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Energy management study of aeration system for Nile tilapia fish pond using solar photovoltaic together with utility grid system

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ABSTRACT

This paper presents the energy management models of the aeration system for the Nile tilapia pond using the electrical energy from solar photovoltaic (PV) and the utility grid system (Grid). The solar photovoltaic system is installed on nine panels in which each panel has a dimension of 2×1 m^2 with 325 Wp of polycrystalline silicon solar cell type to produce the electricity for the aeration motor of 2.05 kW. In addition to using electric power, things to keep in mind are the Dissolved Oxygen (DO) that affects fish survival. In Nile tilapia aquaculture, the aeration phase is divided into 4 phases, in which each phase is determined into 4 models of energy management. The results for the period time of Phase 1, Phase 2, Phase 3, and Phase 4 are 66, 48, 14, and 20 days, respectively. Phase 1 uses the energy management model PV; electricity is used only during the daytime, and no use of the aerator at night time, so there is no effect on electricity saving. While other three Phases 2^{nd} - 4^{th}, the optimize energy management model is model 3, which uses the least electrical energy during the daytime from solar PV together with the utility grid system (solar PV&Grid) and at nighttime by using Grid system which the total energy consumptions are 19.21, 21.70, and 24.34 kWh/day, respectively. For one crop by choosing the energy management model can reduce the electrical energy consumption of 1,018.82 kWh/crop, and a total saving is 4,411.49 Baht/crop.

Keywords: energy management, aerator, solar photovoltaic system, dissolved oxygen, Nile tilapia

INTRODUCTION

According to the Alternative Energy Development Plan 2015-2036, Thailand needs to promote the proportion of renewable energy, increasing by about 30% (AEDP, 2015). The interesting renewable energy that has been promoted is solar energy in the form of both heat and electricity. The government sets a target to increase the proportion of solar energy from 3.10-10.24% in all sectors such as industries, commercial buildings, households, and including the agriculture sector in farming, gardening, and aquaculture.

Moo Ban Thung Yao is an agricultural community locates in San Sai District, Chiang Mai Province. The total area of the community, about 70-80% have fish farming, such as Nile Tilapia and catfish in natural ponds. The fish growth period is about 4 months per crop. During culture, fish needs to use oxygen for breath and decomposition of organic material in the pond. During the daytime, phytoplankton will photosynthesize and releases oxygen, increasing the amount of Dissolved Oxygen (DO) that is sufficient for fish. On the other hand, during night time, there is no photosynthesis process; therefore, DO is continually decreasing. Typically, the standard of DO in the fish pond is not less than 3 mg/L (Choochote, 1993). If the DO is lower, the fish may have stress conditions, reduced food intake also results in reduced growth rate as well, and finally, it causes the fish to lack oxygen. Therefore, using the aerator in the fish pond is necessary to use the oxygen increasing in the water. Most of the farmers in Moo Ban Thung Yao use the surface propeller aerator. However, the motor of the aerator is big and consumes much electric power for motor-driven, then it causes the fish costs to increase. Therefore, a sand head aerator is used; instead, the advantage is that the motor runs at low pressure, so it uses less electricity and to reduce production costs. For the previous researches about energy management in the fish pond, Phan-Van et al. (2008) studied the assessed impact of 3 factors affecting water temperature and DO, including water depth, seasons, and fish bioturbation. Statistical data analyzed by Multifactor-ANOVA, and it was found that fish bioturbation and water depth affected the DO. Due to the activities of fish during the summer 8:30-10:00 a.m., when the depth decreased, the DO would decrease, accordingly by about 2.38-4.77, 2.08-4, and 0.62-1.08 mg/L, respectively. Tran-Duy et al. (2008) studied the DO for the Nile tilapia growth. The water flow rate was pumped at 6 L/min to gradually decrease at a continuous-time by setting weight classes (37 g small size, 90 g big size) and two DO levels ($DO \leq 3.5$ mg/L, low and $DO \geq 5.0$ mg/L, high). From the study,

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it was found that when the amount of DO increasing the growth rate of the small fish was increased more than the big fish. Nalinanon et al. (2017) studied Nile tilapia in the conventional cage in which water circulated by the aerator about 22 hr/day and turn off 2 hr from the average initial body weight was 0.25±0.01 g. When feeding about 12 weeks, the average weight of the last fish was increased approximately 23±0.47 g resulting in weight gain, specific growth rate (SGR) was about 19 %/day. For the normal systems, the amount of DO was between 1.9-5.8 mg/L, which was inferior in quality to the aeration in the system resulting in DO increased about 7.90±0.84 5.8 mg/L. Aziz et al. (2020) mentioned the utilization of the PV-grid connected system had proven to be an effective energy supply option and had gained favor where it was accessible and that had a suitable amount of solar radiation. While the installation of off-grid PV systems is increasing dramatically around the world, solar PV systems connected to the electrical network are growing more rapidly and continue to account for the majority of global PV power.

This research provides an idea to reduce the dependence on electricity from the utility grid system. The objective of this study was to study the energy management model of the aeration system for Nile tilapia by using the solar PV system together with the utility grid system.

MATERIALS AND METHODS

Solar Photovoltaic System combined with Utility Grid

A schematic diagram of the solar photovoltaic (PV) system combined with the utility grid for the fish pond aerator is shown in Figure 1(a). The total power of solar panels is 2.925 kW, installed 9 panels of poly crystalline type in which each panel has dimension 2×1 m^2 with a maximum power of 325 Wp. The generated electricity will pass through 2.2 kW inverter that uses to convert direct current (DC) into alternating current (AC) (Model: SINAMICS V20, voltage range 200-240 V) to the sand head aeration motor of 2.05 kW size and 3,450 rpm/min. In the case of the electricity from solar PV system is not enough, the utility grid electricity will be used to supply the aerator when following the demand load of the aerator. The experiment solar PV and the sand head aerator are shown in Figure 1(b) and 1(c).

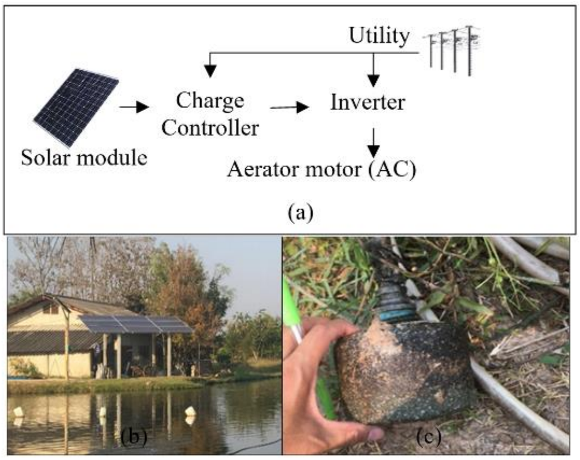

Figure 1. (a) Schematic diagram of the solar photovoltaic (PV) system combined with the utility grid system. (b) Solar PV system installation and (c) Sand head Aerator

Nile Tilapia fish farming

The experiment Nile Tilapia fish pond is located at Moo Ban Thung Yao. The fish pond area is approximately 5,000 m^2, the depth of the pond is 4 m. The farming density is 2 fish/m^2; therefore, the farmer chooses Nile Tilapia fish size by the bodyweight of fish is not less than 30 fish/kg, with a rate of reduced to 11,900 fish before harvesting. The fish culture divides into 4 periods of time (Phase 1, Phase 2, Phase 3, and Phase 4), by the average weight of fish are 0.27, 0.44, 0.47, and 0.51 kg/fish, respectively, as shown in Figure 2. Feeding time conducts two times in the morning and evening at 10:30 a.m. and 5:00 p.m.-5:20 p.m., respectively. The total electricity usage is 2,449.00 kWh/crop or totaling 10,615.60 Baht/crop with an average electricity cost of 4.33 Baht/kWh.

Figure 2. Size of Nile Tilapia fish in 1 crop.

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Energy management model for DO analysis

Normally, the aerator motor is turned on during the daytime and nighttime between 9:00 a.m.-5:00 p.m. and 11:00 p.m.-9:00 a.m. In this condition, define it as a control system. In Table 1, five types of energy management models of aeration systems are being studied using a solar PV system combined with a utility grid system, and there are determined for DO changing.

Table 1. Energy management models for the aeration system.

Model	Aeration system	
	Daytime*a	Nighttime
PV*b	Solar PV system	No use aerator
1	Solar PV system	Grid system*c
2	Solar PV system	Grid system (DO<3mg/L)*d
3	Solar PV&Grid systems	Grid system
4	Solar PV&Grid systems	Grid system (DO<3mg/L)

*a At daytime turns on the aerator motor between 9:00 a.m.-5:00 p.m.
*b Mode PV l uses only the first phase of fish culture.
*c Nighttime, modify the time to turn on all 4 phase motors, 1st – 4th (3:00 a.m.-9:00 a.m., 1:00 a.m.-9:00 a.m., 0:00 a.m.-9:00 a.m. and 11:00 p.m.-9:00 a.m., respectively.)
*d Nighttime, minimum time period is set for turning on the motor at 11:00 p.m.

Data collection for energy management analysis is divided into 2 parts as follows;

1) Collects data and analysis the electrical energy

The electrical data is measured by a clamp meter. The maximum voltage (V_m) and maximum current (I_m) of direct current (DC) will be calculated the maximum electrical power by using Equation (1) and calculates the electrical energy by using Equation (2).

$$P_m = I_m V_m \tag{1}$$

Where P_m is maximum power (W), I_m is maximum current (A) and V_m is maximum Voltage (V)

$$E = P_m \times t \tag{2}$$

Where *E* is maximum energy (Wh) and *t* is a time of operating (h)

Solar radiation intensity data (I_T) was collected using Apogee measuring instrument (Model: SP-100-L, Accuracy ±5%), and the input and output power consumption data of the inverter was collected using clamp meter (AC/DC) (Model: UNI-T UT204) measuring instruments. The diagram of measurement and data collection is shown in Figure 3.

2) Collects data and analysis the DO

The DO is measured by the DO meter (Model: Lutron DO-5512SD). Used as an indicator to compare DO with the control system for energy management in the aeration of each phase model.

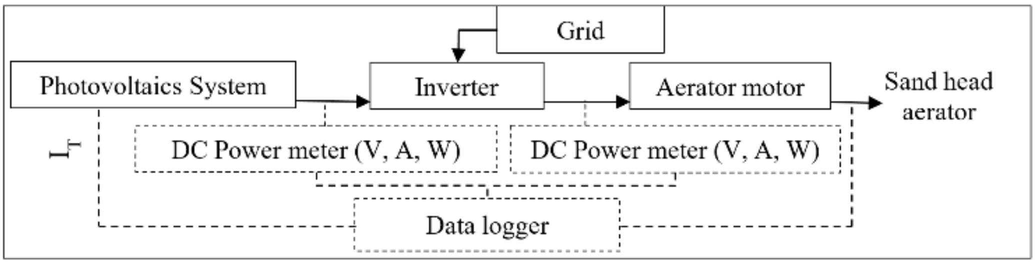

Figure 3. Measurement and data collection.

RESULTS AND DISCUSSION

The results from the energy management model of the aeration system are divided into 4 phases as follows:

Aeration of Phase 1

In Phase 1 of Nile Tilapia culture, the size fishes are small, so they do not need much oxygen for breathing. In addition, the behavior of non-breathing fish on the surface will observe in the morning so that the DO is sufficient for fish breathing. From Figure 4(a), it can be seen that in

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the control system (without aerator using), the DO will increase from the morning time since 6 a.m. to 4 p.m. with the highest value of 5.70 mg/L due to many aquatic plants photosynthesis and release oxygen, however after the sun sets, the DO will begin to decrease. The lowest DO is 1.00 mg/L, and the average daily DO is 2.05 mg/L. It can be seen that the DO is lower than the standard; when there is no aeration, the oxygen content decreases rapidly. But with continuous aeration, the DO slowly decreases, and the fish can still survive. In the first phase, fish are still small, less density, and therefore have a low oxygen demand than Phases 2nd - 4th.

When the aerator is turned on by all energy management models, it is found that all models reach higher DO values than the control case. The highest DO is occurred by Model 4 followed by Model 3, Model 2, and Model 1, respectively. This investigation can be concluded that every model of the aerator pattern can operate without the DO affecting in accordance with the conventional pattern (control system). Therefore, the quantity of electricity from the grid system is a decision for electricity choosing. The result of electrical energy using in Phase 1 is shown in Table 2.

Table 2 (Phase 1) shows the electrical energy that produces from the solar PV system and grid system. During the experiment, all days have similar, with an average value of 12.91 MJ/day. The results show that Model PV is most suitable for use during the Phase 1 cultured period because there is no electricity from Grid. While other models have to use electricity from Grid such as Model 1, and Model 3 which the electricity is used about 7.57 kWh/day, and 7.66 kWh/day, in addition, these results are less than Model 2 and Model 4, which uses electricity from Grid about 12.70 kWh/day and 12.78 kWh/day, respectively.

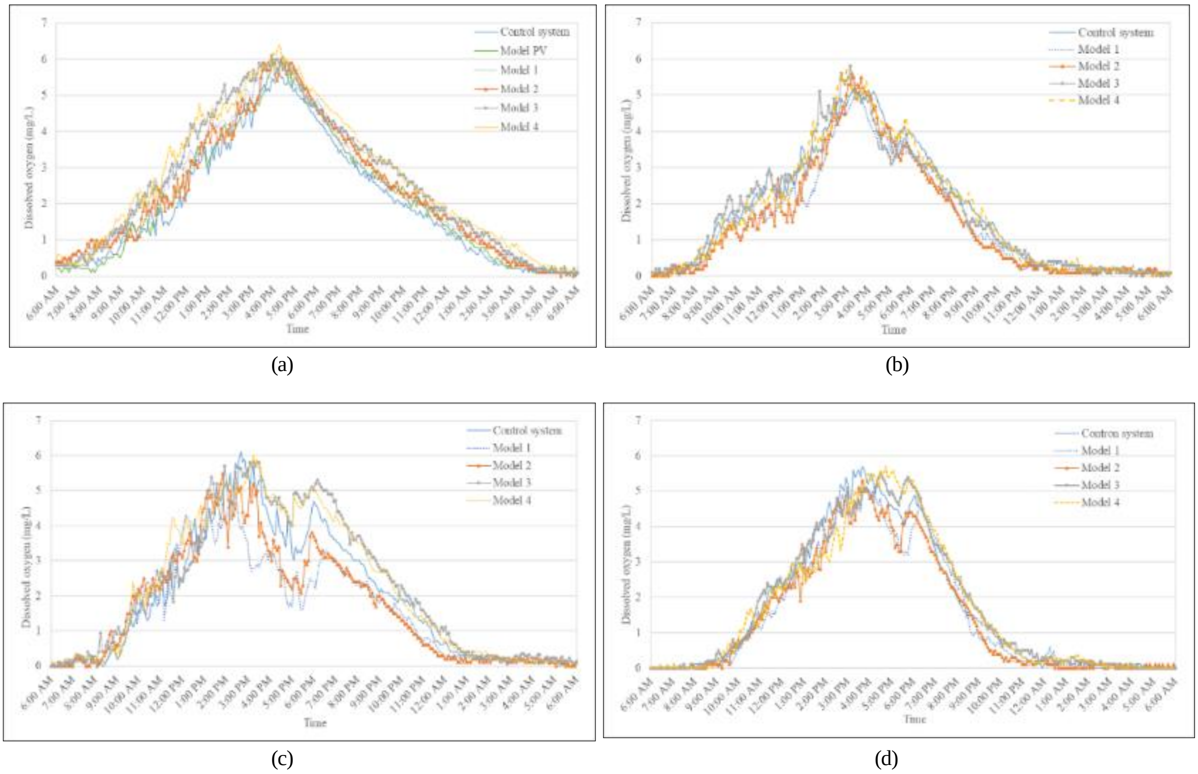

Figure 4. The amount of dissolved oxygen in all Phases.

Aeration of Phase 2

Phase 2, Nile tilapia fish is cultured around 48 days. After raising, it can be seen that the fish has increased growth and therefore needs more oxygen as well. On daytime and night time, if the aeration system operates with only a Model PV pattern in the early morning before the sun rises, fishes breathe on the water surface in order to find oxygen, which means DO in the water is not enough for fish. Therefore, Model PV is not considered in Phase 2 culture.

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Table 2. The energy consumption in the aeration.

period	Model	Total Solar radiation (MJ/m^2day)	DO $_{average}$ (mg/L)	Energy			
				PV$_{daytime}$ (kWh)	Grid$_{daytime}$ (kWh)	Grid$_{nighttime}$ (kWh)	Total Grid$_{all-day}$ (kWh)
Phase 1	Control	12.78	2.05	-	-	-	-
	Model PV	12.99	2.19	10.77	-	-	-
	Model 1	13.06	2.39	10.97	-	7.57	7.57
	Model 2	12.96	2.36	10.78	-	12.70	12.70
	Model 3	12.81	2.61	10.63	9.41	7.66	17.07
	Model 4	12.85	2.73	10.56	9.42	12.78	22.20
Phase 2	Control	14.08	1.77	-	20.68	13.05	33.73
	Model 1	13.99	1.52	11.40	-	10.12	10.12
	Model 2	14.13	1.53	11.44	-	12.53	12.53
	Model 3	14.13	1.79	11.48	8.94	10.18	19.12
	Model 4	14.11	1.77	11.46	8.88	12.69	21.57
Phase 3	Control	11.88	1.96	-	19.85	12.66	31.51
	Model 1	11.90	1.59	9.78	-	11.22	11.22
	Model 2	11.95	1.73	9.85	-	12.50	12.50
	Model 3	12.00	2.25	9.99	10.41	11.29	21.70
	Model 4	11.99	2.24	9.99	10.40	12.60	23.00
Phase 4	Control	11.27	1.67	-	19.77	12.88	32.65
	Model 1	10.97	1.49	8.83	-	12.55	12.55
	Model 2	10.95	1.47	8.80	-	12.83	12.83
	Model 3	11.01	1.75	8.83	11.60	12.74	24.34
	Model 4	11.09	1.70	8.92	11.40	12.72	24.12

Table 2 (Phase 2) shows energy consumption. The control system consumes electricity around 33.73 kWh/day from the grid system (Daytime: 20.68 kWh/day, Nighttime: 13.05 kWh/day). When considering all models, Model 1 and Model 2 have minimum electrical energy consumption at 10.12 kWh/day and 12.53 kWh/day followed by Model 3 and Model 4. The Model 3 has an operation time at 9:00 a.m.-5:00 p.m. and 1:00 a.m.-9:00 a.m. with total electricity consumption of 19.12 kWh/day (Daytime: 8.94 kWh/day, Nighttime: 10.18 kWh/day). For Model 4, total electricity consumption is 21.57 kWh/day (Daytime: 8.88 kWh/day, Nighttime: 12.69 kWh/day), respectively. However, when considering the DO as shown in Figure 4(b), it is found that the increase of DO is similar to the Phase 1 range, with the control system has the highest DO values 5.20 mg/L at 4:15 p.m. and the daily average DO is 1.77 mg/L.

Model 1, and Model 2 have DO lower than control systems all-time with an average of 1.52 mg/L and 1.53 mg/L, respectively; therefore, these models are not suitable for aeration system because the effect on fish growth may happen. While Model 3 and Model 4 has the DO higher than the control system with 1.79 mg/L and 1.77 mg/L, respectively. In conclusion, both the DO and electricity consumption must be considered simultaneously, so the results from Model 3 Model 4 are more suitable for aeration use, which can reduce the electricity consumption from the grid system by 14.61 kWh/day or 701.28 kWh during the Phase 2 culture.

Aeration of Phase 3

Phase 3, Nile tilapia fish is cultured around 14 days. Fish has a more increased growth rate, so the aeration system is necessarily similar to Phase 2 during the daytime. Figure 4(c), it is found that Model 1 and Model 2 are not suitable because the DO is lower than the control system, while the DO of Model 3 and Model 4 result obviously. When considering the electricity consumption, as shown in Table 2 (Phase 3), it is found that the control system consumes higher electrical energy about 32.51 kWh/day (Daytime: 19.85 kWh/day, Nighttime: 12.66 kWh/day) than other models. In addition, Model 3 activates at 9:00 a.m.-5:00 p.m. and 0:00 a.m.-9:00 a.m. is most suitable for use because it uses less energy than Model 4, with electricity from grid system about 21.70 kWh/day (Daytime: 10.41 kWh/day, Nighttime: 11.29 kWh/day) and 23.00 kWh/day (Daytime: 10.40 kWh/day, Nighttime: 12.60 kWh/day), respectively. If considering only the electricity usage from the grid system, every model would increase electricity consumption because, during the rainy season, the solar intensity fluctuates. In the case of Model 3, it can reduce electricity consumption from the grid system by about 10.81. kWh/day or 151.31 kWh.

Aeration of Phase 4

Phase 4, Nile tilapia fish, has a culture day of 20 days. The suitable model in Phase 4 is Model 3 that has been proposed to use electricity during the daytime with a solar PV&grid system at 9:00 a.m.-5:00 p.m. and at 11:00 p.m.-9:00 a.m. with the only Grid system. The energy consumption of many models, as shown in Table 2 (Phase 4), the control system consumes electricity from a grid system about 32.65 kW/day (Daytime: 19.77 kWh/day, Nighttime: 12.88 kWh/day). The results of Model 4 obtain has the least grid consumption about 24.12 kWh/day (Daytime: 10.40 kWh/day, Nighttime: 12.72 kWh/day); moreover, it is less than the results of Model 3, which consumes electricity from grid system about 24.34 kWh/day (Daytime: 11.60 kWh/day, Nighttime: 12.74 kWh/day). Anyway, it is found that the DO of Model 4, especially during the daytime, is lower than the DO of the control system, as shown in Figure 4(d), while The DO of Model 3 is higher than the control system. Therefore in this period culture, Model 3 is most suitable for aeration system use, which can reduce electricity consumption from the grid by about 8.31 kWh/day or 166.20 kWh.

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When considering the one crop as shown in Table 3, in the case of the control system consumes electricity of 2,727.18 kWh/crop while the adjustment of the aerator operation according to the above scheme (Phase 1 use Model PV and Phase 2, Phase 3, and Phase 4 use Model 3) will consume electricity from Grid 1,708.36. kWh/crop, so the electricity-saving is equal to 1,018.82 kWh/crop, representing an electricity saving of 4,411.49 Baht/crop (the average electricity charge is 4.33 Baht/kWh).

Table 3. Energy consumption of the aeration system from the utility grid system.

Phase	Period time (day)	Energy consumption from the utility grid system					
		Control system		Model 3		Saving	
		kWh/day	kWh/Phase	kWh/day	kWh/Phase	kWh/day	kWh/Phase
1	66	-	-	-	-	-	-
2	48	33.73	1,619.04	19.12	917.76	14.61	701.28
3	14	32.51	455.14	21.70	303.80	10.81	151.34
4	20	32.65	653.00	24.34	486.80	8.31	166.20
Sum (kWh/crop)			**2,727.18**		**1,708.36**		**1,018.82**

CONCLUSIONS

In the experiment, five models will test the usage of aerators and choose the best model which consumes the least electricity; moreover, the DO value in the fish pond must be not lower than the control system that farmers use. The results can be summarized according to the fish culture period as follows;

During the phase 1 culture period, the suitable model of the aeration system is Model PV. During the day, the aerator is turned on from 9:00 a.m.-5:00 p.m. using only electricity from the solar PV system. But since the control system had no aeration, so there is no effect on electricity saving. While the other three Phases 2nd - 4th, the control system uses 33.73, 32.51, and 32.65 kWh/day of electricity from the grid system, respectively. The optimize energy management model is model 3, which uses the least electrical energy during the daytime from solar PV together with the utility grid system (solar PV&Grid) and at night time by using Grid system which the total energy consumptions are 19.12, 21.70 and 24.34 kWh/day, respectively, resulted in a reduction in electricity consumption by about 14.61 kWh/day (701.28 kWh), 10.81 kWh/day (151.34 kWh) and 8.31 kWh/day (166.20 kWh), respectively.

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