Solar PV Plant as a Replacement for Power Supply of Irrigation Water Pump

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Abstract The southern side of Subak Babakan Yeh Kuning has an agricultural irrigation water shortage due to the dry season's drought. In 2016, the Ministry of Public Works and Public Housing resolved that by giving diesel-powered irrigation water pump system and groundwater irrigation network, however the high operations cost resulted an abandonment of it. This study conducted a solar power plant design for submersible pumps at the southern side of Subak Babakan Yeh Kuning by calculating the amount of irrigation water needed, designing the solar power plant and the investment costs, and comparing the operations cost between the new and old system. Based on the design, the capacity of the solar power plant was set at 12,54 kWp using 33 solar module units and a 18,5 kW inverter unit. The pump could operate for 5 hours and 30 minutes on a sunny weather with a water discharge of 253 m^3 or fulfill 17,5% of water needs for an area of 16-hectare. The investment costs of the solar power plant pump system were IDR 171.193.500. The operations cost of the new system (solar-powered) per hectare was IDR 6.495/day. Meanwhile, the operations cost of the old system (diesel-powered) per hectare was IDR 15.950/day.

Index of Terms*– *Diesel , Irrigation, Subak , Solar Power Plant

I. Introduction

Based on 2015 - 2050's *Rencana Umum Energi Nasional* (RUEN) which is the guide of national energy development in Indonesia, it determines solar power plant as one of the sources of renewable energy that has been and will be developed. In RUEN, it is stated that in 2025 Indonesia targets a national solar power plant capacity of 6,5 GW [1]. That target will be distributed to 34 province of Indonesia, Bali province as of 2025 is set to achieve a solar power plant capacity as much as 108 MW. Therefore, to achieve the target of 108 MW solar power plant capacity, power plants must be built in several areas of Bali [2].

There were many applications and researches regarding solar power plants, here are a few examples of solar power plants (PLTS) located in Bali Province: PLTS 1 MWp Bangli [3], PLTS 158 kWp Bali Governor office [4], PLTS 24 kWp at Indonesia Power [5], PLTS 26 kWp part of microgrid Udayana University [6], dan PLTS roof of PLN Bali [7]. One of the fields worth studied for the applications of solar power plants is agriculture, more specifically subak irrigation system.

Subak is a traditional farming organization that focuses on water and crop management used by Balinese people with the qualities of sociography, religious, and economic that keeps growing and developing historically [8]. Subak Babakan Yeh Kuning located at Yeh Kuning village, Jembrana sub-district with an area of 40 hectares, with 93 farmers, that subak is divided into two areas, the northern part with an area of 24 hectares and the southern part with an area of 16 hectares separated by Bilak Poh river. There are two main irrigation water sources used to irrigate Subak Babakan Yeh Kuning, which is Pergung river for the northern side and Bilak Poh river for the southern side.

Subak Babakan Yeh Kuning is very dependent by both of the river's water discharge, making rice cultivation limited to be done only in the rainy season. Meanwhile in the dry season, the farmers switch to palawija (other plants cultivated in a field such as nuts, corn, potatoes) due to the drought of the river. This condition made the farmers difficult to take care of their agricultures. In 2015 and 2016, both the northern and the southern side of Subak Babakan Yeh Kuning received an aid from the Ministry of Public Works and Public Housing to resolve their shortage of water problem for irrigation. The aid is in the form of diesel-powered irrigation water pump system which consists of pump house and groundwater irrigation network. The pump house contained 1 submersible pump unit, 1 diesel-fueled machine, 1 generator unit and a control panel. The working principle of the aid is by using the diesel-powered machine as a prime mover to rotate the generator's rotor so that It generates electrical energy to supply the submersible pumps funneled through the control panel.

However, the operations cost to use that diesel-powered irrigation water pump system became a burden for the farmers, making the aid to not be used anymore. From that background, this study designed a solar power plant system as an alternative energy source for the irrigation pump specifically for the southern side of Subak Babakan Yeh Kuning.

II. Literature Review

A. *Renewable Energy*

Renewable energy is an energy source that can be recovered naturally with sustainable process. Renewable energy is also called regenerative or alternative energy, it has been utilized since before fossil fueled energy. Types of renewable energy are as follows: wind power, hydropower, geothermal energy, bioenergy, and solar energy. [9]

B. *Solar Power Plant (Solar PV System)*

Solar power plant is an electric generator that converts solar energy into electrical energy using photovoltaic effect. Photovoltaic effect is a phenomenon of a photovoltaic cell absorbing the solar radiation in the form of light and converts it into electrical energy [10].

Solar power plant is one of the solutions to fulfill the electric needs of isolated areas, outermost islands and areas out of the State Electrical Company's reach. Furthermore, the utilization of solar energy has almost no negative effects towards the environment compared to conventional fuels. Solar power plant system is divided into two configurations, Off-Grid and On-Grid [4]. The components of solar power plant are as follows:

1. Solar Panel

Solar panel is the main component of a solar power plant to convert solar energy into electrical energy. The capacity of a solar panel is measured in Watt-peak (Wp).

2. Inverter

Inverter is an electronic device used to convert direct current (DC) output from the solar panel (PV array) into alternating current (AC) whether it is a one phase or three phase system.

C. *Submersible Pump*

Pump is a mechanical equipment driven by engine power. Its function is to move liquid from one place to another desired place through a pipping medium [10].

A submersible pump is a type of hermetically sealed pumping device that operates by pushing, not pulling, water during the pumping process. Its principle of operations consists of the action of a multistage centrifugal pump usually installed, for offshore applications, either within the well or on the sea floor. As the name suggests, the pump is fully submerged in the liquid to be pumped. This allows the pump to be lowered down into a deep hole for pumping needs without running into problems like pump cavitation. There are two types of submersible pump:

1. Well submersible pump, its application is used for clean water supply needs from deep well springs. It is commonly used for household and industrial purposes.
2. Shallow well submersible pump, its application is used for pool, water storage, water circulation and draining dirty water.

Although both of them are submersible pumps, shallow well submersible pump has the advantage of being portable. [11]

D. *Solar Powered Water Pump*

Solar powered water pump is a pump system that works based on photovoltaic technology, the operations time and how long it operates depends on the solar radiation. Therefore, this system commonly has a water storage tank to store excess water to fulfill water needs when it is cloudy or at night. There are two types of solar water pump system shown at figure 1-2.

1. Solar Powered DC Pump

This system is designed to directly transfer the power generated by the PV array to the DC pump via pump controller, this system will pump water only when the solar radiation is present. Therefore, the raised water discharge is very dependent on solar radiation and the DC pump's rated flow.

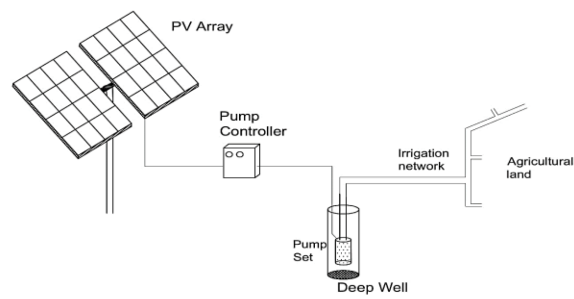

Fig. 1. Solar Powered DC Pump Configuration

2. Solar Powered AC Pump

This system basically resembles the solar powered DC pump system, however there are differences that can be seen, which is the usage of AC pump and inverter in this system. The advantage of this system is there are many types of AC pumps with various rated flow on the market. By using this system, it is also possible to use other energy sources to supply the pumps. For example, using electricity provided by the State Electricity Company.

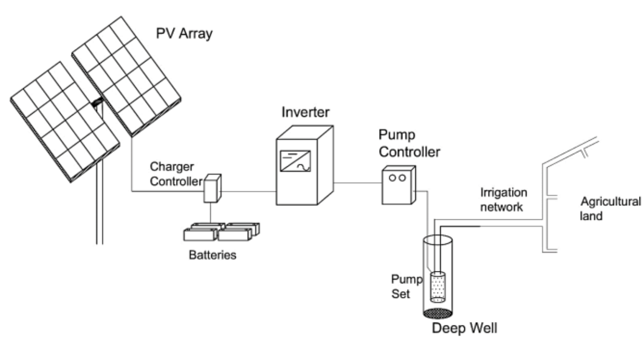

Fig. 2. Solar Powered AC Pump Configuration

III. Research Method

This study was conducted at the southern side of Subak Babakan Yeh Kuning. The first step was to do a research location survey and identify its geographical location. The next step was to collect the data of the sun irradiation and the data of the diesel-powered irrigation water pump system, an aid given by the Ministry of Public Works and Public Housing to the farmers of Subak Babakan Yeh Kuning. Calculating the water needed for the irrigation system of the southern part of Subak Babakan Yeh Kuning with an area of 16 hectares. Then, the solar PV array is designed based on the power requirements of the submersible pump installed in the southern side of Subak Babakan Yeh Kuning, followed by calculating the pump's working hours. Lastly, calculating the investment costs of the solar PV system and comparing the operations cost of the new system (solar PV system) with the old system (diesel-powered).

IV. Results and Discussions

A. *The Southern Side of Subak Babakan Yeh Kuning*

The southern side of Subak Babakan Yeh Kuning has an area of 16 hectares, it is located next to the southern part of Tukad Bilak Poh's river flow which is its main water source for irrigation. The aid given by the Ministry of Public Works and Public Housing to resolve the irrigation water shortage is a diesel-powered irrigation water pump system that consists of a house pump and a groundwater irrigation network. Inside the pump house, there is one Perkins 1103A-33G brand diesel machine connected to a single shaft with a Stamford PI114G brand generator and two control panels to start/stop the diesel engine and to control the submersible pump.

On the outside of the pump house there one Grundfos SP46-6 brand submersible pump with a power of 9,2 kW. The pump is used to draw water from the drilled well which then flowed into the rice field through the groundwater irrigation network.

An average of 1,5ltr/dt/ha of water is needed for agricultural water irrigation along the process of cultivating the land, planting seedlings, up until the growing and the flowering period of the rice [12].

For 16 hectares of subak the amount of water needed for irrigation is:

$$= 1{,}5 ltr/dt/ha \times 16\ ha$$
$$= 24 ltr/dt$$
$$= 24 ltr/dt \times 86.400\ dt$$
$$= 2.073.600\ ltr/day\ atau\ 2.073{,}6 m^3/day$$

The watering pattern used by Subak Babakan Yeh Kuning is intermittent irrigation. Intermittent irrigation pattern is the act of drying and inundating the agricultural land alternately. By doing intermittent irrigation pattern, it can save water for irrigation up to 30% without reducing the amount of yields [13]. Therefore, the amount of water needed for agriculture irrigation using the intermittent irrigation pattern is:

$$= 2.073{,}6 m^3 - (2.073{,}6 m^3 \times 30\%)$$
$$= 1.451{,}5 m^3/day$$

Based on the calculations above, the amount of water needed for the irrigation of 16 hectares of agriculture land is 1451,5 m3/day. Therefore, the average amount water needed for the irrigation of 1 hectare of agriculture land is 90,7m^3/day.

B. *Designing the Solar PV System*

This study analyzed the dry season where the source of agricultural irrigation water only came from the Grundfos SP46-6 submersible pump.

The solar panels used in this study are solar panels with the highest and biggest Wp capacity that are available in Indonesia. After conducting a survey, the JB Series 380M type solar panel with the capacity of 380 Wp was selected. Table I shows the JB Series 380M type solar panel's specifications.

TABLE I
JB Series 380M Solar Panel Specifications

Module	JB Series 380M
Dimension (L/W/H) (mm)	1955 / 992 / 35
Max System Voltage	1000 V
Max Power (Pmax)	380 Wp
Module Eficiency (η)	19,59%
Max Power Point Voltage (Vmpp)	38 V
Max Power Point Current (Impp)	10 A
Open Circuit Voltage (Voc)	46,27 V
Short Circuit Current (Isc)	10,5 A

The capacity of the solar PV system must be bigger than the energy needed because the input power received by the solar panels from the solar radiation is not 100% received by the inverter. This is due to the component and system loses in the solar PV system [14] [15]. Table II shows the type of losses:

TABLE II
Losses

Losses	%
Temperature losses	14%
Module quality losses	1,50%
Unfortune-loss due to mismatch	2%
Cable losses	1,20%
Inverter losses	3%
Soiling losses	3%
Total	24,7%

Therefore, the capacity of the designed solar PV array is:

$$= Submersible\ Pump\ Power + Solar\ PV\ Array\ Losses$$
$$= 9{,}2\ kW + (9{,}2 kW \times 24{,}7\%)$$
$$= 11{,}47\ kWp$$

Based on the solar PV array capacity, the number of solar panels needed can be seen in (1) [14] as follows:

$$\text{Number of solar panels} = \frac{Solar\ PV\ Array\ Capacity}{P_m} \quad (1)$$
$$= \frac{11.472\ Wp}{380\ Wp} = 30{,}2 \approx 31\ unit$$

The units were rounded up to 33 units to simplify the configuration of the solar panels. Therefore, the capacity of the solar PV array is 33 units × 380 Wp = 12.540 Wp or 12,54 kWp. The area of land needed can be calculated as (2) follows:

$$\text{Land area} = \text{width of 1 solar panel unit} \times Amount \quad (2)$$
$$= (1995mm \times 992mm) \times 33\ units$$
$$= 65.308.320\ mm^2\ or\ 65{,}3m^2$$

The designed solar PV system is an off-grid using fixed supports with the height of 2,2 meters above the ground. Bali island is located south of the equator; therefore, the solar panels' orientation would be facing north to acquire optimal solar radiation. The geographical location of the southern side of Subak Babakan Yeh Kuning has a coordinate point of -8,3911ºS dan 114,6595ºE. To determine the tilt angle of the solar panel, can be done with (3) and (4) [16]:

$$\alpha = 90^O + lat - \delta \quad (3)$$
$$= 90^O + 8{,}39^O - 23{,}45^O$$
$$= 74{,}94^O$$

The optimum tilt angle that the solar panel must form against the earth's surface (β) is:

$$\beta = 90^O - \alpha \quad (4)$$
$$= 90^O - 74{,}94^O$$
$$= 15{,}06^O$$

Whereas:

α = solar altitude (º)
δ = solar declination (23,45º)
β = PV array tilt angle (º)

C. *Inverter*

Inverter in an electrical device for converting DC into AC, whether it is single or three phase system. Based on a survey of an inverter manufacture and supplier website, an INVT type GD100- 018G-4-PV inverter with the capacity of 18,5 kW was chosen. Table III shows the specification of INVT GD100- 018G-4-PV:

TABLE III
SPESIFIKADI INVERTER GD100-018G-4-PV

Technical Data	GD100-018G-4-PV
Input (DC)	
Max. DC *input Voltage* (V)	800
Start-up Voltage (V)	300
Min. DC *input Voltage* (V)	250
Max. *input current* (A)	47
Default MPPT *voltage* (V)	400
Output (AC)	
Rated output power (W)	18.500
Nominal AC *voltage* (V)	380V (-15%) ~440(+10%)
Output frequency(Hz)	50Hz / 60Hz
Max. AC *current* (A)	38
Efficiency	
Max. *efficiency*	97%

The equation of (5)–(7) are used to determine the solar panels' configuration for the 12,54 kWp solar PV array design [4]:

Known:

Open Circuit Voltage (Voc) : 46,27 V
Max Power Point Voltage (Vmpp) : 38 V
Max Power Point Current (Impp) : 10 A
Max. Input Current Inverter : 47 A
Min. DC Input Voltage Inverter : 250 V
Max. DC Input Voltage Inverter : 800 V

$$Min.series = \frac{Vmin\ Inverter}{Voc\ solar\ panel} \quad (5)$$
$$= {}^{250V}/_{46,27V} = 5{,}4 \approx 6\ unit$$
$$Max.series = \frac{Vmax\ Inverter}{Vmpp\ solar\ panel} \quad (6)$$
$$= {}^{800V}/_{38V} = 21{,}05 \approx 21unit$$
$$Max.parallel = \frac{Imax\ Inverter}{Impp\ solar\ panel} \quad (7)$$
$$= {}^{47A}/_{10A} = 4{,}7 \approx 4\ unit$$

Based on the calculations, it is set that every 11 unit of solar panels will be assembled in series and which then paralleled into a combiner box. Therefore, there are three parallel circuits in the combiner box. Fig. 3. Shows a single line diagram of the solar powered water irrigation pump system:

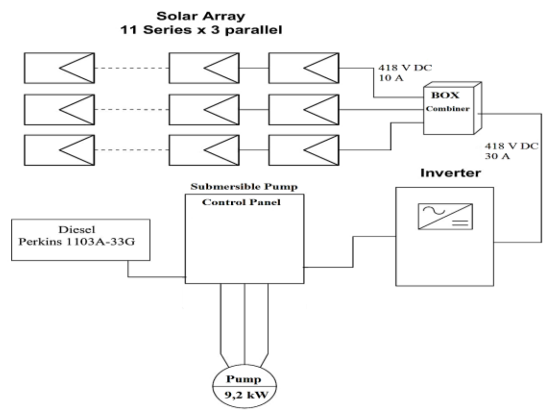

Fig. 3. Single Line Diagram of the Solar Powered Water Irrigation Pump System

D. *Potential of 12,54 kWp Solar PV System*

The output power of the solar PV system depends on the sun irradiation amount of an area and its weather. In this study, the data of solar irradiation is acquired from Jembrana Climatology station and other studies that discussed the output power of a solar PV system that has been installed in Bali, assuming the irradiation received has not much of a difference for dry climate regions. Table 4 shows the sun's irradiation from four main data source, which is: (A1) Jembrana Climatology Station, (B2) Peruna Villa, (C3) Solar power plant at DH Bukit Jimbaran Building. (D4) Solar power plant at Bali Governor's Office [4] [17].

TABLE IV
SUN IRRADIATION DATA

Time	Irradiation (W/m^2)					
	A1	B2	C3	D4		
Ket.				sunny	sunny cloudy	cloudy
06.00	6,7	0,0	75,9			
06.30			219,9			
07.00	222,9	106,3	365,8	60	44	98
07.30			511,2	289	68	148
08.00	493,6	357,3	650,1	386	149	139
08.30			772,5	453	280	194
09.00	736,6	604,5	870,6	652	508	282
09.30			957,2	993	509	314

10.00	920,1	835,5	1.021,4	958	874	348
10.30			1.066,5	1.160	1.008	340
11.00	1.028,0	1.063,8	1.071,6	1.155	1.001	341
11.30			1.104,1	1.167	989	329
12.00	1.056,4	1.042,7	1.058,8	1.153	945	332
12.30			1.006,8	1.159	1.021	337
13.00	1.000,6	943,5	944,5	1.152	1.044	313
13.30			850,0	1.169	746	312
14.00	870,6	851,2	749,1	1.154	284	311
14.30			632,0	1.090	197	307
15.00	669,7	654	469,9	949	195	310
15.30			296,7	762	188	311
16.00	418,9	479,1	127,4	592	131	307
16.30			89,0	432	150	194
17.00	158,5	238,3	25,1	320	90	138
17.30			0	165	28	64
18.00	0,7	0,0	0	28	5	4

E. *Output Power 12,54kWp Solar PV System*

Based on the irradiation data in Table IV, the output power generated every hour by the 12,54 kWp solar PV system and the power needed by the Grundfos SP46-6 to operate can be seen in Figure 4 and 5.

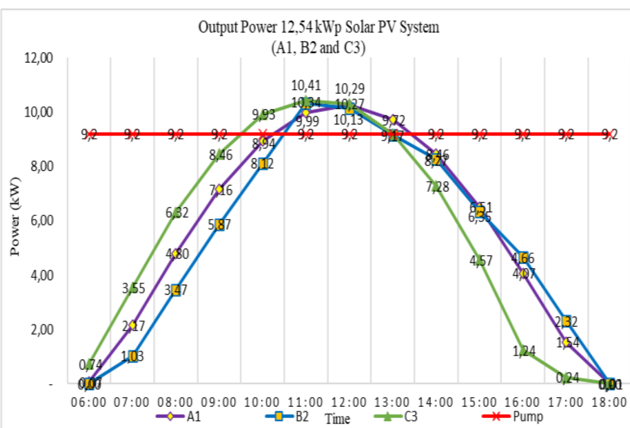

Fig. 4. Output Power 12,54 kWp Solar PV System (A1, B2 and C3)

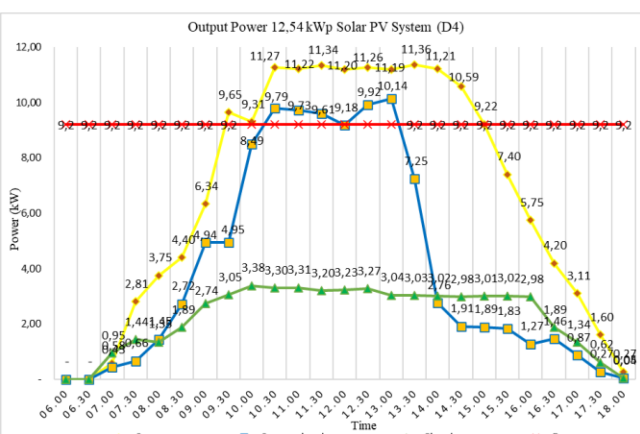

Fig. 5. Output Power 12,54 kWp Solar PV System (D4)

Figure 4 and 5 shows the output power 12,54kWp solar PV system, from the graph it can be seen that the Grundfos SP46-6 submersible pump operates between 2 hours and 30 minutes up to 5 hours and 30 minutes in one day. Based on the Grundfos SP46-6 submersible pump datasheet, it has rated flow of $46m^3$/hour. Therefore, the water discharge obtained for 5 hours and 30 minutes of operations is: $46m^3$/hour × 5 hours and 30 minutes = $253m^3$.

Based on the results of the previous calculation, the southern side of Subak Babakn Yeh Kuning with an area of 16 hectares needs water for irrigation as much as 1451,5 m3/day. Therefore with a water discharge of 253 m^3, the area of the southern side of Subak Babakan Yeh Kuning that can be irrigated during the dry season is:

$$\frac{1.451,5\ m^3}{253\ m^3} = \frac{16\ ha}{n\ ha}$$
$$1.451,5 \times n\ ha = 16 \times 253$$
$$n\ ha = \frac{4.048}{1.451,5} = 2,8\ ha$$

F. *Investment Costs*

The initial investment costs (IC) of solar PV system for the southern side of Subak Babakan Yeh Kuning includes: Solar panels, installation, shipment, and the solar panels' support. Table V shows the total of initial investment costs of the 12,54 kWp solar PV system worth IDR 171.193.500.

TABEL V
INITIAL INVESTMENT COSTS

Product	Quantity	Price	Total
Solar panel JB 380M	33 unit	IDR 2.300.000	IDR 75.900.000
INVT GD100-018G-4-PV	1 unit	IDR 25.500.000	IDR 25.500.000
System component	1 set	IDR 14.037.000	IDR 14.037.000
Installation	1	IDR 8.106.000	IDR 8.106.000
Transportation	1	IDR 9.848.000	IDR 9.848.000
Support rack solar panel	11 unit	IDR 3.436.591	IDR 37.802.500
		Total	IDR 171.193.500

G. *Cost of Operations and Maintenance.*

Operations and maintenance costs (O&M) for a solar PV system is generally calculated as much as 1–2% of the total initial investment costs (IC) [14]. The operations and maintenance costs (O&M) for the solar PV system per year in this study are as follows:

$$\begin{aligned} O\&M &= 1\% \times \text{IC} \\ &= 1\% \times \text{IDR } 171.193.500 \\ &= \text{IDR } 1.711.935/\text{year} \end{aligned} \quad (8)$$

Then, the operations and maintenance cost (O&M) for 25 years of service life of the solar PV system with interest (i) of Bank Indonesia per 11th May 2020 as much as 4,5% calculations are as follows:

$$\begin{aligned} O\&M_p &= O\&M \left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] \\ &= \text{IDR } 1.711.935 \left[\frac{(1+0,045)^{25} - 1}{0,045(1+0,045)^{25}}\right] \\ &= \text{IDR } 25.384.930 \end{aligned} \quad (9)$$

H. *Cost of Component Replacement*

In this study, the inverter will be replaced once every 5 years according to the technical data and warranty form the manufacture. Therefore, the present value from the anticipated inverter component replacement costs over the life of the system is calculated with (10) [16]:

$$R_{pw} = F(1+i)^{-n} \quad (10)$$

Whereas:

F = Inverter price (IDR 25.500.000)

i = interest rate (4,5%)

TABEL VI

COST OF COMPONENT REPLACEMENT

Component	Cost (IDR)
Inverter 5th year	IDR 20.462.502
Inverter 10th year	IDR 16.420.156
Inverter 15th year	IDR 13.176.371
Inverter 20th year	IDR 10.573.393
Total	IDR 60.632.422

I. *Calculation of Life Cycle Costs*

The life cycle cost of the solar PV system for the southern side of Subak Babakan Yeh Kuning is determined by the initial investment costs (IC), the operations and maintenance costs during the life of the project (O&Mp), and the component replacement costs (Rpw). Equation (11) is used to calculate the life cycle cost of this study:

$$LCC = IC + O\&M_p + R_{pw} \quad (11)$$

$$= \text{IDR } 171.193.500 + \text{IDR } 25.384.930 + \text{IDR } 60.632.422$$

$$LCC = \text{IDR } 257.210.852$$

J. *Operations Cost of Solar Powered Water Pump System*

For the solar powered irrigation water pump to operate accordingly to its service life, it needs to be treated well by the farmers of the southern side of Subak Babakan Yeh Kuning. Therefore, an organization is needed to maintain and manage the solar powered irrigation water pump. Fig. 7. Shows an organizational structure in charge of maintaining it:

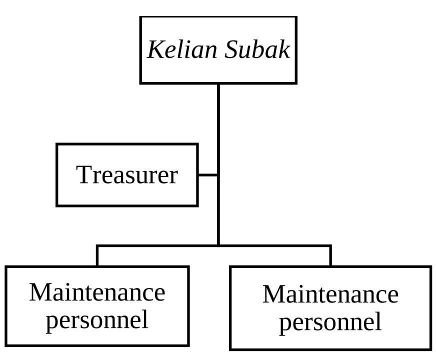

Fig. 7. Organizational Structure

The operations cost needed to pay wages for the organization's committee is IDR 2.550.000/month, with details *the Kelian Subak* and treasurer each receive IDR 400.000/month, and each maintenance personnel received IDR 875.000/month.

In managing the solar powered irrigation water pump, the farmers of the southern side of Subak Babakan Yeh Kuning is required to have their own budget collected by the members of the *subak*. The budget can be collected once a month or according to the agreement made by the *subak* farmers. The calculation of minimum fees or operations cost to maintain the solar powered irrigation water pump are based on:

1. Cost of O&M every year
   Based on the previous calculation, it is known that the cost of O&M per year is IDR 1.711.935/year.

2. Cost of R_{pw} every year
   The inverter is replaced every 5 years where as the current price of the inverter INVT GD100-018G-4-PV is IDR 25.500.000. Therefore, the inverter cost per year is:

$$\text{IDR } 25.500.000 \div 5\ year = \text{IDR } 5.100.000/year$$

3. Cost of Organization Committee Wages Every Year
   For the organization committee's wages that has the duty to maintain and manage the solar powered irrigation water pump is IDR 2.550.00/month. Therefore, the wages per year are:

$$= \text{IDR } 2.550.000/month \times 12 months$$
$$= \text{IDR } 30.600.000/year$$

The total operations cost that the farmers pay of the southern side of Subak Babakan Yeh Kuning for using the solar powered irrigation water pump per year are:

$$= \text{IDR } 1.711.935 + \text{IDR } 5.100.000 + \text{IDR } 30.600.000$$
$$= \text{IDR } 37.411.935/year$$

or

$$= \text{IDR } 37.411.935/year \div 12\ months$$
$$= \text{IDR } 3.117.661/month$$

Based on the previous calculations, the operations cost of the solar powered irrigation water pump is IDR 37.411.935/year or IDR 3.117.661/month. Therefore, the cost that the farmers pay for 1 hectare of rice field is:

$$\text{IDR } 3.117.661/month \div 30\ days = \text{IDR } 103.992/day$$
$$= \text{IDR } 103.992\ day \div 16\ ha$$
$$= \text{IDR } 6.495/ha/day$$

K. *Operations Cost of Diesel-Powered Water Pump System*

As presented previously, the southern side of Subak Babakan Yeh Kuning received an aid in the form of diesel-powered irrigation water pump system from the Ministry of Public Works and Public Housing. Based on the conducted interview with the *Kelian Subak*, it is known that the operations cost of the system is based on:

1. Fuel Costs
   The type of fuel used is diesel-fuel with the price per month of June 2020 of IDR 5.150/ltr [18]. Based on the fuel consumption datasheet of diesel-powered Perkins 1103A-33G machine is 7,1 ltr/hour. Assuming the operations time of diesel-powered water pump is the same as solar powered water pump, which is 5 hours and 30 minutes per day. It can be calculated as follows:

$$7{,}1\ ltr/hour \times operation\ time\ =$$
$$7{,}1\ ltr/hour \times 5\ hour\ 30\ minutes = 39{,}05\ ltr$$
$$39{,}05\ ltr\ \times \text{IDR}\ 5.150/ltr = \text{IDR}\ 201.107{,}5/day$$

2. Operator Costs

Based on the conducted interview with the *Kelian Subak*, it is known that the operator cost of the diesel-powered machine is IDR 9.835/hour. Therefore, the operator costs of diesel-fueled machine for 5 hours and 30 minutes are:

$$= \text{IDR}\ 9.835/hour \times 5\ hour\ 30\ minutes$$
$$= \text{IDR}\ 54.092{,}5/day$$

The total cost that the farmers pay to operate the diesel-powered irrigation water pump system per day is:

$$= \text{IDR}\ 201.107{,}5 + \text{IDR}\ 54.092{,}5$$
$$= \text{IDR}\ 255.200/day$$

Based on the operations cost of diesel-powered irrigation water pump system, it can be calculated on how much the farmers pay for irrigating 1 hectare of rice field per day:

$$= \text{IDR}\ 255.200/day \div 16\ ha$$
$$= \text{IDR}\ 15.950/ha/day$$

From the calculations of operations cost for both of the systems. It can be seen that the operational cost of solar powered irrigation water pump is cheaper than diesel-powered irrigation water pump.

V. CONCLUSION

Based on the solar PV system design as an alternative energy supply for the submersible pump at the southern side of Subak Babakan Yeh Kuning, it is determined that the solar PV system capacity of 12,54 kWp using 33 units of solar panels applying optimal tilt of 15,06^{o} and using an inverter unit with the capacity of 18,5 kW. From the output power of the solar PV system, it can supply the energy needed for the submersible pump to operate from 2 hours and 30 minutes up until 5 hours and 30 minutes. The water discharge obtained for 5 hours and 30 minutes of submersible pump operation time is 253 m^3, which fulfills the water needed for irrigating an area of 2,8 hectares of rice field.

The initial investment costs to construct a 12,54 kWp solar PV system is IDR 164.873.500. The operations cost of the new system (solar PV system) is IDR 103.992/day for an area of 16 hectares agricultural land, every 1 hectare of agricultural land, the farmers have to pay fees of IDR 6.495/day. Meanwhile, the operations cost of the old system (diesel-fueled) is IDR 255.200/day for 16 hectares of agricultural land, every 1 hectare of agricultural land, the farmers have to pay fees of IDR 15.950/day.

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