Improve Continuity Supply Of PV System Using Arduino-Based Transfer Switch

Syafii, Sisri Anisar Putri, Yona Mayura

Abstract: This paper presents the design and construction of a new power transfer switch mechanism for solar home system based on the Arduino controller to improve PV system continuity supply. The purpose of this study is to provide PV system as the main source and the electricity from State Electricity Company (Perusahaan Listrik Negara, PLN) as a backup source. The Arduino controller is used to improve the continuity of electricity supply. The measurement results of DC voltage sensors have been calibrated in a laboratory environment and the results fulfill the IEC-61724 minimum-accuracy. The power transfer has been designed to move to PLN supply when the battery remaining capacity 30 % obtained from the battery open circuit voltage which can be calculated using internal resistance prediction. The transfer switch then moves back to PV system after 35% of battery remaining capacity obtained from battery no-load voltage. The test results on various types of loads show that there was no interrupt and voltage sag during the switching process. The duration of PLN outages index is around two hours/time interruption, thus the 30 % setting PV battery SOC enough to cover PLN interruption. Therefore, the Arduino-based power transfer can improve the continuity of electricity supply.

Index Terms: Power Transfer, Transfer Switch, Arduino Controller, Improve Continuity of Electrical Supply.

1. INTRODUCTION

INDONESIA is a largest tropical archipelago country. The number of islands in Indonesia is approximately 17,000 islands [1] with a population of more than 250 million and spread over more than 65,000 regions and islands. One of the important needs in people's lives is the availability of electricity. Almost all community activities currently depend on electricity, both in office activities, households and other activities. The importance of this electrical energy makes electricity consumption increase every year. One effort that can be done to meet these needs is by utilizing a plant with renewable energy sources. Renewable energy is energy produced from sources that are not depleted or can be refilled. Indonesia has great potential to have renewable energy sources to produce electrical energy which Indonesian government policy have target in 2025 that 23% of generation mix is renewable energy. The abundant renewable energies in Indonesia is solar energy. This is due to Indonesia's geographical location across equator line, therefore photovoltaic is one of the feasible resources [2]. The utilization of sunlight energy as an alternative energy source for electricity generation is an extraordinary breakthrough. Because the sun is a very large energy source and the utilization of solar energy does not have a negative impact on the environment. With the location of Indonesia in the equator, Indonesia will always be exposed by sun around 10 to12 hours a day [2]. This makes it possible to make the solar power plant as the main source for electricity supply. In producing electricity, solar power plants are very dependent on the intensity of solar radiation. The intensity of solar radiation is best when the weather is sunny. When sunny weather per m2 solar panel produce daily average energy conversion higher than 6 kWh/m2. Whereas when the weather is not clear, the energy produced is not as much when the weather is sunny i.e less than 5 kWh/m2 [3]. The uncertainty of the power produced by this photovoltaic can disrupt the continuity of electricity distribution. Therefore, a utility power source is still needed to back up the main supply and ensure the sustainability of operational process. A controlled power transfer of critical load to prevent supply interruptions from main source or backup source, which a system can work automatically is needed [4]. This system is usually called Automatic Transfer Switch (ATS) [5]. The current power transfer development and research have use the utility grid as main source and generator as backup source [6][7], to switch emergency power supply of vehicles [8] and for high voltage load transfer. Some application has disadvantage of not using renewable energy sources as the main electricity source, even though renewable energy sources, especially PV system, have the potential to be the main electricity source. In addition, the existing power transfer moves the supply to the backup source when the electricity is completely off there is no option for operation settings.

Power transfer switch commonly used for transferring energy supplies from national grid to generators is imported products made in Canada or the United States, which are quite expensive. In addition, this transfer switch cannot be reset according to requirements. Therefore, as an alternative in this study a power transfer has been designed which can be arranged by Arduino at a more economical price. The results of the design test will be presented in this articleRenewable energy is energy produced from sources that are not depleted or can be refilled. Indonesia has great potential to have renewable energy sources to produce electrical energy which Indonesian government policy have target in 2025 that 23% of generation mix is renewable energy. The abundant renewable energies in Indonesia is solar energy. This is due to Indonesia's geographical location across equator line, therefore photovoltaic is one of the feasible resources [2].

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2 ARDUINO-BASED TRANSFER SWITCH

The Automatic Transfer Switch is an electromechanical equipment that can be controlled and that is used to move the position of the power source from the main grid of PLN to a backup power source when the electricity supply from the utility grid network is cut off. Automatic Transfer Switch will return the power supply to the normal position automatically if the electricity supply from the utility network has returned [9].

In the development of world electricity technology, the automatic transfer switch which works automatically to move power according to needs without any human power to operate it, and the operator no need always be close around the power station when the service interruption happens. For that need a power transfer switch. There are several types of power transfer switch, but the basic logic principle works the same. Likewise, power transfer can be arranged so that the main source is PV system and PLN as backup source. The power transfer design basically consists of relay, timer, contactor, and MCB and work as on – off mathematical logic. The tools in principle such as switches or breakers. An power transfer panel with function of public utility grid as main source with generator backup, using main components such as [10]: relay MK3P 220Vac , relay MK2P 220Vac/24Vdc, timer 220Vac, timer 24Vdc, contactor magnetic 220Vac, MCB 220Vac and panel box. Whereas the proposed power transfer which is used to make PV system as main source and PLN as backup source main components as follow: relay OMRON-MK2PI 220 Vac, relay 5 Vdc, voltage sensor, AC voltage sensor, LCD 16X2, and microcontroller Arduino Mega 2560.

3 RESEARCH METHODOLOGYONS

Power transfer hardware design consisting of DC voltage sensors, AC voltage sensors, Arduino MEGA 2560, 5V Relay, 220V Relay (Omron MK2P-I), LCD 16X2. Figure 1 below shows the hardware design of power transfer with Arduino control.

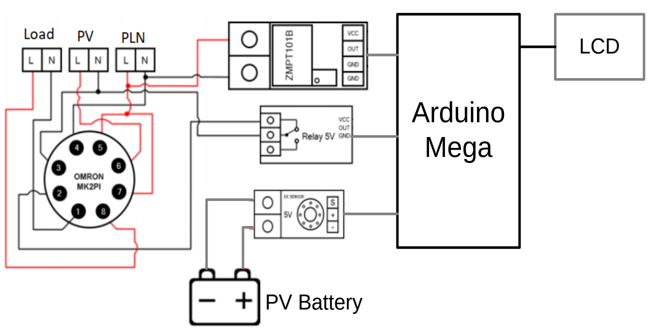

Fig. 1. *Schematic Diagram of Power Transfer*

In this study, smart automatic transfer switch was designed PV system as main source and the State Electricity Company (Perusahaan Listrik Negara, PLN) as backup source. Off grid PV stores the power generated into the battery. By reading the output voltage of the battery, information is obtained about the power remaining in the battery. The PV battery is connected to the voltage sensor module. The PV battery output voltage will be read by the voltage sensor module which will be the input for arduino mega 2560. At the same time the PV battery output voltage will appear on the LCD screen. DC current and voltage sensor modules are used to obtain the charging current and battery terminal voltage. The remaining battery capacity can be obtained from the following equation (1):

$$V_{oc\_Bat} = V_{t\_Bat} + I_{load} * R_{in} \quad (1)$$

where:
V_{oc_Bat} = battery open circuit voltage
V_{t_Bat} = battery terminal voltage
I_{load} = load current
R_{in} = internal resistance

AC load current (I_{load}) is obtained from the PZem sensor reading. As an automatic disconnect switch, a 220 V relay can be used which is driven by a 5 V relay based on Arduino control.

The calculation of available battery capacity follows the solar panel's charging current capability to service the load for each cycle without any interruption. The length of time for PV system is calculated using the following equation (2):

$$T_{Bat} = \frac{(C_{Bat} * V)/1000}{L/1000} \quad (2)$$

where:
C_{Bat} = battery capacity (Ah)
T_{Bat} = The amount of time left to use the remaining battery capacity
L = Load (Watt).
V = battery voltage (Volt)

The voltage that is read by the voltage sensor will be input to Arduino Mega 2560. Where when the battery voltage is less than 23.20 volts, and the source of PLN is available, Arduino will relay the 5V relay to work so the 5V relay is Normally Open (NO), and omron trigger relay MK2P-I to work, so that switching occurs automatically, and the load is supplied by the PLN source. However, when the PV battery output voltage that is read by a voltage sensor reaches 24.90 volts, Arduino will interfere with the 5V relay to work and trigger the Omron MK2P-I relay to work, so that switching occurs automatically, and the load is supplied again by PV system. Program making is done using the Arduino programming language to connect the Arduino ATMEGA 256 microcontroller with a voltage sensor module and a 5v relay. And making programs for display on LCD 16X2.

1. Program for voltage reading by a voltage sensor
2. Program for relay operations
3. Programs for appearance on LCD 16X2
4. Making power transfer prototype

On the project board are arranged 2 pieces of LED series with resistors and batteries, where the first LED is considered as PV supply and the second LED is considered as PLN supply. When the battery is removed, the lamp that will live is the second LED. But when the battery is reinstalled the first LED will turn on. The testing of this system will be carried out at an off grid solar power plant in the electrical engineering department of Universitas Andalas so that it can be seen whether this system works well in the transfer of electrical energy supply.

4 RESULT AND DISCUSSION

Power transfer testing have been carried out using off grid PV system which available in a research room located in the Department of Electrical Engineering, Faculty of Engineering, Universitas Andalas. The solar panel is located on the roof of the department building which consists of 4 pieces installed in parallel. To simplify the conduct of research, the solar cell source terminal is connected via a cable connected to an inverter in the research room. The source terminal of PLN is installed using a cable that has been added with a plug to facilitate the process of transferring the load supply, while for terminal load it is paired with a socket that serves to pair the load.

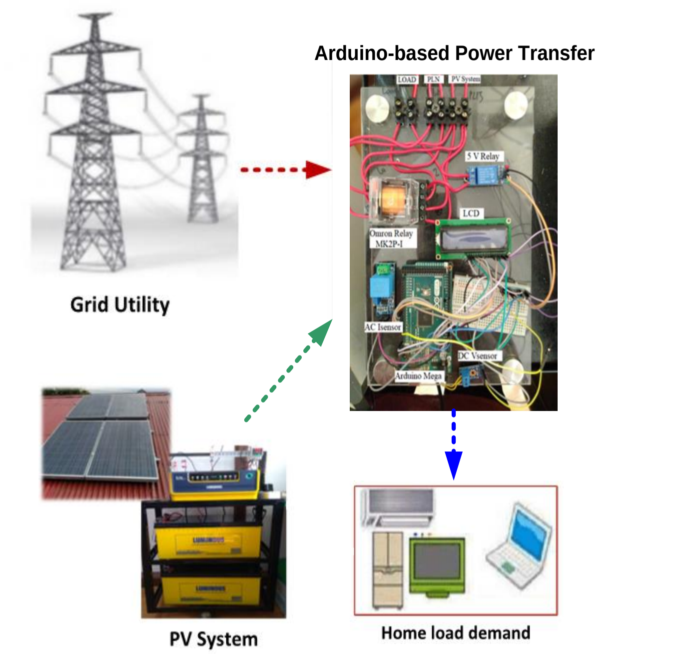

***Fig. 2**. Grid Utility and PV System Power Transfer*

The Figure 2 shows the proposed hardware of power transfer switch that are designed to make PV system as main sources and PLN as backups automatically. The load service status and the battery terminal voltage are displayed on the LCD screen. When the inverter is on, 220V relay will move from NC to NO and the load will be supplied by PV system. The DC voltage sensor and AC will send the PV battery output voltage conditions and the presence or absence of a PLN source to Arduino Mega 2560. The voltage sensor will send continuous data to Arduino Mega 2560. The PV battery output voltage data that has been sent will appear on the LCD screen along with load supply conditions. The results of testing the battery voltage sensor circuit are as shown in Table 1 below:

TABLE 1

BATTERY VOLTAGE SENSOR TEST RESULT

No	V_{sensor}	$V_{measurement}$	$V_{Mismatch}$
1	22.65 V	22.60 V	0.05 V
2	22.76 V	22.85 V	0.09 V
3	22.87 V	22.95 V	0.08 V
4	23.23 V	23.14 V	0.09 V
5	23.49 V	23.54 V	0.05 V
6	23.71 V	23.84 V	0.13 V
7	24.18 V	24.10 V	0.08 V
8	24.27 V	24.18 V	0.09 V
9	24.52 V	24.40 V	0.12 V
10	24.91 V	24.80 V	0.11 V

From the test results it was found that the average error of the measurement results by the DC voltage sensor compared with the measurement results using the SANWA CD800a multimeter was 0.089 V or 0.371%. Based on IEC-61724 standard [11] this value is acceptable because the accuracy less then 1 %. Therefore, data obtained from voltage sensor can be used as working parameter of this power transfer system. Testing the Process of Battery Charging by Solar Panels This test is done to find out whether the solar panel can charge to the battery. This is needed to predict when power will transfer. Following are the charging current data produced by solar panels:

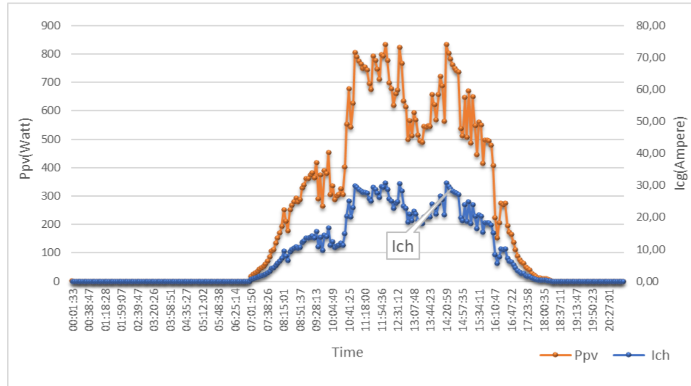

***Fig. 3**. Charging Current by PV Panels*

Figure 3 is the charging current data from solar panels to charge the battery during sunny weather. In order to estimate available battery capacity remaining, the PV loading test was conducted and achieved the result as shown in Table 2.

TABLE 2

PV LOAD TEST RESULT

No	V (Volt)	I (A)	P_{load} (W)	R_{in} (Ohm)
0	24,3	0	0	NA
1	24	0,42	92,40	0,08
2	23,7	0,85	187,00	0,08
3	23,3	1,27	279,40	0,08
4	22,9	1,71	376,20	0,09
5	22,7	2,14	470,80	0,08
6	22,6	2,57	565,40	0,07
7	22,4	3	660,00	0,06
8	22,2	3,41	750,20	0,06

The average internal resistance was used to estimate the battery state of charge (SOC) based on eq (1). The estimation of available battery capacity remaining is as shown in Tabel 3.

TABLE 3

LUMINOUS PV BATTERIES CAPACITY

Vbat	SOC (%)
22,2	0%
22,9	20%
23,6	40%
24,3	60%
25	80%
25,7	100%

The power transfer was designed based on PV battery open circuit voltage and terminal voltage parameters as shown in Figure 4. When the set point of power transfer setting reach, relay 220V will be operated to transfer the load supply. Table 4 show the battery terminal voltage before and after switching under three different test condition. The condition A shows that firstly load supplied by PV system and DC battery voltage decreased until the setting value 23.22 V, and the AC voltage sensor detect that PLN sources was available. The 5 V relay work to energized 220 V relay coil to switch to PLN, then load powered by PLN and the battery voltage after switch was 23.18 V.

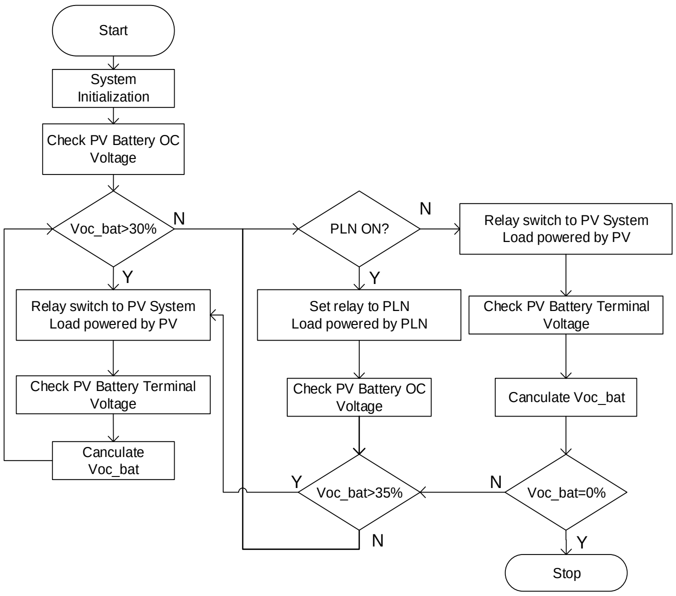

***Fig. 4**. Transfer switch Mechanism*

As well as condition B when the load is supplied by PLN, and suddenly the PLN source interrupt or not available, the Arduino will send a signal to the 5V relay to operate and 5V relay becomes in NC state, so the 220V relay coil gets voltage and moves from NC to NO, so load supplied again by PV System. When the AC voltage sensor detects the PLN source is available and the battery voltage is still below 23.20 V, the Arduino will send a signal to the 5V relay so that the 5V relay becomes NO, the power supply is released, so the coil does not voltage and common relay 220V moves from NO to NC, so that the load is supplied by PLN. However, if the PLN source is off for a long time, the PV will continue deliver power to load until the PV system is used up.

***TABLE 4**.*
EXPERIMENT TESTING RESULT

Condition	PLN	$V^{-}_{battery}$	$V^{+}_{battery}$	Power Transfer
A	ON	23.22V	23.18 V	PV to PLN
B	OFF	22.69V	22.73 V	PLN to PV
C	ON	24.90 V	24.91 V	PLN to PV

The condition C was showed switching process from PLN to PV source. When the battery voltage read by a DC voltage sensor become 24.90 Volt, the Arduino will send a signal to the 5V relay so that the 5V relay becomes NC state, and 220V common relay moves from NC to NO, so that the load is supplied again by PV system. This condition is possible to occur in the morning and sunny weather. When the load night is supplied by the PLN, the next morning when the charging current as seen in Figure 4.9 begins to increase, then when the conditions reach 24.90V the load will be re-supplied by PV system. However, in afternoon power transfer to PLN supply, it is not possible for the system to be supplied by the PV system during the afternoon until the evening, because the charging current is getting smaller and reaches 0 Ampere. Finally, the load condition test during the power transfer switching process was carried out. This test aims to obtain data on the conditions experienced by electrical equipment that are tested during the process of transferring energy supply. Some electrical equipment used in power transfer testing can be seen in Table 5. The result of Table 5 show that the load conditions during the switching process from PV to PLN or vice versa, do not have voltage interruptions and sags.

TABLE 5.
LOAD CONDITION DURING SWITCH PROCESS

Load Type	Power	Condition
Ultraviolet Lamp	8 Watt	No interrupt and sags
Computer (Monitor + PC)	54 Watt	Normal operate and no interrupt
Laminating	598 Watt	Normal work
Dispenser	325 Watt	Normal operate

Based on the tests that have been carried out with several conditions show that power transfer has worked according to the settings that have been set. Where when the PV battery voltage is less than 30% and PLN is available, power transfer is switched to PLN supply. Whereas when the PV battery is more than 35%, power transfer switched again to PV system supply. However, during PLN was unavailable or interrupted, the power transfer operated to switch or maintain PV supply uses the remaining 30% of battery capacity. The Indonesian System Average Interruption Duration Index (SAIDI) realization for 2017 is 14.61 hour/year and System Average Interruption Frequency Index (SAIFI) is 9,69 time/year [12]. In average, the duration of PLN outages is around two hours/time interrupt, thus the 30 % setting of 2@ 200Ah battery capacity sufficient to cover PLN interrupt. Therefore, the Arduino-based power transfer can improve the continuity of electricity supply. The result of solar panels performance test, the charging current produced by solar panels is not constant every hour. The size of the charging current determines the length of the battery charging process. When PLN supplies the load, and the large charging current, it only takes a short time to charge the PV battery. Since the battery is not loaded, so that all charging currents are generated by the solar panel to charge the battery. Therefore, the setting used for the load supplied by PV system is when the battery voltage is 35%. This setting was chosen to maintain load in service. If the setting was chosen 30% when the load is supplied again by PV system will take voltage drop immediately, and a few moments later switching will occur again, and the load will be supplied by PLN. To avoid switching occurring fastly and repeatedly, the setting of battery remaining capacity 35 % has been chosen for return to PV supply.

5 CONCLUSION

Based on the testing results show that power transfer has been able to work in accordance with the settings made in the process of transferring the load supply from PV to PLN or vice versa. The measurement results of DC voltage sensors can be accepted because the error value of the comparison with the SANWA CD800a multimeter measuring instrument is small at 0.089V or 0.371%. The setting chosen to move to PLN is based on the battery terminal voltage and to move back to the PLTS based on the battery open circuit voltage. The Arduino controller is used to improve continuity of electricity supply by switch to PLN during battery remaining capacity be 30% and switch again to PV after charging process which remaining battery capacity to be 35%. The different 5% of switch on and switch off setting was chosen to avoid interrupt when there is small voltage drop during switching process. The results of power transfer testing on various types of loads are when the switching process occurs that objects do not shutting down so that it does not affect load performance. For further research, it is necessary to consider charging conditions and load management in order to improve accurate battery SOC as power transfer operation parameters.

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REFERENCES

[1] Sunaryo and D. Nurachman, “Propulsion system analysis for solar-powered electric water recreational,” in E3S Web of Conferences, 2018, pp. 1–7.
[2] I. N. S. Kumara, T. Urmee, Y. Divayana, I. . Setiawan, A. A. G. . Pawitra, and A. Jaya, “Implementation of Grid-connected PV Plant in Remote Location in Sumbawa Island of Indonesia: Lesson Learned,” in International Conference on Smart Green Technology in Electrical and Information Systems, ICSGTEIS 2018, 2018, pp. 203–209.
[3] M. Mirzaei and M. Z. Mohiabadi, “Comparative analysis of energy yield of different tracking modes of PV systems in semiarid climate conditions: The case of Iran,” Renew. Energy, vol. 119, pp. 00–409, 2018.
[4] B. Tian et al., “400 V/1000 kVA hybrid automatic transfer switch,” IEEE Trans. Ind. Electron., vol. 60, no. 12, pp. 5422–5435, 2013.
[5] C. G. Sărăcin, M. Sărăcin, and D. Zdrenţu, “Experimental study platform of the automatic transfer switch used to power supplies back-up,” in Proc. 8th Int. Symp. on ATEE, 2013.
[6] R. N. Hasanah, S. Soeprapto, and H. Adi Purnomo, “Arduino-Based Automatic Transfer Switch for Domestic Emergency Power Generator-Set,” in 2nd IEEE Advanced Information Management,Communicates,Electronic and Automation Control Conference (IMCEC), 2018.
[7] D. L. Ransom, “Choosing the Correct Transfer Switch,” IEEE Trans. Ind. Appl., vol. 49, no. 6, 2013.
[8] Y. Qian, Y. Zhang, M. Chen, J. Sun, C. Du, and Y. Wang, “Application of Solid State Transfer Switch in emergency power supply vehicles,” in China International Conference on Electricity Distribution, CICED, 2014, pp. 364–368.
[9] A. F. Agbetuyi, A. A. Adewale, O. J. O., and O. D. S., “Design and Construction of an Automatic Transfer Switch for a Single-Phase Power Generator,” Int. J. Eng. Sci., vol. 2, no. 4, 2011.
[10] A. Kurniawan and Y. Taqwa, Ahmad Bow, “PLC Application as an Automatic Transfer Switch for on-grid PV System; Case Study Jakabaring Solar Power Plant Palembang,” J. Phys. Conf. Ser., vol. 1167, 2019.
[11] IEC 61724-1, “Photovoltaic System Performance Monitoring—Guidelines for Measurement, Data Exchange, and Analysis (Part 1),” Tech. Rep. 1; Int. Electrotech. Comm. (IEC)’ Switzerland, Geneva, 2017.
[12] Kepmen-ESDM-No.1567 K/21/MEM/2018, “Rencana Usaha Penyediaan Tenaga Listrik 2017,” PT.PLN (Persero) Tahun 2018-2027, 2018.