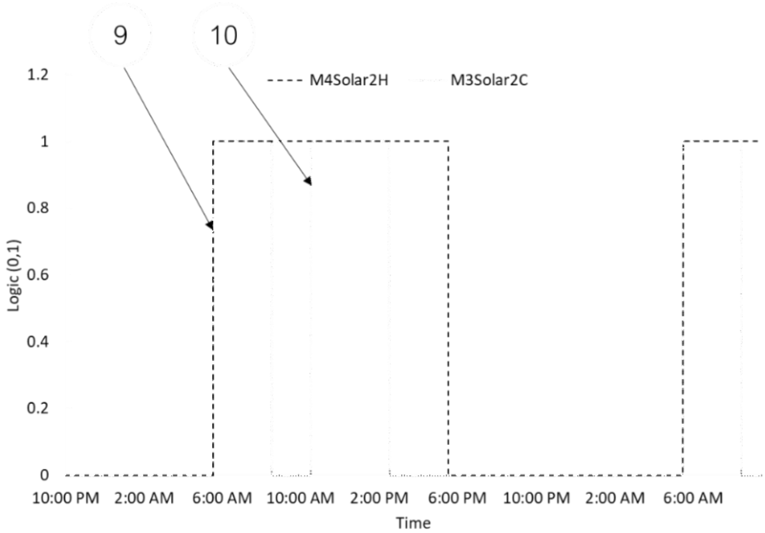


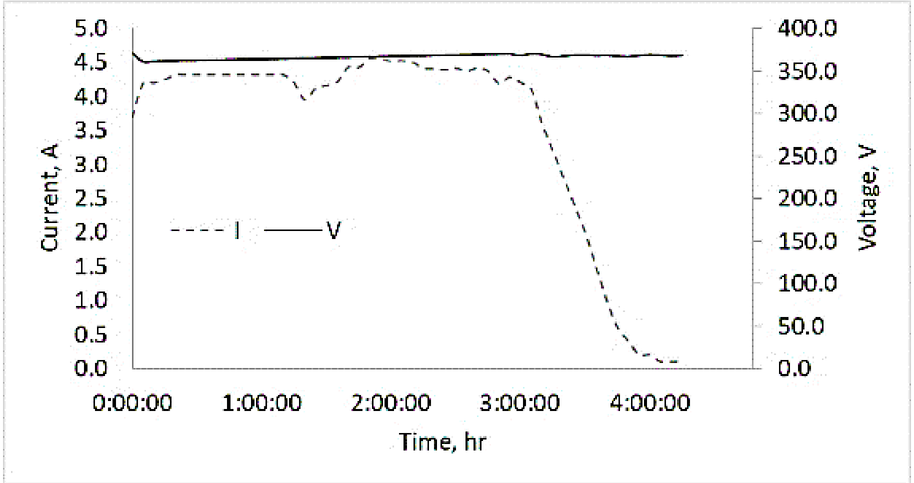
Figure 14. The activities or events in the fishpond run by the role base from solar cell

In the case of the critical period, (5) the utility grid fails close to midnight while the DO level is also below 3.00 mg/L. The controller supplies electrical energy from the battery module to the hybrid inverter suddenly (6:M2BATT2H). Yet if the utility grid fails and the DO level is not lower than 3.00 mg/L, the controller will not supply electrical energy to the hybrid inverter. For normal conditions at night, the battery module is charged by the DC charger after 10.00 p.m. which is the off-peak period (7:M1GRID2C), while the electrical energy from the battery module supplements the hybrid inverter in the early morning hours (8: M2BATT2H).

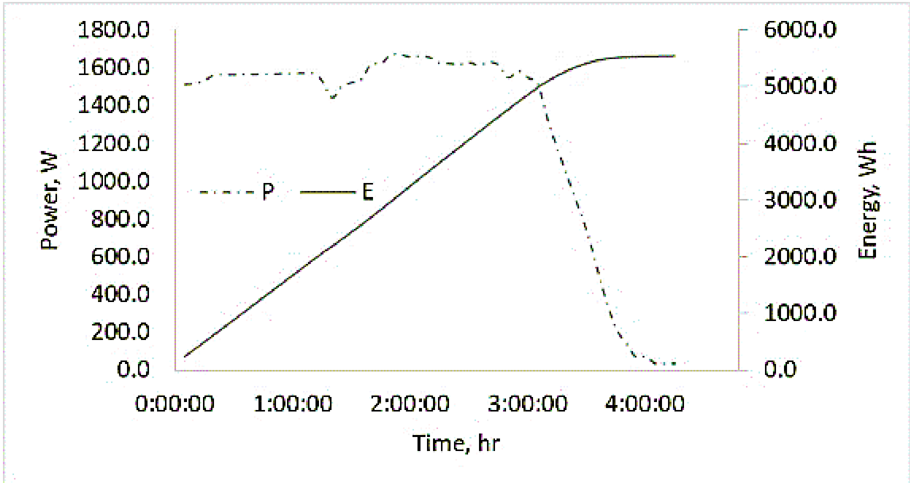
For normal conditions during the day, the electrical energy from the solar cell is supplied to the hybrid inverter (9:M4SOLAR2H), but if the solar intensity during the afternoon is relatively high and the electrical energy from the solar cell is over demand, less electricity form the utility grid will be used. The remaining electrical energy is charged into the battery module (10:M3SOLA2C). All the roles show relatively good responses to the new operational plan in each event in the fishpond.

3.3 Laboratory-scale testing results

The study of the feasibility and potential of a battery module charged by the utility grid shows that it uses an average current at 4.3 A for 3.5 hours, as shown in Figure 15a. A total of 5,509.4 Whr (Fig 15b) of energy was accumulated, which is less than the battery capacity since the efficiency of the DC charger is around 92-97 %. Together, this means that if the battery module is empty, it charges for 3.5 hours. However, if the battery is partially charged with the solar cell during the daytime, the battery will be charged less by the utility grid during the night. The current of the solar cell charging tended to continuously increase, depending on the solar intensity. The time to full charge was almost 6 hours which is about twice as long as the utility grid charging time, as shown in Figures 16 (a) and (b), since the solar intensity is not constant. If considering the possibility to store power during the day, the peak solar hour (PSH) of Chiang Mai province is 4.5 hours [13]. This means that the battery module will be charged by the solar cell and will last for 4-5 hours per day, or about 4.0 - 4.5 kWh. At night this is fulfilled by utility grid charging.

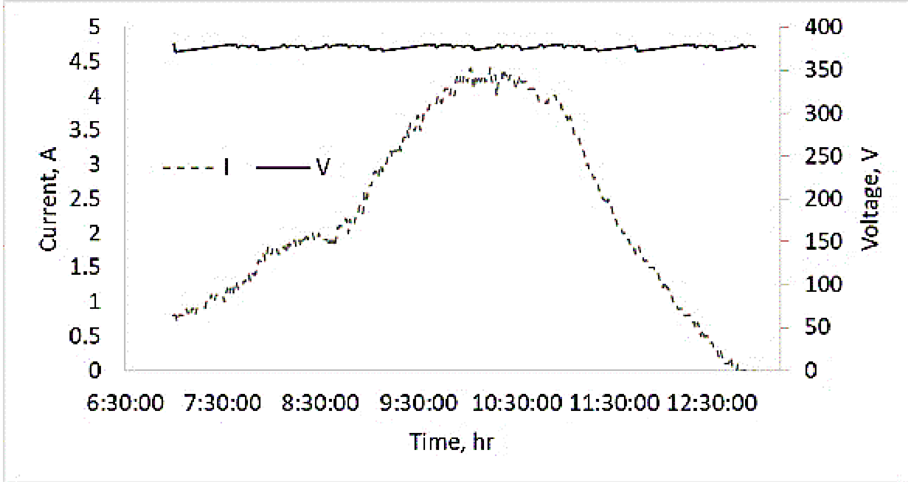


(a)



(b)

Figure 15. The parameters on utility grid charging



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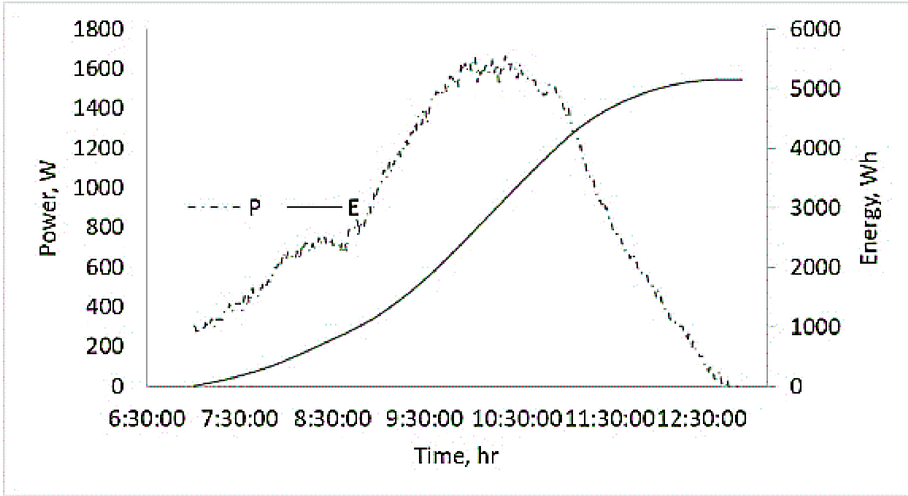
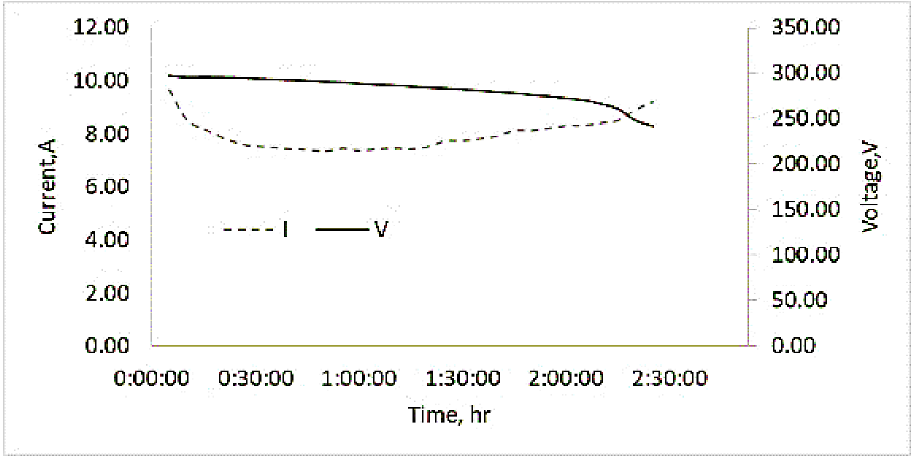


(b)

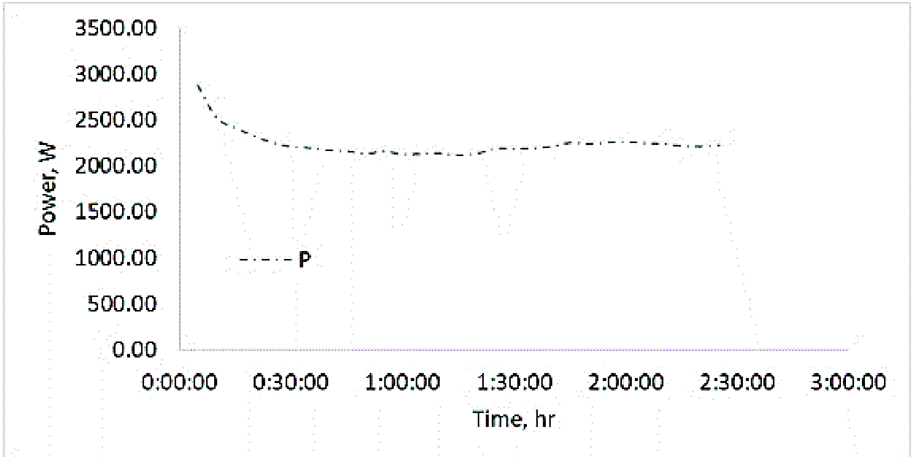
Figure 16 The parameters on utility grid charging

In the case of the battery module discharging as shown in Figure 17, the battery module can supply the aerator with electricity for 2.4 hour. The line graph in Figure 17a shows that the electrical energy still exists, but the voltage of the middle cell of the battery module is lower than the safety zone, or 9 V which risks resulting in a dead battery cell. This issue can be resolved by dividing the battery into three modules, with each module made up of eight pieces. The agriculturist should rotate the battery module a few times per month by rotating the first module with the last module, the second module with the first module, and the last module with the second module.

A total of 2.2 kWh of electricity used to supply the aerator throughout the working time, as shown in Figure 17b.



(a)



(b)

Figure 17 The parameters on battery module discharging

3.4 Return on investment estimation

The present paper focuses on the return on investment (ROI) benefits by estimating the resulting decreased energy consumption and solar panel system costs. The solar panel system cost 94,500 Thai baht (30 Thai baht per watt of solar power). Meanwhile, the energy consumption decrease over the course of one year equates to 9,015.5 Thai baht (3.8 baht per unit of utility grid electricity and 6.5 hours per day, including discharging in the early morning). The solar panel system has a lifetime of 15 years. Hence, the ROI is 43.10%. If considered in terms of the simple payback period, this project will have a payback period of 10.48 years. It appears that this would not be worth the investment, but when considering it carefully, utility grid failures can occur at any time which can affect the fish. A backup energy system is subsequently necessary to limit the potential impacts of a utility grid failure.

4. CONCLUSIONS

This paper designed and developed an electrical energy administration and energy management system to be applied to a Nile Tilapia fishpond. The solar hybrid system was already in use with the fishpond and functions using three electrical energy sources, including the solar panel (10 panels, 325 W polycrystalline), the utility grid, and the battery module (24 pieces, 20 Ah 12 V). The experimental results are divided into three parts. The first result shows the aeration system which uses a three- phase air blower motor with the solar hybrid system and three electrical energy sources. The second result demonstrates a relatively good response to the new operation plan in each event in the fishpond. The third results evidences the feasibility and potential of the battery module under various operations and under varying electrical energy sources. The ROI is 43.10%, while the battery module can accumulate an energy reserve of up to 5,509.4 Whr and can supply the blower for 2.4 hours. Finally, this system has an investment budget of 127,575 Thai baht and a payback period of 10.48 years.

5. ACKNOWLEDGMENTS

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