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RESEARCH ARTICLE OPEN ACCESS

Design and Implementation of Solar Electric System for Village Office and Library Building in Seliu Island Village, Bangka Belitung Province, Indonesia

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Abstract:

The electricity supply of diesel power plant to the village office and library building in Seliu Island Village is still limited, to overcome the limitations of the power supply, then installed solar electric systems. the electrical system is installed by applying the principle of utility priority, Village Office and Library Building each using an automatic transfer switch, Village Office and Library Building will get electricity supply from the solar electric system automatically, if the power source from diesel power plant is not available. The amount of electricity provided by the solar electric system for the Village Office and Library Building on Seliu Island is 920 W respectively, or the total power provided is 1840 W.

***Keywords* — solar electric system, utility priority, automatic transfer switch, seliu island village.**

I. INTRODUCTION

Seliu Island is a village located in the district of Membalong, Belitung regency, Bangka Belitung province, Indonesia, with an area of about 15,300,000 m^2, as shown in Fig 1. Seliu villagers are relying on their economy as fishermen, besides that Seliu Village is actively developing tourism, offering its beautiful beaches, its crystal clear waters, its white sand and exotic granite rocks [1].

Then, while the need for electricity to Island Village Seliu served by diesel power plant, diesel power plant is owned by the state-owned electricity company called Perusahaan Listrik Negara (PLN), in Indonesia PLN is the company has a sole right in the transmission, distribution, and sale of electric power to the consumer [2].

Based on the authors' observations, and information from Seliu Island Village staff, the diesel power plant is only able to supply the electricity needs from 5 pm to 6 am, while PLN will gradually increase the power capacity of the diesel plant, hence, from 6 am to 5 pm, the electricity needs for the Village Office and Library Building are each obtained using a portable generator, however the Village Office staff informed that the use of portable generator was less effective.

Meanwhile, Indonesia is located on the Equator with sunlight irradiating an average of 4.85 kWh/m^2/day, almost evenly distributed throughout Indonesia during the year [3], therefore, to meet the needs of electrical power, when electric power from diesel power plant is not available, especially for the Village Office and Library Building in Seliu Island, as shown in Fig. 2 and 3, then the solar electric system is implemented.

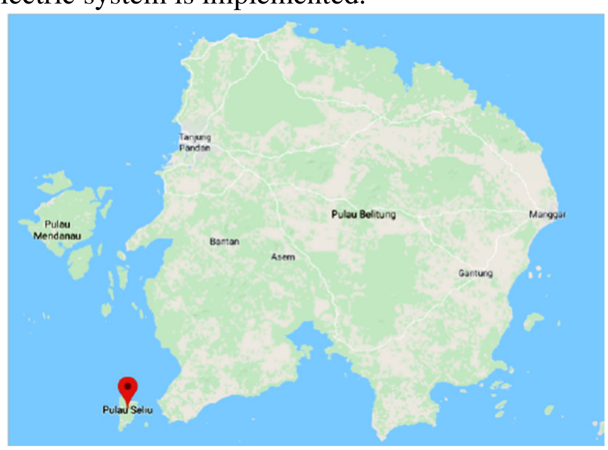


Fig. 1. Seliu Island [1]

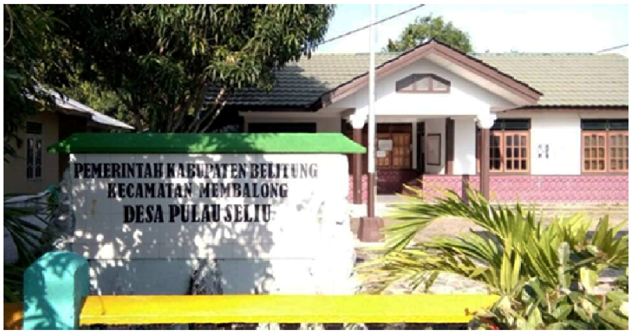


Fig. 2. Seliu Island Village office

Fig. 3. Library Building

II. DESIGN

The solar electric system installed in Seliu Island Village is off-grid, then the basic design of the solar electric system to be implemented for village office and library building by considering:

(1) The location of the Village Office and the Library Building, and the existing power lines of the diesel power plant. Aim to determine the placement of solar electric system equipment and the placement of PV, as shown in Fig. 4.
(2) The electric power from the solar electric system as a substitute power source when the power source of the diesel power plant is not available, or the utility priority.
(3) Using a portable generator, when the power source of both power sources from the diesel power plant and the solar electric system is not available.
(4) The amount of electrical energy needed by the Village Office and the Library Building.

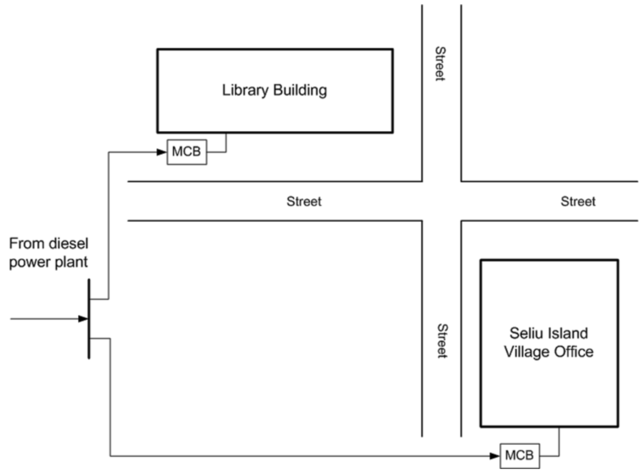


Fig. 4. The Village Office and Library Building location sketch

Sketch of Village office location and Library Building was obtained through a survey location. Then, based on sketch locations in Fig. 4 and design considerations for the implementation of solar electric system for the Village Office and Library Building in Seliu Island Village, and then drawn the layout plan of the solar electric system for the Village Office and Library Building in Seliu Island Village, as shown in Fig 5. [2,4,5].

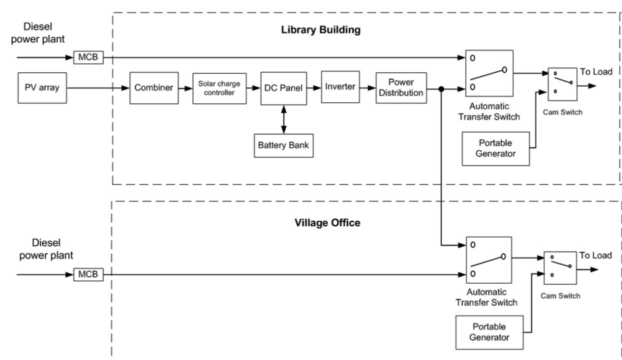


Fig. 5. The layout of the solar electric system for the Village Office and Library Building

Fig. 5 shows that the placement of solar panels (PV strings) is planned on the roof of the Library Building, because by considering the following: [6]

(1) Surface area available to install the given size PV strings.
(2) The solar energy received by PV strings with maximize

(3) Shade minimal, especially during the middle of the day
(4) The strength of structures to support PV strings and installers
(5) How far will PV strings be from the other solar electric system equipment.

Furthermore, in Fig. 5 is shown also that the whole solar electric system equipment is placed in a room in the Library Building, except for automatic transfer switch boxes (ATS) for Village Offices, placed in Village Office Building, because in the Library Building room beside having good air ventilation, it is also close to the location plan for the placement of Solar panels (PV strings). Then is shown also that the solar electric systems using two ATS, respectively for Seliu Island Village Office and Library Building. ATS is a device that automatically transfers a power supply from diesel power plant source to solar electric system source when diesel power plant source is not available until diesel power plant source is restored [7], as shown in Fig. 12. Then if the power supply from the diesel power plant and the solar electric system are both unavailable, then the power supply is obtained from the portable generator using the cam switch manually.

Furthermore, the electrical energy provided for the Seliu Island Village Office and Library Building is obtained using equation (1) [8],

$$E = P\,t \tag{1}$$

Where E is electrical energy in watt-hour (Wh), P is electric power in watt (W) and t is the duration of electric power consumption in an hour (h).

The electrical power provided for the Seliu Island Village Office and Library Building is determined, each of 920 W or the total power provided by the solar power generation is 1840 W, then, the electric power consumption is determined for 5 hours. Then, using equation (1), the electrical energy provided for the village office and library building Seliu Island, respectively 4,600 Wh, or total energy, E_{max}, which is provided is 9,200 Wh.

Furthermore, this paper used the equations of the basics of electrical, as follows [8, 9]:

$$\mathrm{V_{Series}} = \mathrm{V_1} + \mathrm{V_2} + \mathrm{V_3} + \ldots. + \mathrm{V_n} \tag{2}$$

Where V_{series} is the total voltage of several voltage sources connected in series, then, V_1, V_2, V_3, and V_n are the 1st, 2nd, 3rd and nth voltage sources respectively.

Then,

$$\mathrm{I}_{Series} = \mathrm{I_1} = \mathrm{I_2} = \mathrm{I_3} = \ldots. = \mathrm{I_n} \tag{3}$$

Where I_{series} is the total current of some current sources connected in series, then, I_1, I_2, I_3 and I_n are the 1st, 2nd, 3rd and nth current sources respectively.

Then,

$$\mathrm{V_{parallel}} = \mathrm{V_1} = \mathrm{V_2} = \mathrm{V_3} = \ldots. = \mathrm{V_n} \tag{4}$$

Where $V_{parallel}$ is the total voltage of some voltage sources connected in parallel.

Then,

$$\mathrm{I}_{Paralel} = \mathrm{I_1} + \mathrm{I_2} + \mathrm{I_3} + \ldots. + \mathrm{I_n} \tag{5}$$

Where $I_{paralel}$ is the total current of some current sources connected in parallel.

Furthermore, the equation of power can be obtained by

$$P = V\,I\,pf \tag{6}$$

Where P is electric power in watt (W), pf is power factor

A. Photovoltaic (PV)

The maximum power of PV used is determined at 200 WP (watt peak), whereas the PV specification is known through a nameplate taped to the rear of the PV panel, as follows:

1. Maximum power, P_{max}: 200 WP
2. Open circuit voltage, V_{OC}: 35.7 V
3. Maximum Voltage V_{MP}: 30.3 V
4. Maximum Power current, I_{MP}: 6.61 A

Then, the numbers of photovoltaic needed are obtained by using equation (7), as follow [9],

$$PV_{array} = \frac{PV_{array\_peak}}{PV_{peak}} \tag{7}$$

Where PV $_{array}$ is the number of photovoltaic required, PV_{array_peak} is the total maximum power of the PV $_{array}$, PV_{peak} is the maximum power of the photovoltaic.

And,

$$PV_{array\_peak} = E_{max}\frac{1}{\eta}\frac{1}{h} \quad (8)$$

Where, E_{max} is the maximum energy required, η is the inverter efficiency used is 0.8 [10], and h is the peak sun within a 24 hour period, assume the peak sun in the Seliu Island Village is 5 hours [3, 8].
Then,
with the substitution of E_{max} value, η and h to equation (7), then obtained PV_{array_peak} = 2475 W
Then,
by substitution PV_{array_peak} to equation (7), the number of photovoltaic needed is obtained,
PV_{array} = 12 panels.

B. Battery

Using a battery with a voltage of 12 V, and a capacity of 100 Ah, then the battery type is voltage regulated lead acid (VRLA). The equation for calculating the number of batteries needed, obtained by the steps as follows [9],

$$\Sigma Batt\_series = \frac{V_{total}}{V} \quad (9)$$

Where ΣBatt_series is the number of batteries connected in series, V_{total} is battery system voltage, determined of battery system voltage is 48 V, V is a battery voltage, then obtained the number of batteries connected in series,
ΣBatt_series = 4 batteries.
Then,

$$Ah_{total} = \frac{E_{max}}{V_{total}} \quad (10)$$

Where Ah_{total} is the total capacity of the battery bank, then the total capacity of the battery bank is obtained,
Ah_{total} = 225 Ah.
Then,

$$\Sigma Batt\_parallel = \left(\frac{V_{total}\,Ah_{total}}{\%DOD}\right)\frac{1}{Ah} \quad (11)$$

Where, ΣBatt_Parallel is the number of batteries connected in parallel, % DOD is the depth of discharge, determined % DOD is 70%, or 0.7, then the number of batteries connected in parallel is obtained,

ΣBatt_Parallel = 3 batteries.

Then, the total number of batteries needed is obtained through the equation (12),

$$\Sigma Batt = (\Sigma Batt\_series\ \Sigma Batt\_Parallel) \quad (12)$$

Where ΣBatt the total number of batteries, d is the day of autonomy, for the design of a solar electric system in Seliu Island Village, the number of batteries used for d = 1 day.
Thus, the total number of batteries needed is obtained,
ΣBatt = 12 batteries.

C. Solar charge controller

Solar charge controller (SCC) used is a type of photovoltaic charge controller that tracks the maximum power point (MPPT) of the PV-array, which provides maximum current for charging the battery, SCC with MPPT type allows to harvest the maximum energy available from PV_{array} and distribute it to the batteries. The MPPT algorithm continuously adjusts the PV_{array} operating voltage, so PV_{array} continues to operate at maximum power [11].

Furthermore, SCC specifications are used as shown below [12],

1. Battery system voltage: 12, 24, 48 V
2. PV open circuit voltage: 145 V.
3. Nominal PV_{array} voltage: 64 - 145 V.
4. Maximum charging current: 60 A.
5. Maximum PV input power 3200 W.

D. Inverter

An inverter used in Seliu Island Village to convert DC voltage from 48 V to pure sine AC voltage 230 V ± 10%, 50 Hz, power factor = 1, the power capacity of 4000 W [8].

III. IMPLEMENTATION AND DISCUSSION

The needed number of PV panels is 12 panels, then the number of PVs connected in series should consider the SCC specifications, as follows:

(1) The total voltage of the open circuit voltage of the PV connected in series does not exceed the SCC open circuit voltage.
(2) The total voltage of the maximum PV voltage connected in series is not lower than 64 volts,

but preferably close to 130 volts.
Thus, 12 panels of PV are connected in series-parallel as shown in Fig. 6.

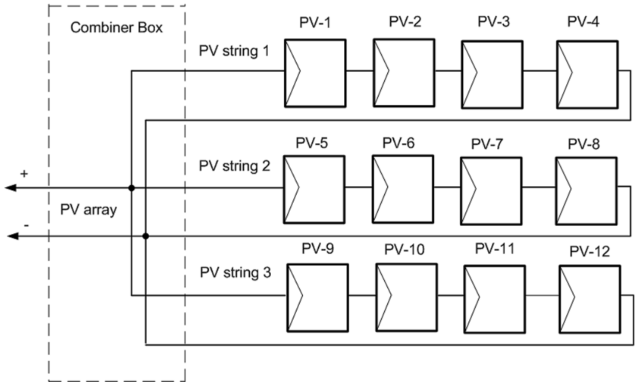


Fig. 6. Schematic 12 panels of PV in the series-parallel circuit.

Fig. 6 shows that,

1. PV string 1 is PV-1, PV-2, PV-3, PV-4 are connected in series.
2. PV string 2 is PV-5, PV-6, PV-7, PV-8 are connected in series.
3. PV string 3 is PV-9, PV-10, PV-11, PV-12 are connected in series.
4. PV array is PV string, PV string 2 and PV string 3 are connected in parallel using combiner. The combiner as shown in Fig. 8.

Thus, the total output voltage of PV string 1, PV string 2 and PV string 3, using equation (2) is obtained as follows:
maximum voltage, V_{MP} = 121.2 V, respectively, and,
open circuit voltage, V_{OC} = 142.8 V, respectively.
Then, the total current output from PV string 1, PV string 2 and PV string 3, using equation (3) is obtained as follows: maximum power current,
I_{MP} = 6.61 A.
Thus, the output of the PV array is as follows:

1. Maximum voltage using equation (4) is obtained, V_{MP} = 121.2 V, and open circuit voltage, V_{OC} = 142.8 V.
2. Maximum current using equation (5) is obtained, I_{MP} = 19.83 A.
3. Maximum power is obtained by substitution of V_{MP} and I_{MP} values to equation (6), thus obtained, P = 2403 W.

Furthermore, the PV array is mounted on the roof of the Library Building, as shown in Fig. 7.

Fig. 7. PV array is mounted on the roof of the Library Building in Seliu Island Village

Then, PV string 1, PV string 2, and PV string 3 are paralleled by MCB 1, MCB 2, and MCB 3 in the combiner box. Furthermore, the output of the combiner box is called the PV array connected to the SCC, as shown in Fig. 8.

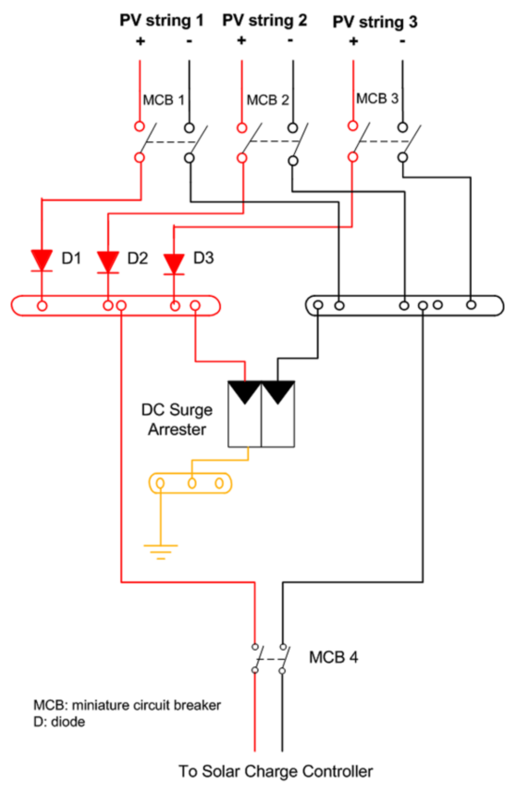


Fig. 8. Electrical wiring of PV Combiner

Furthermore, SCC will charge the battery when the input voltage of the PV array is 64 V to 121.2 V. And SCC will not be damaged, since the input voltage of the PV array does not exceed than 145 V.

Then, the output of SCC is connected to the DC panel, as shown in Fig. 5 and 9, the DC panel functions are:

1. Connecting the output of the SCC to the battery bank through a molded case circuit breakers (MCCB), MCCB 1 and 2, to charge the battery bank and provide power from the battery bank to SCC.
2. Connecting the inverter to the battery bank through MCCB 2 and 3.

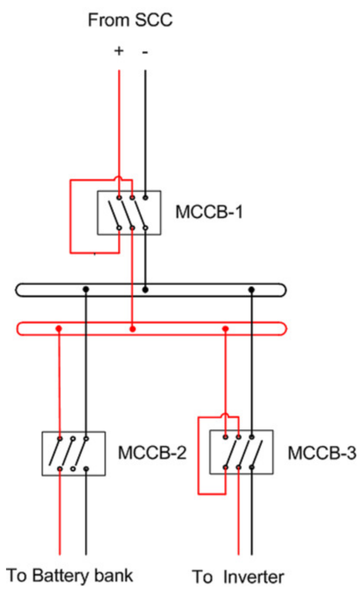


Fig. 9. Electrical wiring of DC panel

Then, based on the calculation of the total number of batteries needed, and the number of batteries connected in series is also connected in parallel, then, is obtained of series-parallel connection configuration for the batteries as shown in Figure 10, called the battery bank.

Battery bank connected to the inverter input through MCCB2 and 3 in the DC panel. An inverter is used to convert DC voltage 48 V from battery bank into pure sine AC voltage 220V / 230 V ± 10% 50 Hz. The inverter has a safety system features for a low or high battery voltage, when the battery voltage drops to 42 V then inverter shutdown, as well as when the battery voltage is 64 V [10].

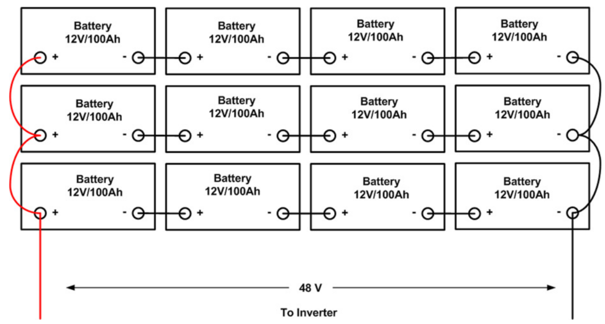


Fig.10. Battery Bank for solar electric system
for Village Office and Library Building in Seliu Island Village.

Furthermore, the output of the inverter is connected to the power distribution input, then in the power distribution panel the electric current is divided into two, for Seliu Island Village office and library building through the MCB 4 A. Then using equation (6), electric power supplied for the Village Office and Library Building are 920 W ± 10% respectively, then the total power supply provided by the solar electric system is 1840 W ± 10%, Fig. 11 shows the power distribution panel.

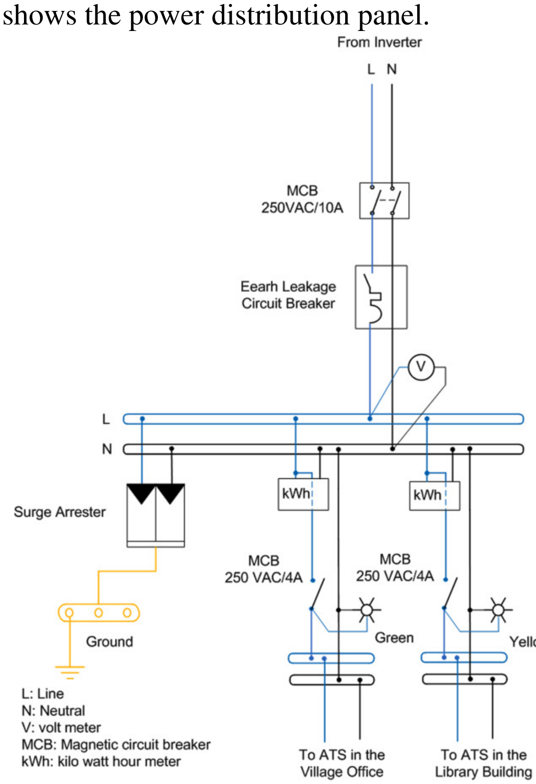
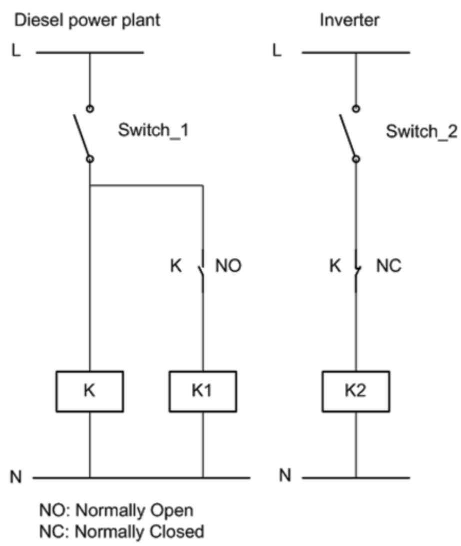
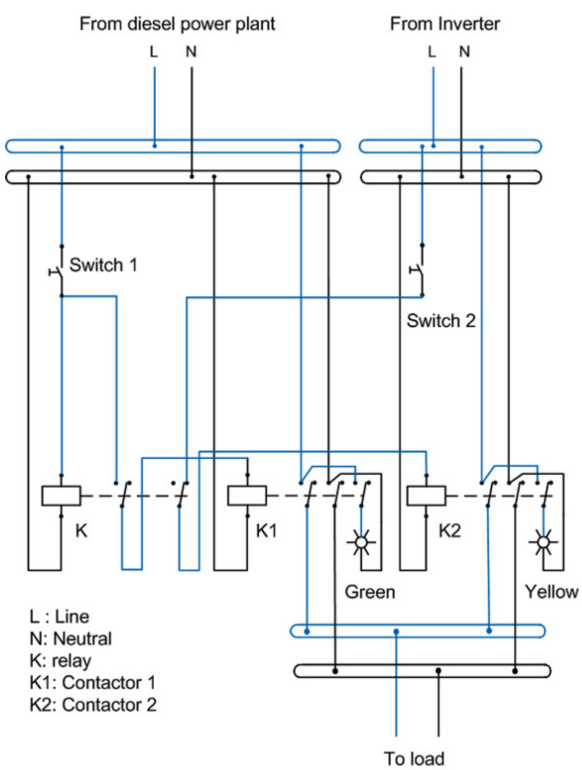


Fig. 11. Electrical wiring of power distribution panel

Then, the output from the power distribution panel is connected to two ATS boxes, each for the village office and the library building. Fig. 12 shows the ATS.



a. Control system of ATS



b. Electrical wiring of ATS

Fig.12. The automatic transfer switch

Fig.12.a. shows, K relay function to determine contactor coil K1 or K2 are energized, then contactor K1 to connect/disconnect the power source from diesel power plant to the load, while the contactor K2 to connect/disconnect the power source from the inverter to the load.

The working principle of ATS as shown in Fig. 12 are as follows:

1. If the power supply from diesel power plant is available, then the relay coil K energized, consequently through NC switch of relay K, disconnect power from the inverter into K2 contactor coil, so the K2 contactor coil is not energized.
   And, through the normally open switch of the K relay, connecting the power from the diesel power plant to the contactor coil K1, so that the contactor coil K1 is energized.
   Thus, the electrical load gets the power supply from diesel power plants through the K1 contactor.
2. If the electricity from the diesel power plant is not available, the K relay coil is not energized, consequently through the normally closed switch of the K relay, connecting the power source from the inverter to the contactor coil K2, so that the K2 contactor coil is energized.
   And, through the normally open switch of the K relay, disconnect the power source from the diesel power plant to the K1contactor coil, so that the K1 contactor coil is not energized.
   Thus, the electrical load obtains the power supply from the inverter through the K2 contactor.

Furthermore, the entire solar electric system is placed in a room in the Library Building, as shown in Fig. 13, except for ATS for Village Office, as shown in Fig. 14.

Furthermore, solar electric systems tested to supply electricity to the village office and library, data such as shown in Figure 13 are:

1. Solar charge controller
   a. Measurable battery voltage 54.5 V
   b. Charging current to battery 12.3 A

2. Inverter
    a. Output voltage 230 V
    b. Frequency 50 Hz
3. Automatic Transfer Switch
    It automatically switches connected to the inverter.
4. Distribution panel
    a. Village Office:
        Voltage 230 V, current 0 A, power 0 W. The current and power show each 0 A and 0 W, since the Village Office building is being renovated, so the electricity supply is turned off.
        Furthermore, on July 18, 2018, obtained data that the electrical energy that has been used from the solar system of 281.94 kWh.
    b. Library Building:
        Voltage 230 V, current 0.26 A, electric power 53.6 W

Fig. 13. The equipment of the solar electric system for Village Office and Library Building at the Seliu Island Village.

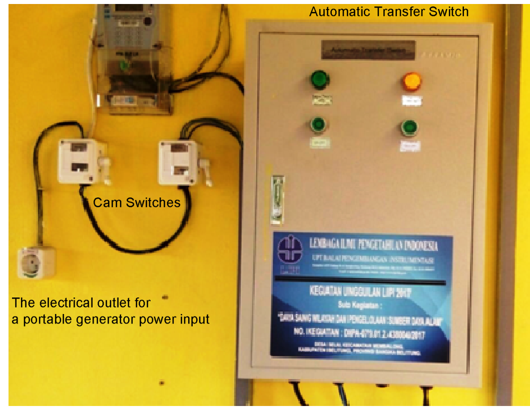


Fig. 14. The automatic transfer switch and cam switches at the Seliu Island Village Office

IV. CONCLUSIONS

The solar electric system is implemented for the Village Office and Library Building, designed by applying the utility priority principle using two automatic transfer switches, each mounted in both buildings. The Seliu Island Office and Library Building Office will obtain the supply of electricity from the solar electric system automatically if the electric supply of diesel power plant is not available. Then, if the electricity supply of both sources is not available, then the electric power is obtained from the portable generator manually.

The electric supply provided from the solar electric system for the Seliu Island Village Office and Library Building is a maximum of 920 watts respectively.

ACKNOWLEDGMENT

The solar electric system has been installed at the Seliu Island Village Office, and the Library Building in December 2017, designed by the author and supported by Kegiatan Unggulan LIPI 2017. The authors would like to thank all leaders of the Indonesian Institute of Sciences, all the team of Kegiatan Unggulan LIPI 2017 in the Seliu Island Village, and also to Seliu Island Village Chief and his entire staff.

REFERENCES

1. *Pulau Seliu. (online) Available: http://www.belitungisland.com/new/_destination.php?id=150&lang=Bahasa. [accessed: February 11, 2018].*

2. *I. N. S. Kumara, M. Ashari, A.S. Sampeallo, A.A.G.A. Prawira," Simulated Energy Production and Performance Ratio of 5 MW Grid-Connected Photovoltaic under Tropical Savannah Climate in Kupang Timor Island of Indonesia", International Journal of Engineering and Technology Innovation, vol. 7, no. 2, 2017, pp. 117 – 129.*

3. *I. R. Setiawan, A. Munandar, and A.Turnip, "Design implementation of hybrid energy pico hydro/photovoltaic for the electric water pump, case study: Samosir Island, North Sumatera", Pekan Presentasi Ilmiah-KIM ke 40, Pusat Penelitian Metrologi - Lembaga Ilmu Pengetahuan Indonesia, June 24-25, 2014, pp. 277-288. (National Proceeding)*

4. *C. Roos, M. Nelson, and K. Brockman, "Solar electric system, design, operation and installation, Extension Energy Program, Washington State University, 2009.*

5. *A guide to Photovoltaic (PV) System Design and installation, California Energy Commission, 2001.*

6. *W. Brooke and J. Dunlop, PV Installation Professional Resources Guide, Nabcep, NY, 2013.*

7. *M. Rouse, "Automatic Transfer Switch (ATS)", [online]. Available: http://searchdatacenter.techtarget.com/definition/Automatic-transfer-switch-ATS. [Accessed: February 6, 2018].*

8. *R. Mayfield, Photovoltaic design and installation for dummies, Wiley Publishing, 2010.*

9. *D.R. Patrick and S.W. Fardo, Electrical distribution systems, second edition, The Fairmont Press, Inc., 2009.*

10. *User's Manual, Inverter/Charger EP3000 Pro 1kW-6kW, Must.*

11. *Installation and Owner's Guide, Conext MPPT 60 150 Solar Charge Controller, Schneider Electric, 2013.*

12. *User's Manual, MPPT Solar Charge Controller 45A/60A, Must, 2014*