Real-Time Microgrid For Submersible Pump Energy Consumption Based On Fuzzy Logic Controller

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***Abstract*—With increasingly depleting fuel sources for electrical energy needs, the use of photovoltaics (PV) in microgrid systems can be a solution to meet electrical energy needs. The use of submersible pumps generally still uses electrical energy from the utility grid. When the location of the submersible pump is in a location within reach of the utility grid, PV can be used as a source of electrical energy. The aim of this article is to design a microgrid system with a PV source equipped with batteries to supply electrical energy to submersible pumps in rural areas. Apart from that, to regulate the energy flow to the pump, a Fuzzy Logic Controller (FLC) is used. FLC uses PV and battery inputs and DC voltage output. The method used in this research is a real-time implementation of a microgrid system and a 5 Hp three-phase submersible pump controller. Microgrid uses multi-PV with a capacity of 20 kWp. The study results show that the PV source and battery in the microgrid system are capable of supplying electrical energy to the submersible pump. When the weather is cloudy the battery is able to supply energy to the load.**

Keywords*—*Microgrid, Multi-PV, Submersible Pump, Fuzzy Logic Controller, Battery

I. Introduction

Submersible pumps are those that are submerged in water. This type of pump is often used in industry, restaurants, housing, government buildings and remote areas. For use in residential areas, many pumps are used with capacities between 1 HP and 5 HP. The weakness in using this type of pump is that it causes electrical energy consumption, which is caused by the starting current being quite high. The controller for low power submersible pumps still uses the DOL (direct line) system. Therefore, an electrical energy source is needed that is able to meet the loads energy needs. Therefore in this study a microgrid system is proposed [1], [2].

The authors research [2] on the supply of energy sources for microgrids suggests providing electrical energy sources for homes equipped with microgrid systems. The suggested microgrid system is linked to the utility grid and has the ability to function in islanded mode. The microgrid synchronizes with the utility grid when it is connected to the grid. Photovoltaic (PV) sources and batteries for energy storage power a microgrid. The load demand in the suggested system is modified in response to the harmonic currents magnitude and the reactive powers appearance. The system of electrical energy supply for dwelling with continuous power supply is proposed by author [3]. The size of the solar panels and battery storage are taken into consideration in the suggested design. Batteries and solar panel energy flow is regulated using a novel control technique. The increase in load power can be satisfied using this technique. A DC/AC inverter is incorporated with the suggested control mechanism. Author [4] suggests using renewable energy to modify the IEEE 39-bus system using a linear model. The CHPIP-SACC model is the one being utilized to track the energy sources flow characteristics. In the meantime, a power supply to housing with linear quadratic control is suggested by the author [5]. Using an LCL filter, a PV source is connected to a single-phase grid in this manner. The Perturb and Observe (P&O) technique is used to maximize the PV output in order to achieve DC bus stability. Simulated and actual data were compared to conduct the study. The usage of solar energy is rising in tandem with the number of dwellings. The suggested solution makes use of an autonomous DC-AC that is linked to the utility grid and a bidirectional DC-DC converter. The system uses a DC bus voltage of 1500 V. By adopting energy management, the power supply to homes can be made more stable. Efficiency will rise when the appropriate DC voltage is obtained using this technique [6], [7]. As control tactics advance, the use of PV keeps expanding. PV arrays, which are made up of PV modules coupled in series and parallel, are utilized to offer a substantial supply of electrical energy. In order to provide load energy stability in the event of PV output fluctuations, the grid-connected PV array mode is employed [8]–[10]. An incremental adaptive filter is suggested in order to enhance PV performance. When the utility grid varies, this technique uses numerous PV and batteries to match the load requirements. In order to lower output harmonics, adaptive filters are employed to modify the PV and battery output to the inverter. When applied to non-linear loads, this filter will also raise the power factor. The suggested system's battery will enhance the housings energy smoothing [11].

By implementing a monitoring system, solar energy from photovoltaic cells can be used more efficiently. Power generating researchers face a challenge from the ever-changing nature of renewable energy. Authors [12], [13] suggest using solar energy sources for Internet of Things (IoT)-based monitoring. The amount of solar energy that can be converted into electrical energy is estimated by the author. When compared to the prior approach, prediction utilizing the selection operator algorithm and the least absolute shrinkage yields good accuracy. Accurate forecasts of solar energy are generated with limited data. The results of simulation and implementation demonstrate how well IoT works in solar and photovoltaic systems. A dependable Internet of Things design with sensors and communication technologies is put out by author [14]. Battery monitoring with SOC settings is done

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using the Internet of Things system. It is possible to provide dwelling loads with battery and photovoltaic energy by making arrangements based on the availability of battery energy. In addition, the author employs the MPPT algorithm on the DC-DC converter to boost the PV output. For the purpose of managing electrical energy in homes, it is crucial to forecast the strength of solar radiation in regions with notable weather variations. Up to 20% less errors can be made in the author's forecasts [15]. Author [16] suggests using IoT to track solar energy availability in order to improve PV energy flow. As a result, the author creates a schedule to determine the solar energy's potential intensity. For the purpose of maximizing potential from the source side, the author employs a linear program (LP). The research findings show 58.25% against LP. Using the AquaE-lite prototype, author [17] created a monitoring system that can detect optical signals up to 30 m away. The author used 1.6 Mbit/s and 1.2 Mbit/s data rates. When it comes to assessing the potential of solar energy for meeting electrical energy needs, the monitoring system performs well. Reseachers [18]–[20] IoT devices with weather sensors integrated to forecast the amount of solar radiation. One approach to forecasting and other signal processing is to use the internet and cloud services. Nevertheless, in order to store picture data and stream the cloud to household loads, this system needs a lot of bandwidth. As a result, the author combines a convolutional autoencoder (CAE) with IoT. The similarity index is 99% and the image capacity is 2% less with this method than with the original data. To deploy IoT, a Raspberry Pi is used. An Internet of Things system with a converter to control the energy flow to the load is suggested by authors [21]–[23]. Authors can more easily estimate solar energy with the help of IoT. The study's findings indicate a 12% boost in efficiency compared to the industry-standard IoT model. The converter in use is based on a switch with a capacitor. The suggested IoT system generates an efficiency of 82,4% during the simulation phase. Furthermore, the monitoring system can make use of the Arduino Uno gadget. In order to minimize forecast errors, author [24] is interested in utilizing IoT to predict battery energy as a backup energy source in addition to solar energy for communication channels that use uplink access and two-stage RL networks. According to study findings, an IoT system that uses an RL network performs better. The advancement of IoT offers ways to use smart grids more effectively, such as improved meter infrastructures (MI). Renewable energy is used by several smart grid sources. IoT is used by author [25] to show daily MI statistics. IoT was invented with backscatter communication by the author [26]. The primary goal of this approach is to enhance IoT performance through the usage of sensors. Finally, the author [27] suggests utilizing the Internet of Things to solve the power schedule problem (PSP) and regulate load power and other electrical equipment. Metaheuristics were used in this study's development of the PSP algorithm, which produced a high program execution capability. In order to achieve the balance between the source and the load sides, this method is applied to the load on the housing.

Based on previous research, the author focuses on the design of a microgrid system to supply submersible pumps. Microgrids use multi-PV and batteries. To regulate the energy flow to the load, a Fuzzy Logic Controller (FLC) is used. Energy flow regulation is implemented using the Outseal Mega V2 PLC. The structure of this article after the introduction is Part II: Multi-PV model, Part III: Proposed Method IV: Results and Discussion, and Part V: Conclusion.

II. MULTI-PV MODEL

In using photovoltaics (PV) in a microgrid system, a PV model is carried out to analyze the magnitude of changes in DC output relative to the intensity of solar irradiation. A PV model can use one diode, two diodes, multiple diodes according to the required output energy parameters. In this research, a diode and multiple diodes will be used, to differentiate each required parameter. Figure 1 shows a model of a PV.

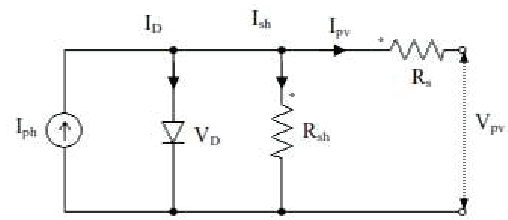

Fig. 1. PV equivalent model.

The power performance of a PV array depends on solar radiation and environmental temperature. The power output in this model is determined as follows

$$P_{pv} = \eta_{pv} \times A_{pv} \times I_r \tag{1}$$

Based on equation (1), the PV output power (P_{pv}) depends on the PV generation efficiency (η_{pv}), the PV cross-sectional area (A_{pv}) , and the intensity of solar radiation (I_r) . Meanwhile, PV generation efficiency (η_{pv}) is influenced by PV module efficiency (η_r) and power conditioning efficiency (η_{pc}). The module efficiency (η_r) depends on the temperature coefficient (β) and the difference between the cell temperature (T_c) and the reference cell temperature (T_{cr}), the equation is as follows.

$$\eta_{pv} = n_r \times \eta_{pc}[1 - \beta(T_c - T_{cr})] \tag{2}$$

The temperature coefficient (β) is 0.004 - 0.006 / ºC. The magnitude of the reference cell temperature (T_{cr}) is greatly influenced by changes in environmental temperature (T_a), still according to equation (2). Meanwhile, the influence of solar radiation intensity (I_r) in this equation also depends on the nominal operating cell temperature (T_{op}). The equation for a PV can be expressed with the following equation.

$$I_D = I_0 \left\{ \exp\left(\frac{V+IR_S}{nN_sV_t}\right) - 1 \right\} \tag{3}$$

Based on the PV cell equivalent circuit, the total current at the PV module terminals is expressed by the following equation

$$I = I_{pv} - I_0 \left\{ exp\left(\frac{V+IR_S}{nN_sV_t}\right) - 1 \right\} - \frac{V+R_sI}{R_{sh}} \tag{4}$$

Figure 2 shows the equivalent circuit of the multi-PV model. Under ideal conditions R_{sh} has a very large value so that the current flowing through the resistance is small, while R_s has a very small value to avoid a decrease in the output voltage.

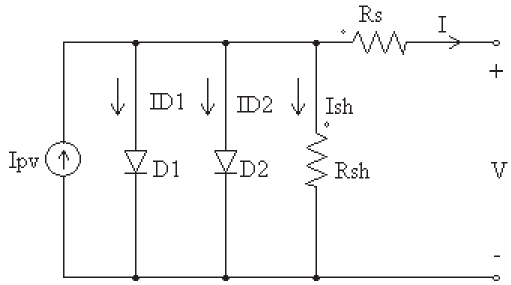

Fig. 2. Multi-PV equivalent model.

For an arrangement of PV cells connected in series and parallel each will provide an output voltage and output current, so that it is mathematically expressed by the following equation

$$R_{sP} = \frac{N_s}{N_p} \times R_s \quad (5)$$

$$I_{pvP} = N_p \times I_{pv} \quad (6)$$

III. Proposed Method

In this research, Fuzzy Logic Controller (FLC) microgrid based control method is proposed to regulate the output of multi-PV and batteries in supplying the load. The proposed FLC uses Outseal PLC Mega V2. Microgrids use solar energy which can be obtained for free in Indonesia. In this study multi-PV with a capacity of 10 kWp. Multi-PV consists of PV-A, PV-B, PV-C, and PV-D. PV-A and PV-B are controlled simultaneously with the DC-DC converter, while PV-C and PV-D are also controlled simultaneously with the DC-DC converter. In this system a battery bank with a capacity of 5000 Ah is used. FLC will control each circuit breaker (CB) on multi-PV and battery. FLC is designed with three inputs, namely PV-AB, PV-CD, and battery, while the output is DC bus voltage. The proposed microgrid design is shown in Figure 3.

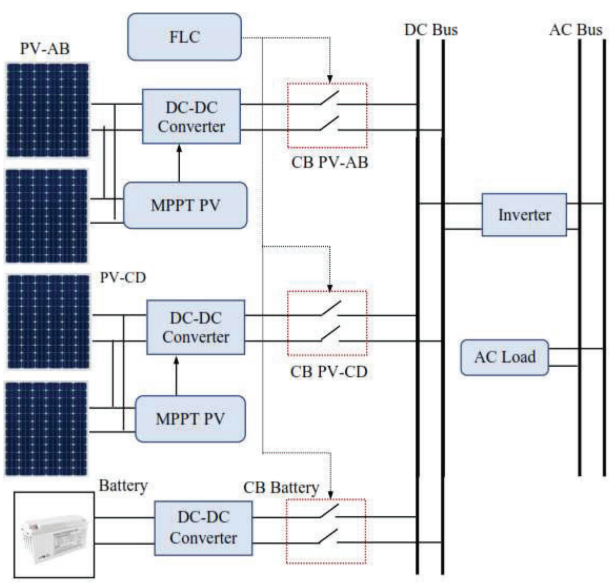

Fig. 3. Block diagram of microgrid design.

The FLC design is shown in Figure 4. Each input has three membership functions, while the output also has three membership functions. Fuzzy Mamdani was used in this study.

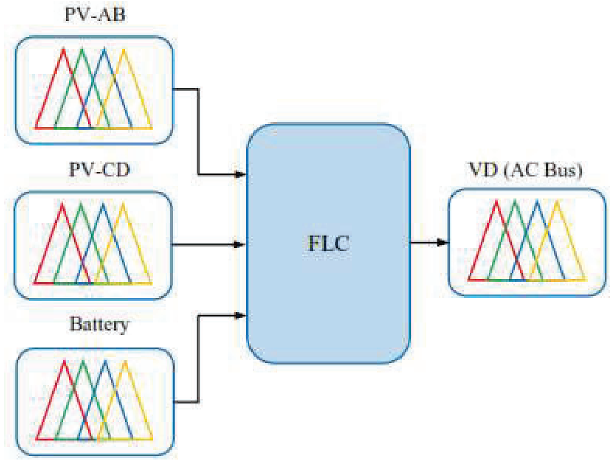

Fig. 4. Block diagram of FLC design.

TABLE I. Rule Base FLC

PV AB \ PV CD, B	N	Z	B
N	Z	B	N
Z	N	ZE	B
B	B	N	ZE

Table 1 shows the FLC rule base for regulating the energy flow of each PV and battery to the submersible pump, while Table 2 shows the PV data used in the microgrid system.

TABLE II. PV Parameter

Parameter	Value
Maximum power Pmax (Wp)	500
Voltage at Pmax (V)	42.8
Current at Pmax (A)	11.69
Open circuit voltage (V)	51
Short circuit current (A)	12.28
Panel size (mm)	2185 x 1098 x 35
Weight (kg)	26.5
Cell type	Mono-crystalline silicon

IV. Results and Discussion

This study was conducted in the Gunungpati area, Semarang city, Central Java. The area is not covered by the utility grid. In the initial stage of this study, measurements of the intensity of solar irradiation were carried out as shown in Figure 5. Measurements were carried out in the time range from 06.00 to 18.00. This aims to determine the potential of solar energy to be used for microgrid systems. In this study, the irradiation intensity was highest during five hours, namely from 09.00 to 14.00. The irradiation intensity in this study was 700 Wh/m^2. The intensity of solar irradiation begins to decrease as the afternoon approaches. This is a problem in microgrid systems, because PV output depends on the intensity of solar irradiation. Apart from that, cloudy weather also greatly influences PV output. Therefore, in the proposed microgrid system, to overcome changes in PV output, batteries are used.

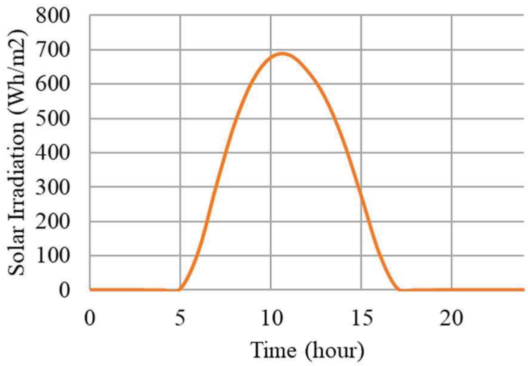

Fig. 5. Radiation intensity.

Fig. 6. Location of submersible pump.

Figure 6 shows the installation location of the submersible pump. The location in this study is in a rural area that is not covered by the utility grid. In this location a three-phase pump with a capacity of 5 HP is installed. In this research, a soft starter was used for a submersible pump motor with type ATS01N212QN. This aims to reduce the motor starting current which is usually very large at start. The Direct On Line (DOL) system will provide a high initial current when used for submersible pumps, which is usually five times the nominal current. The motor control system using a soft starter is shown in Figure 7.

Fig. 7. Control system for submersible pumps.

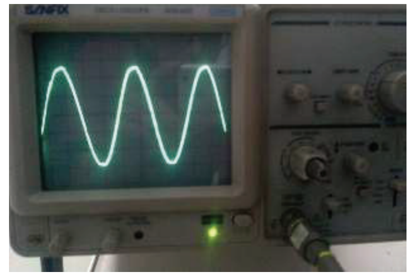

Fig. 8. Solar inverter output voltage.

In Figure 7 there is also a centralized controller using an outseal PLC. Meanwhile, Figure 8 shows the output voltage of the solar inverter in a microgrid system. The output voltage of this inverter is used as submersible pump controller input or soft starter input. The figure shows that the voltage for one phase is 220 V, because the submersible pump operates at a three-phase voltage of 220 V.

Fig. 9. PV Control System.

Figure 9 shows the control system for multi-PV. In the system shown in Figure 9 it is used to regulate the energy flow from PV-AB or PV-CD. The system is equipped with MPPT to maximize PV output.

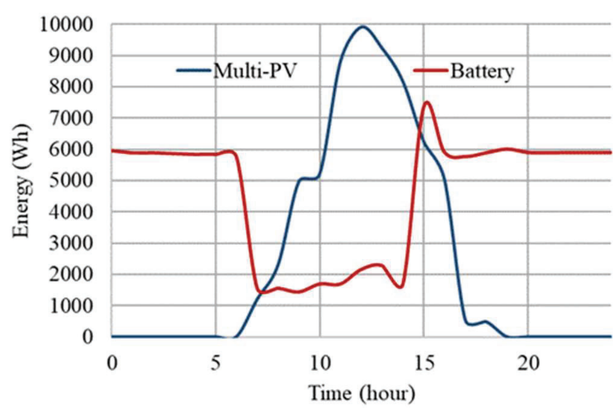

Fig. 10. Multi-PV and battery energy output.

Figure 10 shows the arrangement of electrical energy from each PV and battery to the load. In the figure, it can be seen that multi-PV provides maximum energy to the load from 10.00 to 14.00. in the figure you can see the battery supplies energy to the submersible pump from 18.00 to 07.00. Before 10.00 multi-PV and battery simultaneously supply the load.

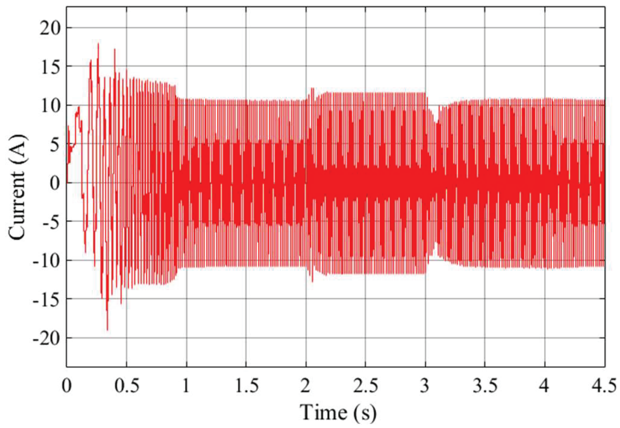

Fig. 11. Submersible pump motor current.

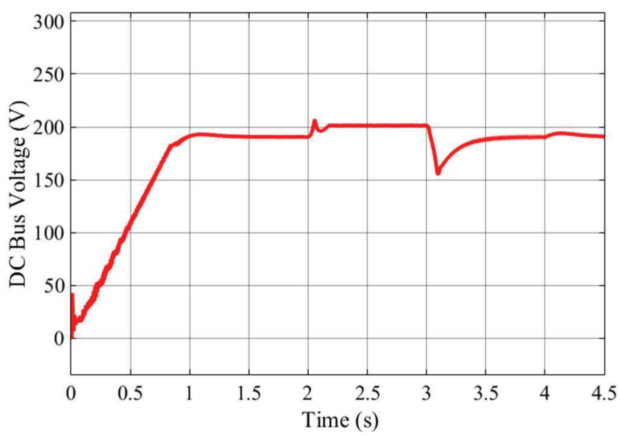

Fig. 12. Voltage on DC bus.

Figure 11 shows the motor current when operating to rotate the submersible pump. It can be seen in the figure that from 3 seconds to 4.5 seconds the motor is supplied from the battery, while from 0 seconds to 3 seconds the motor is supplied from multi-PV. Figure 12 shows the DC bus voltage with a PV source and battery. Voltage changes are caused by changes and changes in the supply of energy sources. Within 0 seconds to 3 seconds the DC bus is supplied from the multi-PV, then the DC bus is supplied from the battery.

V. CONCLUSION

Microgrid systems are really needed to meet electrical energy needs in remote areas that are not covered by utility grids. The use of solar energy sources with PV can be used as the main source in a microgrid system. However, the use of PV experiences intermittency due to weather changes and to overcome this problem in this study batteries are used, so that they can serve the load needs. The study results show that the microgrid system can be used to supply electrical energy for submersible pump operations. Apart from that, the use of a soft starter controller is very helpful in saving electrical energy in the microgrid system.

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