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Energy Efficient Smart Home Based on Solar Panels

Meilana Siswanto[1], Dafit Ari Prasetyo[2]

[1]Teknologi Rekayasa Mekatronika, Jurusan Teknik, Politeknik Negeri Jember, Jember, Jawa Timur, Indonesia

[1,2]Teknik Energi Terbarukan, Jurusan Teknik, Politeknik Negeri Jember, Jember, Jawa Timur, Indonesia

meilana_siswanto@polije.ac.id, dafit@polije.ac.id

Abstract. Renewable energy has been and is still a hot issue today, especially in the era of the industrial revolution 4.0, where everything will be connected to the internet or the internet of things. The application of Internet of Things (IoT) to a system will require non-stop electrical energy to ensure the system can work properly. Various efforts have been made to find alternative energy sources that are sustainable and environmentally friendly to overcome the energy crisis that will hit the world. Solar energy is one of the renewable energies that is in great demand and is predicted to experience significant development compared to other renewable energy sources. Apart from being environmentally friendly, solar energy is also easy to maintain, install and is a sustainable source of energy. This paper will discuss the design and application of solar panels for a smart home to save electricity consumption. The saving percentage of electrical energy consumption after installing solar panels 1440 Wp in ideal conditions regardless of weather and other factors is between 54.91% - 60.84%.

Keywords**—***renewable energy; smart home; smart home solar panels; energy efficiency; solar panels*

1. Introduction

The energy crisis that has hit the world has made research on the topic of energy, especially renewable energy, very interesting and attractive. Renewable energy has become a hot issue in the world lately, various efforts have been made to find alternative energy sources that are sustainable and environmentally friendly. Solar energy is one of the renewable energies that is in great demand and is predicted to experience significant development compared to other renewable energy sources. Apart from being environmentally friendly, solar energy is also easy to maintain, install and is a sustainable source of energy. One of the biggest investments in the utilization of solar energy is in the battery and its maintenance, therefore the proper controlling of the battery through monitoring and the use of smart control for setting the on-off level of the battery voltage is needed to keep the battery durable.

IoT allows objects to be controlled remotely through existing network infrastructure resulting in increased efficiency, accuracy and economic benefits in addition to reduced human intervention. This technology has many applications such as smart home, smart city, smart village and solar street light and so on [1]. Smart homes have been seen with increasing interest by both the home owner and the

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research community in recent years. One of the reasons for this development is the promising use of modern automation technology in homes and buildings energy savings that simultaneously reduces the operating costs of the home during its entire life cycle [2]. This research will focus on measuring and optimizing the energy efficiency of solar panel-based smart homes where the percentage of potential electrical energy savings will be investigated and calculated.

2. Related Works

The global energy crisis that has hit the world demands the search for new energy sources and the use of renewable energy that is environmentally friendly and sustainable. Solar panels are one of the innovations in renewable energy that are widely used because of their practicality and can be applied to areas that are not covered by the PLN electricity network [3]. A study on solar cell optimization for smart home design has been carried out by Zulfian Azmi et al., where the orientation of the solar cell to the direction of sunlight is carried out using a fuzzy logic system [4]. This research is motivated by the absorption of solar panels that are not optimal if they are not precise and focus on the projection point of the sun. The load tested in this study is only in the form of LED lights, while the orientation of the solar panel is carried out using a microcontroller where the LDR (Light Dependent Resistor) sensors are placed on the right, center and left of the solar panel. Design of the power monitoring system on solar panels has been carried out by Galih Irvan et al., where the solar panel system is only used as the main source of electrical energy in smart open parking only. In this study, the charging system design and power monitoring were carried out online and in real time. The system is integrated with a data base, connected to the internet and uses an Android application as a monitoring medium. The voltage sensor, ACS712 current sensor and DHT22 sensor are controlled by the Raspberry Pi3 connected to the converter for battery charging. The monitoring results showed that there were error measurements of voltage, current, and power of 0.12 V, 0.004 A, and 0.34 W, respectively. IoT based smart home using renewable solar energy has been applied by Princy S et al. by using Arduino and ESP8266 Wi-Fi module without mentioning the energy efficiency that has been achieved.

3. Methodology

The cost investment in installing solar panels is in batteries and inverters which will convert the DC voltage generated by the solar panels into AC electricity. In addition to the relatively expensive price, the two devices have a lifespan that is not long in the range of 5 years, and even then specifically for batteries, they must be regularly maintained. Meanwhile, an inverter that works non-stop 24 hours will certainly speed up its life time, especially if the load is overloaded. Because the air conditioner (AC) has a high starting wattage, the first step in conducting this research is to separate the power grid for the air conditioner load from the power grid for other loads. The next step is to calculate and analyse the amount of power from the installed load including lights, water pumps, koi pond pumps, washing machines, refrigerators, Wi-Fi adapters, fans, cell-phone chargers and sensors. Furthermore, the system and electricity network design will be carried out, at this stage the load location in the form of lights, pumps, sensors, battery, battery control regulator (BCR), ATS (Automatic Transfer Switch), maximum power point tracking (MPPT) solar charge controller and solar panels will be arranged in such a way. so that solar panel energy storage can be optimized. Testing of equipment such as solar panels, batteries, BCR, ATS, and sensors is carried out prior to system integration. The next stage is testing the installed system, monitoring the system and analysing data in the form of voltage, power, and current in the battery, on the loads.

4. The System Implementation

System implementation begins by calculating the total load or electrical power installed in the house. The next step is to separate the power grid for air conditionings (ACs) from other electrical loads. This step is taken to reduce the load on the inverter and extend its life time. The total power calculation is used to determine how much solar panel output power will be targeted, the number of solar panels and the design of the panel circuit. After that, the current and output voltage of the solar panels can be

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estimated. The amount of current and panel output voltage estimation is used to determine or select the control system components which include ATS, MPPT solar charge controller, BCR and relays and their miniature circuit breaker (MCB).

4.1. Total Electrical Loads

The following table lists the types of electrical loads, the total load and installed power in the house as a whole along with the approximate duration of working time per hour in a day.

Table 1. List of total electrical loads at home running per day

Load types	**Load Numbers**	**Running Duration** (Hours)	**Wattage** **Starting Wattage** (Watt)	**Running Wattage** (Watt)
Lamps	1	12	11	11
	3	12	10	10
	2	12	9	9
	3	3	11	11
	7	3	10	10
	2	3	9	9
Water pump	1	2	150	125
Pond pump	1	24	38	38
Aquarium pump	1	24	18	18
Refrigerator	1	24	165	97
Electrical iron	1	1	350	300
Laptop	2	9	130	130
Computer	1	5	250	250
Washing machine	1	1	350	350
Air conditioner (AC)	2	10	395	389
Total			**2,551**	**2,396**
Total without AC			**1,761**	**1,618**

The total electric power of all the electrical loads installed at the house at the start of work is 2551 watts, while after running it will decrease by 155 watts to be 2396 watts. In designing an energy-efficient house based on solar panels, it is only intended for electrical loads other than air conditioner (AC). As seen in Table 1, the initial electricity load without AC is 1761 watts and after running it will drop to 1618 watts. The load in the form of lights will run at night, while the washing machine and iron even though it is used for only about one hour, the load may run simultaneously with other loads so that the load calculation is still included.

4.2. Electrical loads at the day

The calculation of the load without air conditioning and lights will eventually get the peak load of household electricity during the day of 1761 - 180 or 1581 watts where the overall lamp load is 180 watts. Meanwhile, the household electricity load when working is 1438 watts as shown in Table 2. Based on the habit of using washing machines and irons that are not used simultaneously, where the washing

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machine is always used in the morning while the iron is used during the day, the peak power load can be recalculated in detail. The total initial wattage when running with the washing machine without an iron and with the iron without the washing machine equals approximately 1,231 watts because both loads have the same power consumption at start-up. While the electric load when running with a washing machine without an iron is 1438-350 watts or 1088 watts, and when using an iron without a washing machine is 1138 watts.

Table 2. Electricity consumption at the day per day

Load types	Load Numbers	Running Duration (Hours)	Wattage: Starting Wattage (Watt)	Wattage: Running Wattage (Watt)
Water pump	1	2	150	125
Pond pump	1	24	38	38
Aquarium pump	1	24	18	18
Refrigerator	1	24	165	97
Iron	1	1	350	300
Laptop	2	9	130	130
Computer	1	5	250	250
Washing machine (WM)	1	1	350	350
Total loads at the day			**1,581**	**1,438**
Total loads without iron			**1,231**	**1,088**
Total loads without WM			**1,231**	**1,138**

4.3. Electrical loads at night

Peak load and running load at night are calculated regardless of the load of washing machines and irons that are always used during the day, so the starting wattage values are 1761 - 700 or 1061 watts and 1618-650 or 968 watts when running. Table 3 shows a list of electrical loads that are active at night and a calculation of the total power consumption.

Table 3. Electricity consumption at a night per day

Load types	Load Numbers	Running Duration (Hours)	Wattage: Starting Wattage (Watt)	Wattage: Running Wattage (Watt)
Lamps	1	12	11	11
	3	12	10	10
	2	12	9	9
	3	3	11	11
	7	3	10	10
	2	3	9	9
Water pump	1	2	150	125
Pond pump	1	24	38	38

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Aquarium pump	1	24	18	18
Refrigerator	1	24	165	97
Laptop	2	9	130	130
Computer	1	5	250	250
Total at night			**1,061**	**968**

So the largest peak power load during the day is 1231 watts and 1061 watts at night. The highest peak power load of 1231 watts is used as the basis for determining the power of the solar panels to be installed. Taking into account the decrease in power efficiency generated by solar panels, a solar panel with a power of 1440 watts was finally installed, consisting of 4 solar panels with a power of 370 wp per panel.

5. Results, Analysis and Discussions

Calculation of energy requirements can also be carried out in accordance with ISO standards Building energy performance - Calculation of energy use for heating and air conditioning [5], in which three alternative calculation methods are described: semi-stationary, simplified hourly dynamic method, and detailed dynamic method. Korjenic and Bednar [6] presented the concept of using dynamic simulations as instruments to improve total energy performance and conduct an HVAC system analysis in an office building. Research shows that preliminary information about establishing an energy demand profile including energy use for HVAC equipment is needed to predict energy consumption correctly and to get accurate results. The integrated simulation method can be divided into two groups: analytic and numerical which have been explained in detail by Clarke [7] and Underwood and Yik [8]. Although both of these methods have their advantages and disadvantages, both are suitable for evaluating building energy performance. However, in this study, the ISO standard has not been applied due to several considerations.

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Table 4. Electrical energy consumption per day based on starting wattage

Load types	Load Numbers	Running Duration (Hours)	Starting Wattage (Watt)	Energy	
				Energy Consumption at Night (KWh)	**Energy Consumption at the Day** (KWh)
Lamps	1	12	11	0.132	-
	3	12	10	0.36	-
	2	12	9	0.216	-
	3	3	11	0.099	-
	7	3	10	0.21	-
	2	3	9	0.054	-
Water pump	1	2	150	0.3	0.3
Pond pump	1	12/12[a]	38	0.456	0.456
Aquarium pump	1	12/12	18	0.216	0.216
Refrigerator	1	12/12	165	1.98	1.98
Electrical iron	1	1	350	-	0.35
Laptop	2	4/6[b]	130	1.04	1.56
Computer	1	3/5[c]	250	0.75	1.25
Washing machine	1	1	350	-	0.35
Total at night				5.813	-
Total at the day				-	6.462
Total energy					**12.275**
Total energy with AC					**20.175**

[a] 12 hours at night, 12 hours at the day.
[b] 4 hours at night, 6 hours at the day
[c] 3hours at night, 5 hours at the day.

The calculation of the potential savings in electrical energy after solar panels are installed can be estimated by separating the air conditionings (ACs) from the household electricity load list. Then, because the electric load at night and during the day is different, the calculation of the use of electrical energy at night and during the day will be carried out separately based on the starting wattage. So that the potential value of electrical energy savings during the day and night will be obtained. The sum of the potential values for saving electrical energy consumption at night with electrical energy consumption during the day is the total value of the potential value for electrical energy savings in one day. The calculation of energy consumption based on the starting wattage shows that the total energy consumption during the day is 6.462 KWh and 5.813 Kwh at night. So that the total amount of electricity consumption based on the starting wattage in a day is 12.275 KWh as shown in Table 4.

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Table 5. Electrical energy consumption per day based on running wattage

Load types	**Load Numbers**	**Running Duration** (Hours)	**Running Wattage** (Watt)	**Energy**	
				Energy Consumption at Night (KWh)	**Energy Consumption at the Day** (KWh)
Lamps	1	12	11	0.132	-
	3	12	10	0.36	-
	2	12	9	0.216	-
	3	3	11	0.099	-
	7	3	10	0.21	-
	2	3	9	0.054	-
Water pump	1	2	125	0.25	0.25
Pond pump	1	12/12[a]	38	0.456	0.456
Aquarium pump	1	12/12	18	0.216	0.216
Refrigerator	1	12/12	97	1.164	1.164
Electrical iron	1	1	300	-	0.3
Laptop	2	4/6[b]	130	1.04	1.56
Computer	1	3/5[c]	250	0.75	1.25
Washing machine	1	1	350	-	0.35
Total at night				3.93	-
Total at the day				-	5.546
Total energy					**9.476**

[a] 12 hours at night, 12 hours at the day.
[b] 4 hours at night, 6 hours at the day
[c] 3hours at night, 5 hours at the day.

The upper limit of the range of electrical energy consumption is obtained from the total energy consumption at starting wattage. After running for a while, the consumption of electrical energy on some equipment has decreased which then stabilizes at a certain value. The lower limit of the range of electrical energy consumption is obtained from the stable value of the total electricity consumption after electronic equipment has been running for a while (running wattage). The lower limit of the total range of electrical energy consumption per day is 9,476 KWh as shown in Table 5.

Based on the results of the calculation of energy consumption during initial starting and when it is running, it can be concluded that the potential for saving electrical energy after the installation of solar panels is between 9.476 KWh to 12.275 KWh per day.

The prediction of potential savings in electrical energy in each month in 2020 can be obtained by multiplying the number of days in the month concerned as shown in Table 6. The prediction of potential savings is a rough prediction that does not take into account weather factors that affect the intensity of solar radiation and other technical factors

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Table 6. Predictions of potential savings in electrical energy per month in a year.

	Number of days	Electrical energy consumption (Upper limit: 12.275 KWh)	Electrical energy consumption (Lower limit: 9.476 KWh)
January	31	380.53	293.76
February	29	355.98	274.80
March	31	380.53	293.76
April	30	368.25	284.28
May	30	368.25	284.28
June	30	368.25	284.28
July	31	380.53	293.76
August	29	355.98	274.80
September	30	368.25	284.28
October	31	380.53	293.76
November	30	368.25	284.28
December	31	380.53	293.76
Average		371.32	286.65
Total		4,455.86	3,439.79

6. Conclusion

Prediction data of potential savings in electrical energy in each day, month in one year are summarized in Table 7, where the average range of potential savings per day is 9.476 – 12.275 KWh. The average range of potential electrical energy savings in each month is 286.65 - 371.32 KWh. Meanwhile, the total potential for saving electrical energy in a year ranges from 3,439.79 - 4,455.86 KWh. The prediction of potential savings is a rough prediction that does not take into account the factors of weather changes, seasons that affect the intensity of solar radiation and the amount of output power of solar panels and other technical factors.

Table 7. Summary of potential saving of electrical energy in a day, per month and in a year.

Periods	Potential saving of electrical energy (KWh)
Every day	9.48 - 12.28
Every month	286.65 – 371.32
Year	3,439.79 – 4,455.86

The total amount of electricity consumption as a whole including the AC when starting is 20,175 KWh and after running it has decreased to 17,256 KWh. So that the percentage of electricity savings after installing solar panels in ideal conditions regardless of weather and other factors is between 54.91% - 60.84%.

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