Smart Home System for Controlling Household Appliances Utilizing Photovoltaic Technology

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Abstract

Photovoltaic is a technology that functions to convert solar energy into electrical energy directly. The smart home system for controlling household appliances with Photovoltaic technology is a concept that integrates renewable technology and artificial intelligence to increase the efficiency and sustainability of energy use in households. By using the ESP32 microcontroller as the main control system to monitor and regulate power usage based on the availability of solar energy. The system starts by checking the solar voltage, if it is providing enough power to household appliances. If the solar voltage is insufficient the system will turn off non-essential equipment or reduce power consumption. Users can control the system via smartphone to activate household appliances as needed. The system uses an inverter to convert the DC voltage from the solar panels into the AC voltage required by household appliances. This research combines Photovoltaic and IoT technology in a Smart Home can increase energy efficiency and support environmental conservation efforts. Research can make a positive contribution to the development of sustainable energy solutions for modern households.

Keywords: ESP32, Electronic Equipment, Sensors, Solar Panels

1. Introduction

Solar cells are a set of modules to convert solar power into electrical energy. A solar module consists of many solar cells which can be arranged in series or parallel (Siswanto & Prasetyo, 2020). It is a semi-conductor element that can convert solar energy into electrical energy. Technology that functions to change or convert solar energy into electrical energy directly is called Photovoltaic (Safitri et al., 2020; Singh et al., 2018). Photovoltaic technology that utilizes solar cells is starting to become popular apart from the depletion of fossil energy reserves and the issue of global warming. Energy produced with photovoltaic technology is also very cheap because the energy source (solar) can be obtained for free. Utilization of photovoltaic technology which is primarily sourced from solar energy is one of the uses of renewable energy that is environmentally friendly (Ali & Windarta, 2020). New, renewable energy has an important role in meeting energy needs. One of the efforts to fulfill renewable energy is developing Solar Power Plants (PLTS), better known as solar cells (Photovoltaic cells), which are more popular because they can be used for various relevant purposes and in various places, one of which is meeting household energy needs (Idris, 2019).

Energy needs, especially electrical energy, are growing unprecedentedly. Electrical energy is easily converted into various other forms of energy. However, this need has an
impact on dependence on petroleum, the main energy source. Petroleum is increasingly scarce and expensive, while its use increases carbon dioxide gas emissions which have a negative impact on the environment. Electronic devices with Photovoltaic technology have become part of people's modern lives in homes to provide comfort using environmentally friendly renewable energy (Hatti, 2020; Meteier et al., 2023).

1.1. Photovoltaic Technology

Solar cells convert sunlight energy into electrical energy using the Photovoltaic effect process (Singh et al., 2018). The resulting electric voltage is sufficient to be used to supply a 12V battery, around 0.6V without load or 0.45V with load. Solar panels will be able to produce high current and voltage. Types of solar panels: a) Monocrystalline (Mono-crystalline) the most efficient panels produced with the latest technology & produce the highest electrical power per area; b) Polycrystal (Poly-Crystalline) solar panels which have a random crystal arrangement because they are manufactured using a casting process; c) Thin Film Photovoltaic solar panels (two layers) with a microcrystal-silicon and amorphous thin layer structure with a module efficiency of up to 8.5% so that the surface area required per watt of power produced is greater than monocrystal & polycrystal.

Source: Safitri et al., (2020)

Figure 1. Solar Cell Schematic

Solar Charge controller is an electronic device used to regulate the direct current charged to the battery. 12 Volt solar modules generally have an output voltage of 16 - 21 Volts (Ghezelayagh, 2021). The charge controller applies pulse width modulation (PWM) technology to release current from the battery to the load from the solar module. Solar Charge controller regulates overcharging. An inverter is an electronic device that functions to change voltage and direct current (DC = Direct Current). The DC current source can come from a solar panel system or from a battery/accumulator. In general, what is called alternating current (AC = Alternating Current) in Indonesia. Deep cycle batteries include batteries commonly used for PV (Photovoltaic) and backup power. Deep cycle dry batteries are also designed to produce a stable voltage. The decrease in ability is no more than 1-2% per month without the need for discharge (Luqman et al., 2019).

1.2. Smart Home

Technology makes homes have automation systems with very sophisticated performance. Smart Home systems will increase power efficiency (Nandhini et al., 2020)
and improve the quality of human life. Smart home offers features to monitor the environment using sensors (Noviansyah & Aiyar, 2019) such as temperature, humidity, gas concentration, smoke and others. Smart homes combine information and communication technologies to control and automate various aspects of the home, including controlling household appliances (Zaro et al., 2021; Zode et al., 2023). The smart home application controls home electronic devices using a smartphone that can be controlled remotely (Ruuhwan et al., 2019).

The Internet of Things (IoT) is a structure in which objects or people have a unique identity and the ability to send data over a network without human-to-human interaction, but through devices. IoT has the potential to optimize life with smart devices and objects connected in a network (Nitika et al., 2020). IoT includes devices such as sensors that communicate over a network (Siswipraptini et al., 2021; Sultan et al., 2021).

The Arduino Uno electronic board contains a microcontroller that functions as a small computer and can be used for electronic projects from simple to complex (Rahayu & Nurdin, 2019). The Arduino Uno has an internal bootloader for easy uploading of programs, and USB communication that allows laptop users to connect without the need for additional devices (Ilham & Ariandi, 2022). Can be used to manage digital and analog data via the pins available on the Arduino board.

The ESP32 Microcontroller Module is the flagship microcontroller from Espressif System, the successor to the ESP8266, with lots of I/O pins, analog pins, large memory, and low-power Bluetooth 4.0 support (Bayu et al., 2021). This microcontroller has an integrated Wi-Fi module in a dual core processor, ideal for the Internet of Things. The ESP32 is easy to use, controls devices, sensors and relays, and allows Android and Arduino connection over a Wi-Fi network, even remotely. Enables monitoring of electronic devices at home via an internet connection. ESP32 facilitates the connection of microcontroller devices such as Arduino to the internet via Wi-Fi.

The MQ-135 sensor is a chemical sensor that is sensitive to various types of gas, such as NH3, NOx, alcohol, benzol, smoke (CO), CO2, and others (Kumar et al., 2022). This sensor measures changes in resistance when exposed to gas and has good durability. The sensitivity can be adjusted to the measured gas concentration, for example, for NH3 (100 ppm) or alcohol (50 ppm) in the air.

Electronic circuit breadboards used for prototyping allow circuit assembly without soldering, making it easier to change schematics or replace components (Noviansyah & Aiyar, 2019). The types of breadboards differ in the number of holes available, such as 400-hole breadboards, 170-hole breadboards. Using a breadboard involves understanding the connections between the holes in the board.

2. Research Method

A smart home system with photovoltaic technology as an alternative electrical energy for households apart from using electrical energy sourced from the State Electricity Company (PLN) (Gumilang & Rakhmad, 2020). It is hoped that the use of solar energy can help reduce dependence on PLN and support environmental sustainability (Siswanto & Prasetyo, 2020). In the design, Arduino ESP32 is used to control the smart home system, and a 50 WP solar panel is used to convert solar energy into electricity. The research uses the Prototype method because it will produce a device which is a model of Photovoltaic technology for controlling household appliances. A prototype is defined as a version of a potential system that provides developers and potential users with an idea of how the system will function in its finished form (Salsabila & Kasoni, 2021). Figure 2 is the Prototype stage (Pressman & Maxim, 2020).
The research stages in making a prototype follow the stages according to existing methods. Quick Plan, determine the main objective of developing a smart home system to control household appliances, identify user needs by conducting a survey to determine the equipment most frequently used in the household, select an IoT platform that supports connectivity for household appliances. Modeling Quick Design, designing the overall system architecture, including solar panels, batteries, inverters, and IoT devices, determining the software model for the user interface to be used, identifying usage scenarios and system workflow, determining communication protocols between IoT devices and the central system. Construction of Prototype, building a system prototype using designed hardware and software, integrating solar panels, batteries, inverters, and IoT devices, conducting initial testing to verify the basic functions of the system. Deployment, Delivery, & Feedback, implement the prototype at the test location i.e. user's household, provide training to users on how to use the system, make improvements or adjustments based on the feedback received. Communication, Communicate development progress to stakeholders through regular reports, inform users about routine maintenance and system updates, use effective communication channels, including email, messaging applications, or face-to-face meetings if necessary.

The system design in the research builds tool blocks that can control household electronic equipment using relays and microcontrollers that have been identified and how to process the information obtained by the microcontroller from smartphone commands into information that can be processed further which can be seen in the flowchart in Figure 3. On the system design flowchart, testing ensures whether the design is appropriate. If not, the process is repeated.
In Figure 3, the research problem analysis stage for the use of Photovoltaic technology is weather instability and the possibility of rainy weather, selecting a suitable system for operating household equipment, and determining the amount of electricity needed to supply household equipment.

Making a prototype of a household equipment control system using Photovoltaic technology based on Smart Home aims to utilize solar energy as a substitute electricity source for PLN which can be controlled via smartphone. In order to understand the system, there are several steps that need to be followed: a) Design a solar power-based household equipment control system using the ESP32 microcontroller as a link between the relay and the smartphone application; b) Realizing a solar power-based household equipment control system to ensure the system functions properly; c) Testing household equipment control systems on systems that have been realized for use as household equipment controllers. In system design, it is important to understand the working principles of the ESP32 microcontroller and the relays that connect electronic equipment. The system design in the research involves creating tool blocks to control household electronic equipment using relays and microcontrollers that have been identified. The system also involves processing information received by the microcontroller from smartphone commands.
3. Results and Analysis

A system designed to control household appliances using Photovoltaic technology. So far, household electronic equipment uses electricity from The State Electricity Company (PLN), and the research carried out uses solar power as a source of electricity for household electrical equipment to become an alternative energy source besides using PLN electricity.

3.1. Creating a Diagram Blog

Block diagram of a smart home based on an ESP32 microcontroller with a solar panel to turn on the lights and a socket using a 4-channel relay in Figure 4a. Block diagram of a smart home based on an ESP32 microcontroller with a solar panel to run the MQ-135 sensor as a gas leak detector as in Figure 4b. Figure 4a and Figure 4b are block diagram designs for an electrical equipment control system using ESP32. The input from the system is that solar panels convert sunlight into electrical energy using input which can be processed by the ESP32 module so that the output is as desired and the smartphone can also control connected electronic devices.

3.2. Smart Home Flowchart

In Figure 5, the first smart home design flowchart is carried out when running the system, namely monitoring the voltage produced by the solar panels. After checking the solar voltage, the system will adjust the power usage accordingly. If the solar voltage is sufficient, the system will run household appliances. If the solar voltage is insufficient, the system will turn off non-essential equipment to reduce power consumption. The system can charge the battery using an inverter if necessary. If no equipment needs to be turned on, the system continues to monitor solar and battery voltage. If the equipment needs to be turned on, the system can be activated via smartphone.

In research using the ESP32 module as a smart home circuit control. The ESP32 has several advantages, namely that the WiFi module is also integrated in a dual core processor chip with Xtensa LX6 instructions, which really supports the development of Internet of Things application systems, making it easier to connect microcontrollers via USB, AC to DC 5V power supply cable, or battery (http://ESP32.net/, 2024; Rifky, 2021).
3.3. Software Design using Arduino IoT Cloud Project

In the research, Arduino IoT Cloud is used as a technology platform in IoT projects to become a data intermediary layer. An open source platform and functions as a receiver and data store from the ESP32 microcontroller (Siebeneicher, 2024). The first step is to register for an Arduino IoT Cloud account from the page https://www.arduino.cc/. Arduino IoT Cloud is the main configuration space, all changes made automatically become sketch files. Device configuration is done to add and link to Arduino IoT Cloud by installing Arduino Create Agent. To configure, you need to create a new variable. The created variables are automatically generated into a sketch file. There are special variables, such as Temperature, Speed, Luminance that can be used. To connect to a Wi-Fi network, click the “Configure” button in the network section. Enter the Wi-Fi credentials and click “Save”. This information is generated into a sketch file that the researcher created as in Figure 6.
After configuring variables, devices, and network settings, next program the device that has been created. Arduino IoT Cloud Remote is an application that allows you to control and monitor all dashboards on Arduino IoT Cloud. With Arduino IoT Cloud Remote, you can access the cellphone’s internal sensors such as GPS data, light sensors, IMU, and others. To use the Arduino IoT Cloud Remote application, install it from the provider on Google Play or the App Store, then log in using the Arduino IoT Cloud account that you already have.

3.4. Photovoltaic Technology Hardware Design

The design of a smart home controller for household appliances includes the components used in system design Figure 7.

![Energy Conversion Equipment Circuit Box](image1)

![Solar Panels](image2)
Figure 7a shows the circuit in the box for the process of converting solar energy into electric current from solar panels. Figure 7b is a solar panel that can store solar energy directly from sunlight.

### 3.5. Prototype Testing

In the trial phase, researchers tested the characteristics of smart home devices controlling household appliances. Testing AC electricity on a series of solar panels and ESP32 to power lights and sockets, as well as gas leak detection testing.

![Arduino IoT Remote Smart Home Application Dashboard](image)

Source: Research Result (2023)

In Figure 8, the Arduino IoT Remote application is run to control the lights and sockets so that researchers can control them remotely.

![Testing Household Appliances Using Photovoltaics](image)

Source: Research Result (2023)

**Figure 9. Testing Household Appliances Using Photovoltaics:** (a) Testing Using Lights, and (b) Gas Leak Detection Testing

In Figure 9a, when the relay gets 220V AC electricity input from a series of solar panels and the ESP32 microcontroller gets input from a cell phone, the lights can turn on and the socket can be used for other devices such as charging smartphones or fans and other electronic devices that use electrical energy sources. obtained from Photovoltaic technology. In Figure 9b, a test was carried out using a match as an illustration of a gas leak which will be detected by the MQ-135 sensor and will produce a sound from the buzzer module.
Table 1. Test Results on Household Equipment

<table>
<thead>
<tr>
<th>Test Parameters</th>
<th>Test Result</th>
</tr>
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<tbody>
<tr>
<td>Availability of Solar Energy</td>
<td>Adequate, able to supply power as needed.</td>
</tr>
<tr>
<td>Effectiveness of Remote Control</td>
<td>It works, the system is responsive and can be accessed remotely.</td>
</tr>
<tr>
<td>Data Security and System Access</td>
<td>Secure, data is encrypted, and access to the system is protected.</td>
</tr>
<tr>
<td>Integration with Household</td>
<td>Satisfactory, various household appliances are well integrated.</td>
</tr>
<tr>
<td>Appliances Battery Life When Running Out of Electricity</td>
<td>Satisfactorily, the battery is able to last for the desired period.</td>
</tr>
<tr>
<td>System Reliability in Various Conditions</td>
<td>Good, stable system performance in various weather conditions.</td>
</tr>
<tr>
<td>Responsive to User Commands</td>
<td>Fast, the system responds quickly to user commands.</td>
</tr>
<tr>
<td>Compatibility with Web &amp; Android Apps</td>
<td>Good, user-friendly application interface and can be operated easily.</td>
</tr>
<tr>
<td>Whole System Testing</td>
<td>Meet the overall criteria that have been set.</td>
</tr>
</tbody>
</table>

Source: Research Result (2023)

Each test result is assessed based on standards that have been established at the design and prototype stages. A rating of "Adequate", "Good", or "Meets Criteria" indicates that the system has successfully passed the test according to the expectations and specifications established in the test.

4. Conclusion

Solar panels are an innovative solution that combines IoT technology with renewable energy sources. Smart homes are controlled with Photovoltaic technology, thus creating an environmentally friendly environment. Based on the research results, results obtained regarding energy sustainability are that Smart homes using Photovoltaic provide renewable energy, reduce dependence on conventional energy sources such as coal and help reduce carbon emissions. Regarding energy optimization, the automatic design of a system that will turn devices on and off according to the availability and needs of devices that can be activated and deactivated can optimize energy consumption through intelligent control, so that residents can save significantly on energy costs. Controlling household appliances via smartphone so that they are easy to control with the ability to control household appliances remotely brings comfort and flexibility for residents.

For further research with Photovoltaic technology that can be carried out, among other things, controlling access to smart home security must be prioritized. Ensure remote control is secure and protected from potential cyber threats. With careful planning and implementation, designing a smart home with Photovoltaic technology can be a sustainable and energy-saving solution for modern households towards creating a greener and more sustainable future using new and renewable energy.

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Author Contributions

Mohammad Khoiruddin proposed the research topic; Mohammad Khoiruddin, Endang Retnoningsih compiled the model and designed the prototype; Mohammad Khoiruddin, Endang Retnoningsih, and Syahbaniar Rofiah carried out the tests and analyzed the results.
Conflicts of Interest
The authors declare no conflict of interest.

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