Appropriateness analysis of implementing a smart grid system in campus buildings using the fuzzy method

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ABSTRACT

The smart building campus is still being studied by researchers until now. Given the importance of meeting key performance indicators on smart campuses. Medan Area University is a campus that uses a smart grid system to solve energy management problems. With the position of the Medan Area University being in an area that has the potential to utilize photovoltaic (PV) solar renewable energy sources. With the designation of Google Earth data, the average sunlight intensity in the campus area is 4,528 KWh/m^2. The design of the smart grid system is carried out by making solar PV solar as the main source and 4 computers as loads. The fuzzy method was chosen in the smart grid system simulation that has been designed because the fuzzy method can provide decisions in the intersection area. To facilitate analysis The MATLAB program is used to assist in the simulation. So that the output can show results that are close to real conditions. Based on 144 hours of data that has been entered into the fuzzy method, the output shows the results are appropriate to be implemented.

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1. INTRODUCTION

Electricity as a source of energy in a building has an important role in the sustainability of activities in the building. This also adjusts to campus buildings, lecture facilities, laboratories, administration, and worship require electrical energy to support the activities in campus building. To achieve smart building campus, it must be fulfill key performance indicator (KPI) in smart campus and smart microgrid [1], [2]. Green energy is included in that KPI which obtaining reduce CO_2 emission. Hence, this research utilizes renewable energy to follow that KPI.

Several ways have been done to provide uninterrupted electrical energy, such as wind [3]–[5], micro hydro [6], and solar panels [7]. Utilization of renewable energy as a future energy source needs to be implements in smart grid system to ensure efficient energy management [8]. Meanwhile, according to Alotaibi *et al*. [9] in paper a comprehensive review in sustainability in smart grid that smart grid classified into seven categories that comprise actor and application. The actor include renewable energy generation, smart meter, control systems, programs, decision makers, and telecom stations. The application include energy management, site automation, and energy storage [9].

Therefore, the research method in this paper uses power central plant combine with solar panel system as energy sources. Hybrid inverter as an information processing supports the smart grid system. The information processing controls the electrical transmission from sources to the loads. The infrastructure that uses in this research is four computers in the campus building itself.

Utilization of renewable energy sources is the right step to ensure the availability and sustainability of electrical energy sources. Photovoltaic (PV) solar system that uses in this research is one of the renewable energy sources. The ability of PV solar system depends on the weather condition. Indonesia is called by equator country, which have two season such as summer and rainy season. Which is the sunlight intensity influenced by those seasons. North Sumatera is one of province in Indonesia. Medan Area University is located in North Sumatera. Through the google earth application, it is known that the intensity of sunlight in the Medan Area University area that is located at coordinates (03036’04’’, 98043’06’’) in North Sumatera. It has a sunlight intensity of 4,528 KWh/m^2. Therefore, it can be seen that the Medan Area University area has great potential for solar power generation.

Research that has been carried out by authors are regarding the power flow of the smart grid system in the Medan Area University campus building [10], optimization of the smart grid system in the Medan Area University campus building [11], and electrical energy efficiency with the smart grid system in the Medan Area University campus building [12]. The energy management system of the development of solar photovoltaic technology is a challenging task. Adequacy analysis is carried out by looking at consumer flexibility and performance analysis of energy management systems can be carried out using the MATLAB/Simulink platform [6]. Beside the MATLAB program, the analysis of energy system can be used hybrid optimization of multiple energy resources (HOMER) software [13] and machine learning [14]-[16].

Meanwhile the smart grid system is a system that optimally manages electricity by integrating renewable electrical energy sources and ensuring the availability of electrical energy. To ensure the availability of electrical energy in the designed smart grid system, it is necessary to test using the fuzzy method. Several fuzzy methods is used for decision techniques to evaluate a lot of problem such as, the assessment of battery energy storage [17], the prioritization of renewable energy sources [18], efficiently predict of short term load consumption [19]. On the other hand, fuzzy is also support the reinforcement learning process [20].

In this paper, the authors conducted research related to the smart grid system using fuzzy analysis. Fuzzy logic has been applied to many fields, such as control, and artificial intelligence. Through fuzzy logic, decision-making is not done classically, but is done with a range of membership values [21], [22]. The formula that produce for fuzzy method simulation is using membership value as indicate in (1).

$$\mu(x) = \begin{cases} 0; \; x \leq a \; or \; x \geq c \\ \frac{(x-a)}{(b-a)}; \quad a \leq x \leq b \\ \frac{(b-x)}{(c-b)}; \quad b \leq x \leq c \end{cases} \tag{1}$$

From (1), a fuzzy function will be formed which can be seen in Figure 1. The system will be represented by a constant *U* while membership is represented by a constant *x*, where the value of *x* varies from a to c. For area $x \leq a \; or \; x \geq c$, the system does not match. This means that the source is not able to meet the energy consumption of the load. If the area is in $a \leq x \leq b$, it means that the system will appropriate and the value of its members is $\frac{(x-a)}{(b-a)}$. For a system in the area $b \leq x \leq c$, it means that the system will appropriate and the membership values are $\frac{(b-x)}{(c-b)}$. Thus, the analysis using the fuzzy method can be recommended to determine the electrical management in the campus building that has been implemented.

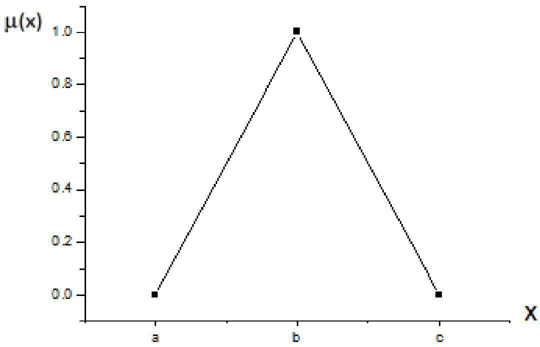


Figure 1. Membership function for set x

To ensure the accuracy of the decision model not only on the source but also on the load (in this case it is used as input to the simulation program) [19]. The predicted electrical system as shown in Figure 2, it shows the main system input more than two inputs. Then it is continued in the database learning system by following fuzzy rules so that it will produce consumption predictions [19].

This paper aims to analyze the appropriate of implementation smart grid on campus buildings using the fuzzy method. Appropriate analysis on a smart grid system is designed by involving a central power plant and solar PV as a source and utilization of electricity in the engineering faculty building as a load. The design of the smart grid system in the campus building is described in the form of a mathematical model. Then the mathematical model was analyzed using the fuzzy method. The fuzzy method will show that the components in the smart grid system are included in the fuzzy membership values, until the smart grid system is implemented. The result of fuzzy analysis means the appropriateness in energy management which designed. To simplify the simulation, the MATLAB program is used to support the analysis of the fuzzy method.

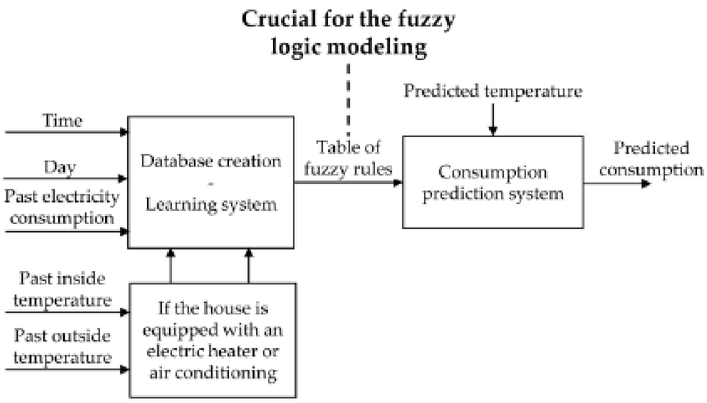


Figure 2. Diagram of electricity prediction system [19]

2. RESEARCH METHOD

The appropriateness analysis of the electrical system in the smart grid system requires communication between sources in making decisions so that the availability of electrical energy sources can be guaranteed. The communication required, namely: i) the system is stable if the source provides sufficient power to the entire load, ii) PV solar/active battery, if power central plant lacks energy, and iii) the battery is charged, if power central plant has more power. Therefore, in this system the battery acts as a source and load. The system simulation in this study can be seen in the following one-line diagram as shown in Figure 3.

Bus 1 consists of G_1 which is a source of power central plant electrical energy called P_{S1}. Bus 2 consists of G_2, which is a source of solar cell energy called P_{S2}, and a battery (P_o) is a source of energy stored by P_{S2} and P_{S1}. Bus 3 is the load on the campus building which consists of 4 (four) computer administration (P_{L1}), (P_{L2}), (P_{L3}), and (P_{L4}) as shown in Figures 3 and 4.

The implementation of a distributed architecture in a smart grid system will achieve reliability, efficiency, and cost reduction through power management as shown in Figure 4 [23]. In this study, one of the components in this smart grid system is a solar power plant. This solar power plant has specifications as shown in Table 1.

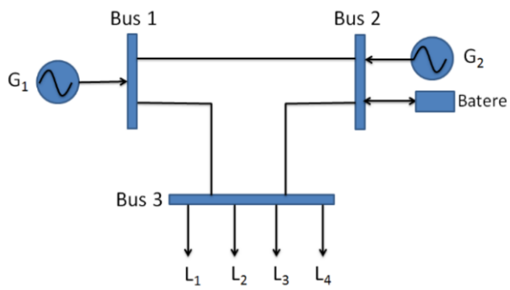


Figure 3. One line diagram system

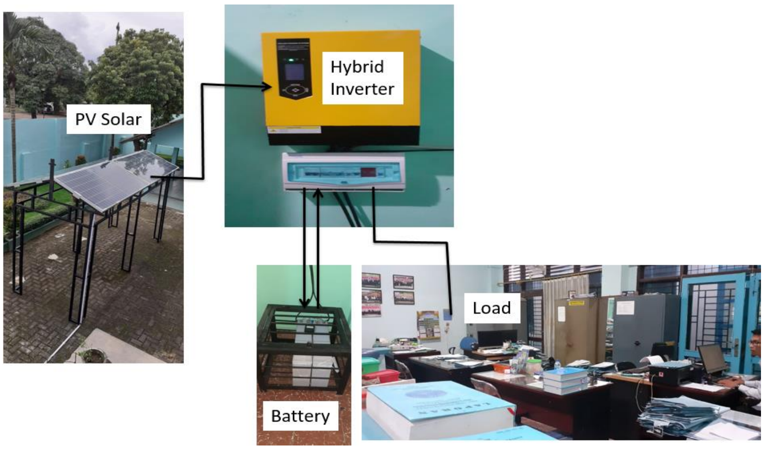


Figure 4. Implementing smart grid system in campus building

Table 1. Specification of PV solar system

Device's Name	Specification	Quantity
Solar Panel	Polycrystalline 400 WP	2
Battery	SMT VRLA 175 AH/12 V	2
Cable	4 mm^2 2 way weatherproof	
Battery Equalizer	Battery equalizer be24	2
Hybrid Inverter	2 kva/revo-e series hybrid solar inverter technical specification built-in mppt solar controller	1

In the solar power generation device, a hybrid inverter is used. Which aims to actualize the automation system on the smart grid system. The optimization technique is required in an automated system to apply some resources optimally [24], [25]. Furthermore, the smart grid power system is analyzed using the fuzzy method. So, it needs to be derived in the form of a mathematical equation. The mathematical modeling of the smart grid system is designed as shown in (2) is being as:

$$SG = \begin{cases} 0 & P_{S2} = P_{L1} + P_{L2} + P_{L3} + P_{L4} \\ P_{S1} & P_{S2} < P_{L1} + P_{L2} + P_{L3} + P_{L4} \\ P_o & P_{S2} > P_{L1} + P_{L2} + P_{L3} + P_{L4} \end{cases} \quad (2)$$

PV and load data collection was carried out for 144 hours as shown in Table 2.

Table 2. The measurement result for 144 hours

No	Day/Date	PV (Watt)	Load (Watt)
1	Monday/27 September 2021	274.56	5.44
2	Tuesday/28 September 2021	302.11	8.02
3	Wednesday/29 September 2021	289	7.59
4	Thursday/30 September 2021	248.89	7.11
5	Friday/1 October 2021	251.89	6.74
6	Saturday/2 October 2021	356.8	8.42
7	Monday/4 October 2021	249.11	7.73
8	Tuesday/5 October 2021	339.67	12.82
9	Wednesday/6 October 2021	298.56	11.49
10	Thursday/7 October 2021	236.33	6.44
11	Friday/8 October 2021	354	11.09
12	Saturday/9 October 2021	370.8	11.77
13	Monday/11 October 2021	304.33	12.45
14	Tuesday/12 October 2021	297	11.64
15	Wednesday/13 October 2021	268.33	10.67
16	Thursday/14 October 2021	296.33	8.15
17	Friday/15 October 2021	255.78	9.88
18	Saturday/16 October 2021	334.4	10.23
19	Monday/18 October 2021	388.8	15.55

From the data shown in Table 2, it is known that the minimum power obtained by PV solar is 236.33 watts and the maximum power obtained from PV solar is 388.8 watts with a peak load of 15.55 watts. Therefore, it can be seen that the output produces three conditions namely:

$$\text{Stable: } 236.33 \le P_{s2} \le 388.8\, watt \quad (3)$$

$$P_{s1} \text{ active: } < 236.33 \quad (4)$$

$$P_0 \text{ active: } > 388.8 \quad (5)$$

Based on these conditions, it can be seen that the fuzzy membership function in stable conditions derived from substitute (3)-(5) to (1), that is:

$$\mu(x) = \begin{cases} 0; & x \le 236.33\ or\ x \ge 388.8 \\ (x - 236.33)/(76.235) & 236.33 \le x \le 312.565 \\ (76.235 - x)/(76.235) & 312.565 \le x \le 388.8 \end{cases} \quad (6)$$

The Figure 5 shows block diagram of decision system which is used in implementation smart grid system in campus building with fuzzy method. Based on Figure 5, the electricity prediction system can be seen in the block diagram. At the moment, it can be modified for decision system such as smart grid implemented in this case.

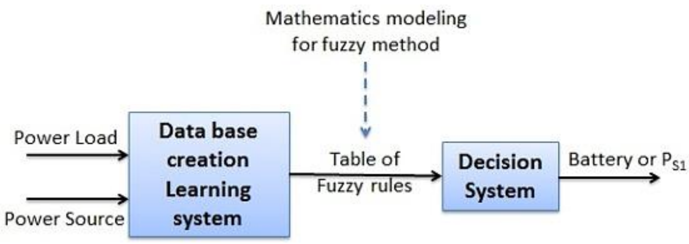


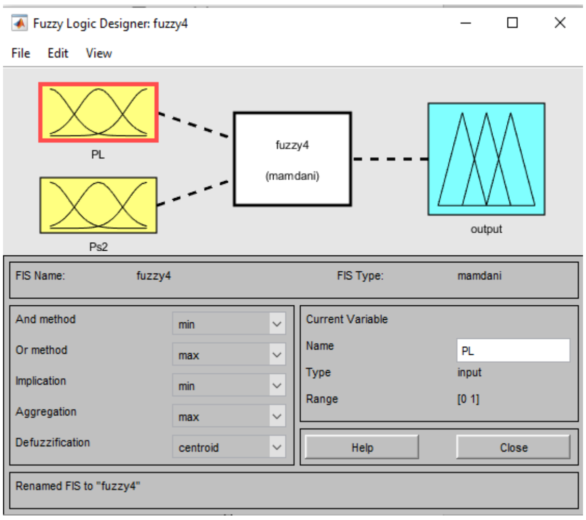
Figure 5. Block diagram of decision system

The block diagram is composed by 2 inputs: power load and power source with data taken from Table 2. The expected results from the decision system are switch source to battery or P_{s1}. The decision system is to make sure that the smart grid system running well without lack of energy.

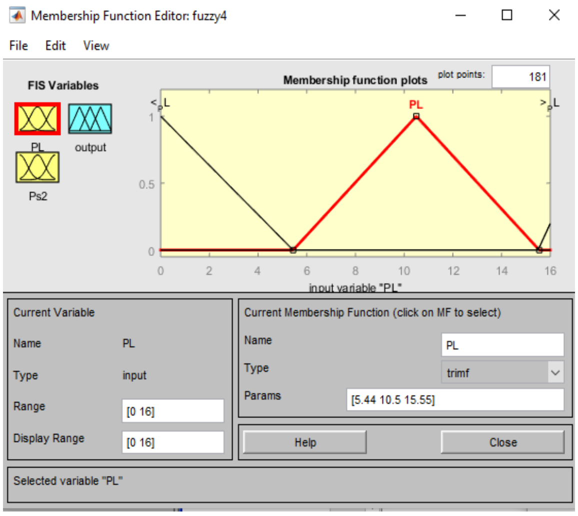
Fuzzy simulation on the optimization of the smart grid system in the Medan Area University campus building was carried out with MATLAB based on data from (6). By MATLAB simulation using fuzzy method will be build the graphical user interface (GUI) design as reinforcement learning [20]. It is shown in Figure 6.

Figure 6(a) shows the fuzzy system method which is automatically created by Matlab program simulation. In this step, the source is initiated by P_{s2} and the loads are initiated byP_L. By double click the P_L block, then Figure 6(b) will be appear. The next step in Figure 6(b) can be seen that to fill the range parameter from 5.44 watt until 15.55 watt that shows the load area in P_L graph. While Figure 6(c) is the third step shows data input process for total renewable energy sources (P_{s2}). The range parameter that used in this case is from 236.3 watt until 388.8 watt that shows the load area in P_{s2} graph. Figure 6(d) is the fourth step for input process for membership areas in fuzzy as the output simulation. Figure 6(e) shows the instruction input process carried out in all cases that occur in the smart grid system in rules model. It shows 3 (three) decision conditions that can explain in Figure 7.

First condition describes P_{s1} in active, the second condition describe P_{s2} active, and the last one describes battery active. The fuzzy decision will appear at area under intersection of 2 (two) lines between P_{s1} active and stable line or between stable line and battery active line. It does mean the decision depends on fuzzy simulation.



(a)



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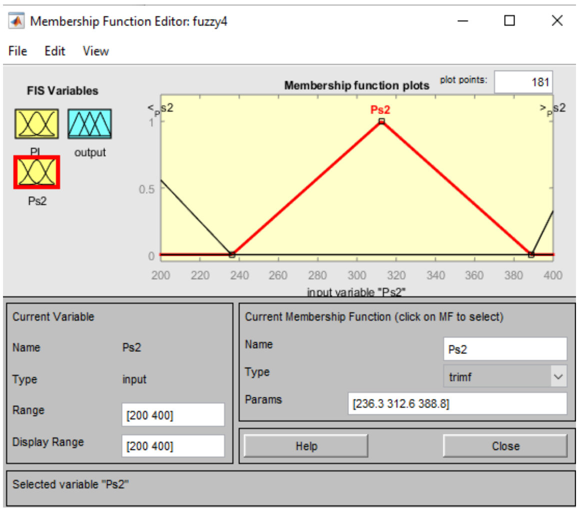

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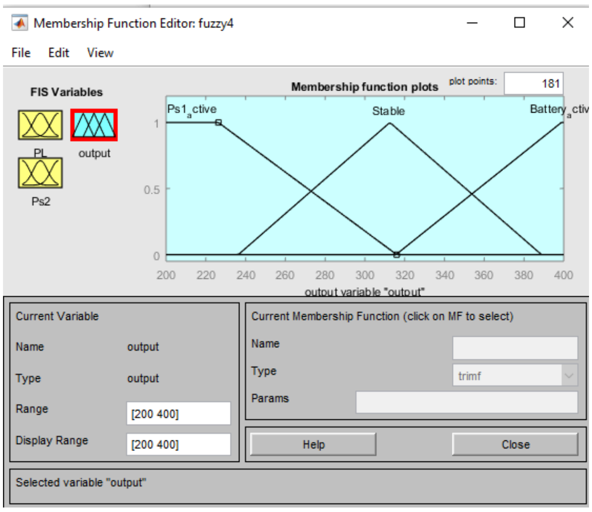
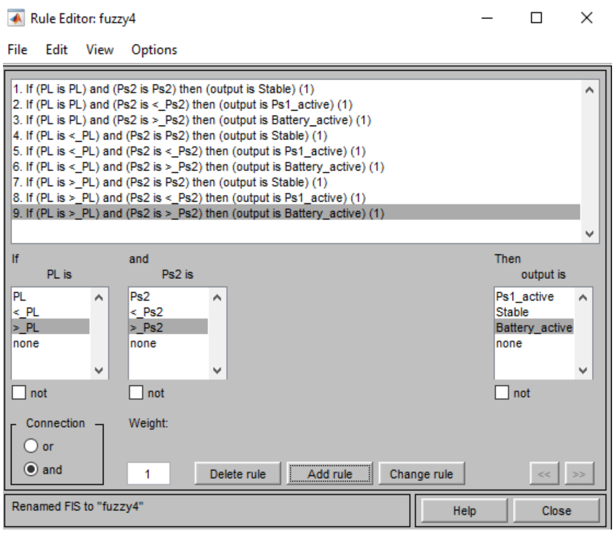


(d)



(e)

Figure 6. MATLAB simulation for (a) total load input, (b) total load input, (c) total solar PV power input, (d) membership area input, and (e) case instruction in smart grid system

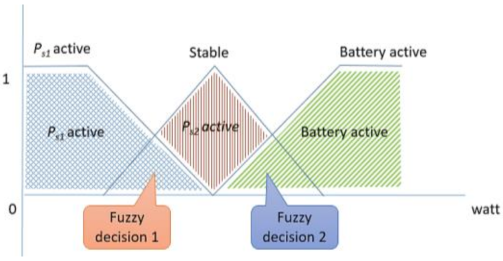


Figure 7. Fuzzy simulation result decision

3. RESULTS AND DISCUSSION

Solar cell PV devices that have been installed on loads in campus buildings consisting of the computer have been operating well suitable with actor components in smart grid according to Alotaibi [9]. Then, it is meet with the smart campus KPI [1]. Figure 8 shows the average usage during the load. Figure 9 shows the solar PV power generated. This shows that solar PV can work to fulfill load requirements.

From Figure 8, the average load per day fluctuates due to different administrative needs in the building, which are adjusted to the needs of students. On the 8th day, there was an increase because students began to actively study. While on the 10th day, there was a decrease in the total burden caused by administrative officers who were not actively working. From Figure 9 shows the average PV power per day fluctuates due to changes in weather that occur, there are days with sunny, cloudy, and rainy conditions. Weather changes will affect the intensity of sunlight intensity that can be absorbed by solar PV.

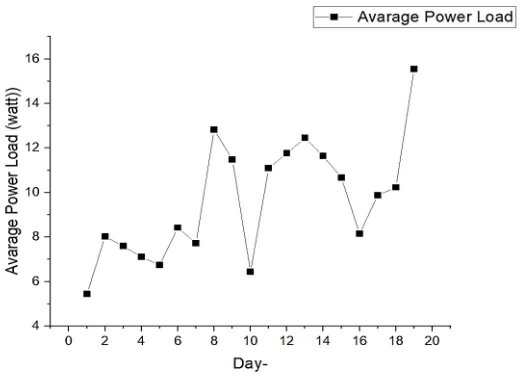


Figure 8. Average power load

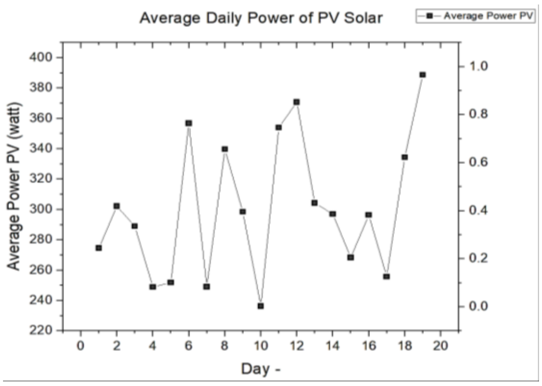


Figure 9. Average daily power of PV solar

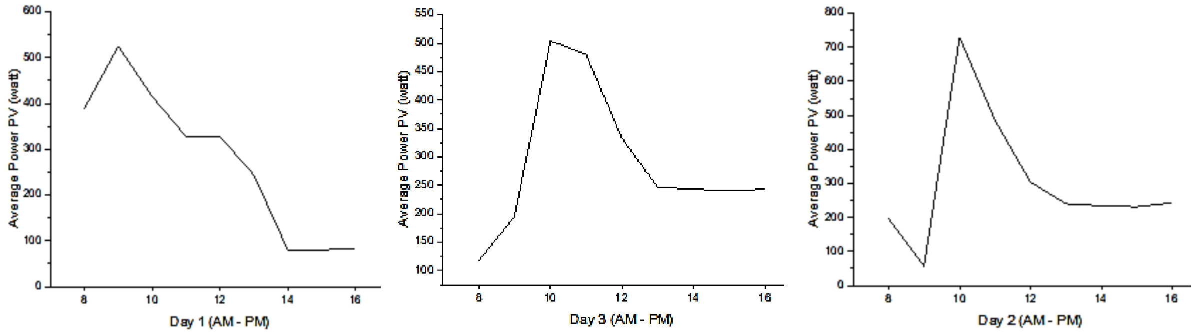
Figure 10 shows the pattern of power generated by solar PV in three days. It can be seen on Figures 10(a) and 10(b) that the PV power will increase in the morning and decrease in the afternoon. However, on Figure 10(c) shows that in the morning there was a PV power decrease. It was caused by changes in the weather to become cloudy.

Based on the data obtained for 19 days, it can be seen in Table 2 the value of the lowest, middle, and highest loads per day as a reference for the peak load value such as lowest power load is 5.44 W, middle power load is 9.88 W, and the highest power load is 15.55 W that must be fulfilled by the source. While the lowest, middle, and highest values of solar PV power are 236.33 W, 297 W, and 388.8 W respectively. It can be seen that PV power is able to satisfy the needs of the total load.

The fuzzy method is used to simulate the scenario of the smart grid system that has been designed in (1) and (2). Based on the simulation results, it can be seen that the smart grid system works in a stable condition, which can be seen in Figures 11. Figure 11 shows that randomly testing $P_L = 8, P_{s2} = 300$, and the resulting output is 313, which is within the membership value so that the condition is stable.

From Figure 12 describe simulation process that derived from Figure 11. If P_L fulfilled (see the shaded area in Figure 12 (a)) and P_{s2} is available (see the shaded area in Figure 12 (b)) and, then the fuzzy decision is appropriate based on the shaded area in Figure 12 (c) as the output results.

From Figure 13 describe simulation process that derived from Figure 11. P_L is fulfilled (see the shaded area in Figure 13(a)) but P_{s2} is not available (see Figure 13(b)), so the fuzzy decision is not appropriate (see Figure 13(c)). It can be seen in Figures 13(b) and 13(c) that there is no shading shown in the figure respectively.



(a) (b) (c)

Figure 10. Three samples of PV solar power daily (a) Day 1, (b) Day 3, and (c) Day 2

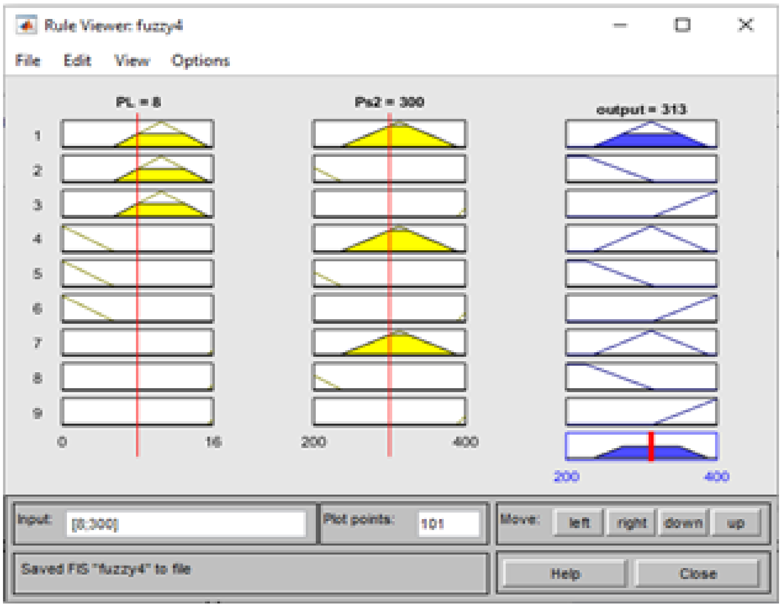
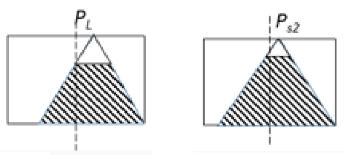
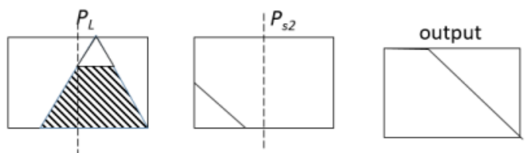


Figure 11. Fuzzy method simulation results in 2D graph



(a) (b) (c)

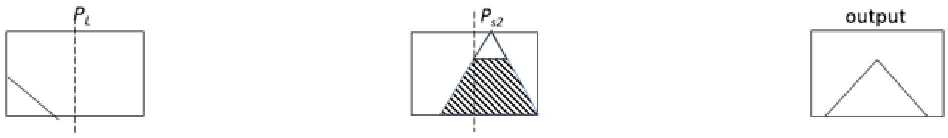
Figure 12. Fuzzy simulation process: (a) P_L input, (b) P_{s2} input, and (c) output in well condition



(a) (b) (c)

Figure 13. Fuzzy simulation process: (a) P_L input, (b) P_{s2} input, and (c) output in P_{s2} off condition

From Figure 14 describe simulation process that derived from figure 11. P_L is not fulfilled (see Figure in 14 (a) but P_{s2} is available (see Figure 14 (b)), then the fuzzy decision is not appropriate (see Figure 14 (c)). It can be seen in Figures 14 (a) and (c) where there is no shading shown in each figure. Based on explanations from Figures 12, 13 and 14 can conclude the fuzzy decision will be appropriate if P_{s2} and P_L are available. Figure 15 shows a 3D graph of the simulation results of the fuzzy method on the optimization of the electrical system with the smart grid system. The 3D graph shows that all variations between P_{s2} and P_L for fuzzy decision. Figure 15 shows a 3D graph of the simulation results of the fuzzy method on the optimization of the electrical system with the smart grid system. The 3D graph shows that all variations between P_{s2} and P_L for fuzzy decision.



(a) (b) (c)

Figure 14. Fuzzy simulation process (a) P_L input (b) P_{s2} input (c) output in P_L not fulfilled condition

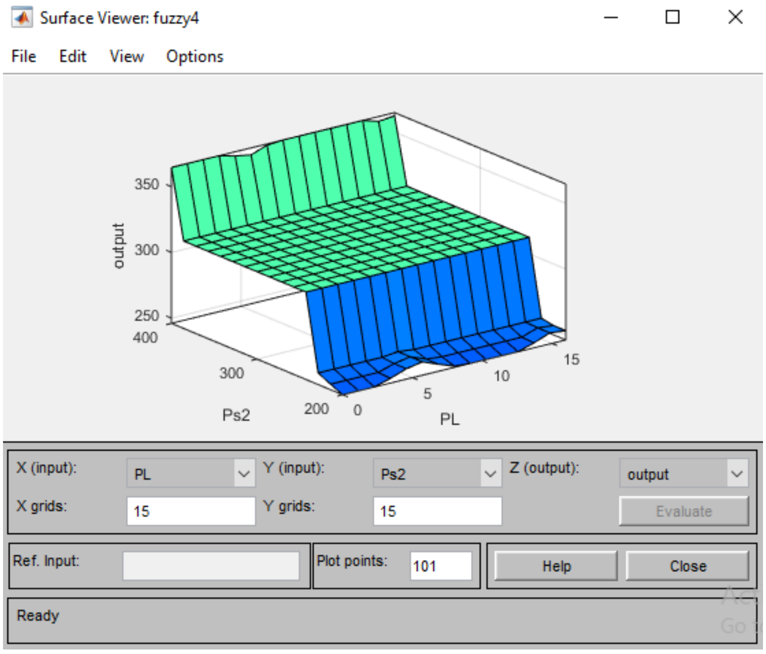


Figure 15. Fuzzy method simulation results in 3D graph

4. CONCLUSION

The Medan Area University, which is located in an area with an average sunlight intensity of 4,528 KWh/m^2, provides an opportunity to utilize PV solar energy sources. The results of measurements carried out for 144 hours, obtained the minimum and maximum power obtained by solar power system (PLTS) are 236.33 watts and 388.8 watts, respectively, and the peak load is 15.55 watts. From the fuzzy simulation there are 3 (three) conditions that indicate fuzzy decisions. The fuzzy decision that has given in the system shows that it is appropriate to implement.

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