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SMART HOME SYSTEM WITH BATTERY BACKUP AND INTERNET OF THINGS

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ABSTRACT
This research enhances Smart Home Systems by integrating an Automatic Transfer Switch (ATS) for seamless power source switching between the grid and a backup battery, ensuring uninterrupted operation during power disruptions. An Automatic Battery Charging (ABC) system optimizes battery charging based on its condition, improving energy storage and efficiency. The system provides on-site electrical equipment control and sensor data access via a Human Machine Interface (HMI). Remote monitoring and control through the Blynk app offer convenience. Additionally, an energy consumption estimation feature allows users to estimate billing costs, with the Battery State of Charge (SoC) indicating the remaining battery capacity. Hardware testing showed the system's reliability with a 2-4 second ATS response and ±2-second ABC response. This research offers homeowners reliable power continuity and energy optimization. It contributes to IoT-based smart home systems, demonstrating ATS and ABC effectiveness, advancing both theory and practice for modern smart living.
Keywords: *Smart Home, Internet of Things, Battery Backup, ATS, Charging*

1. Introduction

Technology innovation rapidly develops, improving human convenience and comfort in various aspects of life. The emerging technology currently used in various fields is the Internet of Things (IoT) (Dey et al., 2016)(Singh et al., 2019)(Asghar et al., 2015). IoT system continuously maintains connectivity to the internet network so that connected sensors or components can be monitored and controlled remotely (Panduardi et al., 2016)(Wardana et al., 2023). This technology is growing popular and attracts more research focus nowadays, such as in agriculture (Atmaja et al., 2021)(Prasetia et al., 2021)(Rahmatullah et al., 2023), animal cage control and monitoring (Farahiyah & Purnama, 2021), inventory systems (Wicaksono et al., 2021), vital human signs (Shahadi et al., 2021), monitoring system (Purnomo et al., 2021)(Wicaksono & Rahmatya, 2022), mobile security vehicles (Husni et al., 2021) and food (Riadi & Syaefudin, 2021).

One of the project developments of IoT is the Smart Home System (Agarwal et al., 2019)(Kim et al., 2015). Smart Home lets users access electronic devices at home anytime and anywhere using the cloud system (Ahmad et al., 2021)(Azman et al., 2023)(F. D. Rahmaniar et al., 2023). Meanwhile, cloud systems allow access to and store data from all sensor activity or components connected to the Internet network, allowing our home appliances to be controlled via smartphones (Haque et al., 2019)(Ransing & Rajput, 2015)(Brundha et al., 2018)(Suesaowaluk, 2020). Currently, there are many IoT platforms, such as Blynk, Ubidots, IBM Bluemix, and Devicepilots (Hisham Che Soh et al., 2019) (Fikri et al., 2021), that can be employed in smart home systems. Various smart home systems have been developed (Kumar & Lee, 2014)(Tharaniya Soundhari & Brilly Sangeetha, 2015)(Yang et al., 2009). Mostly, they used Bluetooth and Wi-Fi for internet connection. The use of Bluetooth is low-cost and easy to install but distance-limited (Naresh et al., 2013)(Withanage et al., 2014)(Vishwakarma et al., 2019). On the other hand, Wi-Fi provides advantages without distance limitations (Somani et al., 2018)(Vaidya & Vishwakarma, 2018)(Salman et al., 2017)(Adiono et al., 2017).

Electrical energy is a fundamental factor in increasing the convenience and comfort of every human activity in today's era (Indikawati & Zamroni, 2019). Both housing, industry, and offices require electricity to operate various electrical equipment. In principle, the distribution of electricity from the generator to the consumer is carried out through an open transmission network. Unfortunately, the open transmission allows disturbances to occur, enabling disruption of power flow from the grid (in Indonesia, supplied by the state-owned company, PT PLN) to consumers (Senen et al., 2022). These disturbances can take the form of damaged circuits, poles, or cables that cause electricity distribution from the grid to stop, which is basically a power outage. On many occasions, a continuous electricity supply for a particular activity is needed. Therefore, a backup power supply is required for the primary power grid.

In many cases, the electricity backup supply is turned on manually, making it less efficient and requiring a longer transition time between the grid supply and the backup supply. A tool such as Automatic Transfer Switch (ATS) was created to solve this problem. ATS is useful for switching from the main supply (grid) to the backup supply (Kurniawan, 2020). Thus, when the electricity from the grid goes out, the backup supply will turn on and supply electricity to the load.

Some researchers have researched ATS on many occasions. Syah et al. (2021) propose Arduino-based ATS which controls the power switch between the grid and the generator. From the experimental testing, they conclude that the switching time from main to backup is 15.13s which is close to the standard time which is 15s. Dev, et al. (2020), propose a three-mode single-phase automatic changeover controller. The power sources used are a grid, solar panel, and generator. The switching time is only 5mS. However, this validation is only in a simulation environment. Nkemjika, et al. (2019) use a comparator to detect the presence of power from the grid as the main supply. If there is no voltage from the grid, the switch connects to the battery. However, their proposed system is not explained in detail.

Batteries as energy storage for backup supply must always be ensured to be fully charged. When fully charged, the battery must also be stopped immediately so that the charging process does not occur; overcharging can shorten battery life. An automatic cut-off device can be made to cut off electricity to the battery if the battery is fully charged to avoid overcharging. The battery can also be over-discharged if continuously used without charging, causing the battery to drain. Similarly, an automatic charging device can be made so that the battery can charge automatically before it reaches its minimum limit to overcome over-discharge.

Meanwhile, research about the use of batteries as power backup was done by Sabry et al. (2019), who proposed a battery backup system using a DC-bus with a DC load. They concluded that the power loss in the conversion process could be avoided using a direct DC bus. Suryanto et al. (2020) proposed a control system of smart home energy management that used a grid supply and battery supply. However, most of the researchers did not utilize any automatic battery charger for their system. Meanwhile, Saleh et al. (2017) used renewable energy sources for energy backup: wind turbines and solar panels. There was no integration with IoT, and it only used the LCD to monitor system conditions.

Smart homes often encountered today are still focused on remotely controlling home electrical appliances and home lighting (Hermanu et al., 2022). Based on the objective of maintaining the continuity of electrical supply, researchers combine the smart home with renewable energy sources (RES) such as solar panels (Saputro et al., 2023). Whereas another uses an electric vehicle (EV) battery which is connected to the home as power backup (Shin & Baldick, 2017)(Mohamed et al., 2023). Both RES and EV batteries are a complex and expensive solution for power outages in a smart home. While, an uninterruptible power supply (UPS), has a limited load and needs additional devices to be connected to the IoT system in the smart home. Therefore, this research aims to propose a Smart Home System with an Automatic Transfer Switch (ATS) and Automatic Battery Charging (ABC), making the Smart Home System be supplied continuously with electricity from a grid or batteries with a low-cost system. The batteries can automatically charge if the power is reduced, and there is a grid electricity supply that can be cut off automatically when the battery is fully charged. Hence, it is more efficient and requires less time to transition between the grid and the backup supply. The IoT system monitors both supply conditions and can be used to turn on/off the load via an internet connection.

Meanwhile, the main contribution of the paper can be listed as follows:

1) This paper presents a smart home system with battery backup that can maintain an uninterrupted electrical supply when a power outage from the grid happens by using ATS as

a switching device. Compared to the conventional generator-set backup, the proposed system uses a standby battery; therefore, it can be directly used when there is an outage.
2) The system has automatic charging for the battery; therefore, the other energy source, for instance, a solar panel, is not required. This means the initial cost for the system is cheaper than using solar panel backup.
3) There are two ways to monitor systems: on-site via HMI and off-side using IoT. The monitoring system controls the electrical device activation and gives the electric billing estimation.

The rest of the paper will be organized as follows. A review of the smart home system, ATS, and ABC will be presented in Section 2, while hardware implementation results will be discussed in Section 3. The last section is the conclusion.

2. Literature Review

2.1 Smart Home System Based on The Internet of Things (IoT)

The concept of a smart home represents a significant technological advancement, offering automated control over electronic devices in various settings, including homes, offices, and more, through internet connectivity. This technology enables real-time monitoring and remote control, enhancing convenience and efficiency in managing daily tasks. However, it's essential to acknowledge that smart home systems, while promising, face challenges related to power outages and manual power source switching. Traditional smart home solutions often overlook the critical issue of power disruptions, leaving users vulnerable to interruptions in electrical supply. Such interruptions can disrupt daily routines, compromise security, and impact overall user experience.

To address these challenges, this research focuses on the development of a Smart Home System that not only offers remote control over lighting and electronic equipment but also incorporates automatic power source switching between the grid and a backup battery. This feature ensures continuous power availability, eliminating the need for manual intervention during power outages. By doing so, the system aims to provide users with an uninterrupted and seamless smart living experience that maximizes efficiency in terms of time and energy utilization.

In the present study, IoT plays a pivotal role in the Smart Home System's functionality. The Arduino acts as the main control for processing the data from the sensor and gives output to the relays. Whereas, it is connected to the internet network through the ESP8266 WiFi module, a cost-effective and versatile component that facilitates internet connectivity for the system (Asman et al., 2020)(Putra et al., 2022). The IoT concept encompasses five layers: perception, network, middleware, application, and business layers, as illustrated in Figure 1. The perception layer of our system comprises essential components, including the PZEM004T sensor for electrical parameter monitoring, a DC voltage sensor, an ESP8266 WiFi module for internet connectivity, and a relay for actuation. This layer collects data from various sensors and devices within the smart home, forming the foundation for real-time monitoring and control. For network communication, the network layer utilizes IEEE 802.11n WiFi, ensuring reliable and high-speed data transfer within the local network. This layer allows seamless connectivity between devices, enabling efficient data exchange. At the middleware layer, the system leverages Blynk Cloud, a robust and user-friendly IoT platform. Blynk Cloud serves as a bridge between the hardware components and the user interfaces, facilitating data exchange and control commands. Additionally, the application layer relies on the Blynk App, which provides an intuitive graphical user interface for remote monitoring and control of smart home devices.

One of the features of the designed smart home system is performing on-site and remote monitoring control. The remote control and monitoring use the Blynk application, while on-site control and monitoring use the Nextion LCD as HMI. The system architecture is shown in Figure 2. Blynk itself is a server service for Internet of Things projects in the form of a digital dashboard with graphical interface facilities for doing the project. The integration of Blynk Cloud and the Blynk App empowers users to monitor and control their home devices remotely and in real-time. Whether adjusting lighting, checking electrical parameters, or ensuring backup power during outages, IoT technology through Blynk offers a streamlined and user-friendly interface.

Nextion LCD is a display module from Nextion as an HMI (Human Machine Interface) that provides a visualization and control interface between humans with processes, machines, and applications. This HMI provides Nextion editor software for GUI (Graphical User Interface) creation/design. This research used USART communication between HMI Nextion and Arduino Mega 2560.

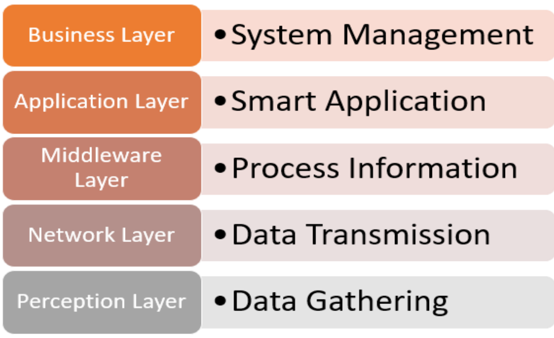


Fig. 1. Layers Of Internet Of Things Architecture (Antão et al., 2018)

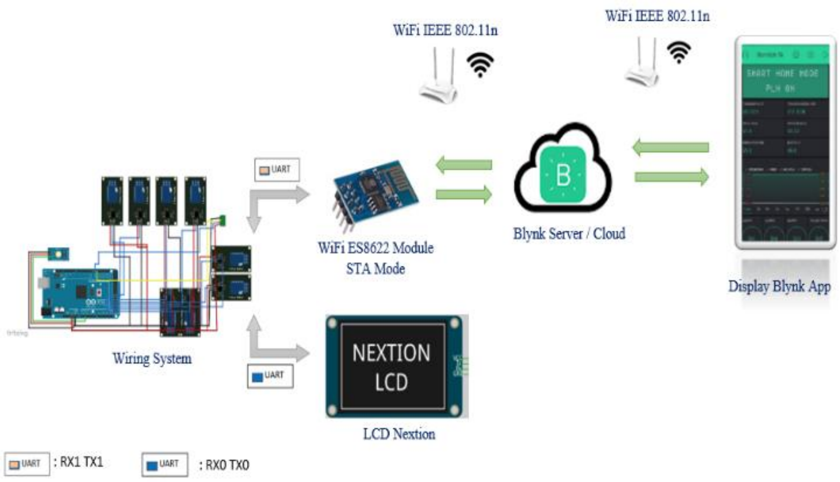


Fig. 2. The Proposed System IoT Architecture

2.2 Automatic Transfer Switch (ATS)

An Automatic Transfer Switch (ATS) serves as a critical component in the Smart Home System, seamlessly transitioning the power source between the grid and the battery backup. ATS operates through complex yet precise mathematical logic reasoning, utilizing a combination of essential tools, including Relays, Timers, Contactors, and MCBs (Miniature Circuit Breakers). These tools function primarily as switches or breakers, ensuring uninterrupted power supply to the home. The choice of ATS components is intricately linked to the electricity consumption patterns within the smart home. In essence, the level of electrical power consumption directly influences the specifications of the ATS components, and the size of the cables used in the system. When electrical power consumption is high, it necessitates the use of robust components and larger cables to accommodate the load effectively.

In our research, the key ATS components are the 5 VDC 30 Ampere relay and the AC voltage sensor, specifically the PZEM004T V3 sensor. The PZEM004T V3 sensor represents a multifunctional electronic module capable of measuring various essential parameters, including RMS voltage, RMS current, active power, frequency, energy, and power factor. Notably, this sensor seamlessly interfaces with open-source platforms like Arduino or ESP8266, enhancing its versatility and compatibility within our Smart Home System. The relay module, on the other hand, functions as a critical electric switch within the ATS. It operates through the transformation of an electromagnet's source voltage, effectively altering the positions between Normally Open (NO) and Normally Closed (NC) states. This dynamic switching capability ensures that the ATS can swiftly respond to changes in the power source, guaranteeing an uninterrupted power supply to the smart home.

2.3 Automatic Battery Charging (ABC)

The Automatic Battery Charging (ABC) system, developed as part of this research, is a critical component of the Smart Home System. It ensures efficient battery charging based on the battery's characteristics and state. The SoC (State of Charge) is a pivotal metric representing the battery's capacity expressed as a percentage. Accurate SoC estimation is fundamental for effective battery management. Several methods exist for estimating SoC, including the Open Circuit Voltage (OCV) method, Coulomb calculation method, neural network method, and Kalman Filter method (Zhang & Fan, 2020)(W. Rahmaniar & Rakhmania, 2021). In this study, we have employed the OCV method for its simplicity and high accuracy (Farmann & Sauer, 2017).

The OCV method relies on the battery's voltage behavior during charge and discharge cycles. It involves measuring the battery's open circuit voltage when it is not connected to any load or charger. By comparing this OCV with pre-determined voltage profiles associated with different SoC levels, our system can accurately estimate the battery's current SoC. Depth of Discharge (DoD), on the other hand, represents the current battery value, expressed as a percentage of the total capacity that has been used. In our research, both SoC and DoD are critical parameters for optimizing battery charging and ensuring efficient energy utilization.

To apply these estimation methods effectively, we have thoroughly characterized the battery's behavior by testing its lower and upper voltage limits. The data obtained from these tests inform the programming of our Automatic Battery Charging system. Specifically, the values entered in the Arduino code are derived from calculations involving both SoC and DoD. In our system, we have set a minimum battery SoC threshold of 30%, which implies a maximum DoD of 70%. SoC and DoD of the battery can be calculated as expressed in (1) and (2), respectively. This ensures that the battery never fully discharges, prolonging its lifespan and maintaining its reliability.

The Automatic Battery Charging (ABC) designed in this research was composed of a 5VDC 30A relay component and a DC voltage sensor. The DC voltage sensor is a voltage divider circuit made into a module. This DC voltage sensor module can measure voltages up to 25 V. This automatic charging system comes from programming after knowing the characteristics of the battery.

$$SoC = \frac{V(\text{currently}) - Vmin}{Vmax - Vmin}\ x\ 100\%$$

$$DoD = \frac{Vmax - V(currently)}{Vmax - Vmin}\ x\ 100\%$$

2.4 Battery Backup

The valve regulated lead–acid (VRLA) battery is a dry battery that uses lead-acid as a chemical. There are two types of this battery, namely a starting battery, better known as the automotive battery, and a deep cycle battery, also known as an industrial battery. In this study, the battery type was a deep cycle. The VRLA battery is more suitable for applications of large amounts of energy storage media but with a low energy charging speed. The specifications of the VRLA SMT1233 battery used are reviewed in Table 1.

Table 1 - VLRA Battery Specification

Model	SMT1233
Voltage	12 V
Capacity	33 Ah
Discharging	Current 0.17 C (FV 1.7V/cell)
Charging	Current 0.25 C Max, Voltage 2.45 V/Cell

Inverters are electronic equipment to convert DC voltage into AC voltage where the output of the inverter can be changed in terms of frequency and voltage. This study used a 500W modified sine wave power inverter with less harmonic distortion than the square wave. Therefore, it can be used for several electrical devices such as computers, TVs, and lights but not for more sensitive loads

3. Research Methods

In this section, we delve into the detailed implementation of software programs within the Smart Home System. The PZEM004T Sensor Reading Program continuously collects real-time data, including RMS voltage, current, power, frequency, and more, through periodic sensor polling and data parsing. Similarly, the DC Voltage Sensor Reading Program interfaces with the DC voltage sensor to provide precise voltage readings.

Central to the system's functionality is the Relay Control Program, orchestrating power source switching based on sophisticated decision-making algorithms. This program considers sensor data and system states; when the grid voltage is absent and the battery voltage surpasses a predefined lower limit, it seamlessly triggers the Automatic Transfer Switch (ATS) to switch to battery backup. The Blynk Application and HMI Programs serve as user interfaces, bridging the gap between user commands and relay control for intuitive remote monitoring and control.

Notably, the ATS and Automatic Battery Charging (ABC) systems exhibit unique characteristics. ATS relies on decision-making algorithms to ensure swift power source switching, while ABC continuously monitors battery voltage, commencing the charging process when the voltage falls below a predefined threshold. The workflow of ATS and ABC, illustrated in Figure 3, involves monitoring grid voltage through the PZEM004T sensor. When grid voltage is absent, the system evaluates battery voltage; if it exceeds the lower limit, ATS triggers the switch to battery power. Conversely, when grid voltage returns and battery voltage is below the lower limit, ABC initiates battery charging, ensuring an uninterrupted power supply.

Within the overall system structure depicted in Figure 4, sensors transmit data to the Arduino as the main controller. Based on the sensor information, the program controls the relays to switch power sources as per predefined criteria, ensuring uninterrupted operation. The safety relay plays a vital role in maintaining secure interactions between the battery and inverter. To assess system performance, rigorous testing methods were employed, including automatic source switching, battery charging efficiency, and relay reliability testing. Success criteria included achieving rapid source switching within predefined timeframes and maintaining a reliable power supply.

Before widespread deployment, the system will undergo thorough small-scale testing, replicating real-world conditions. There are two kinds of load which are lamp and fan used. Parameters such as voltage levels and power interruptions will be carefully monitored and analyzed to ensure system reliability and responsiveness. To check the validity, the measured data from the sensor is compared with the measurement tools such as a multimeter and also manually calculated results.

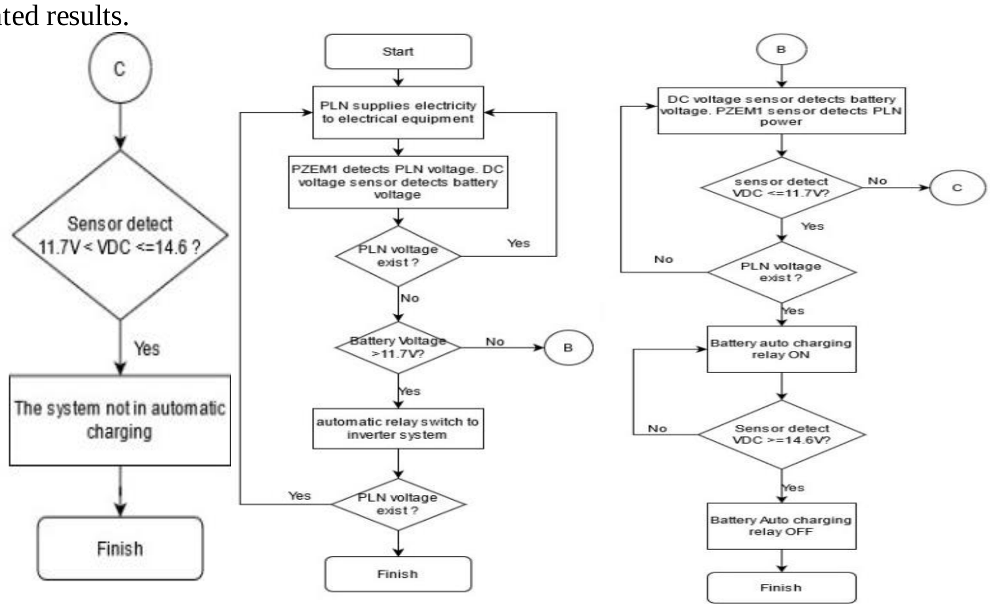


Fig. 3. Flowchart of the proposed system working principle

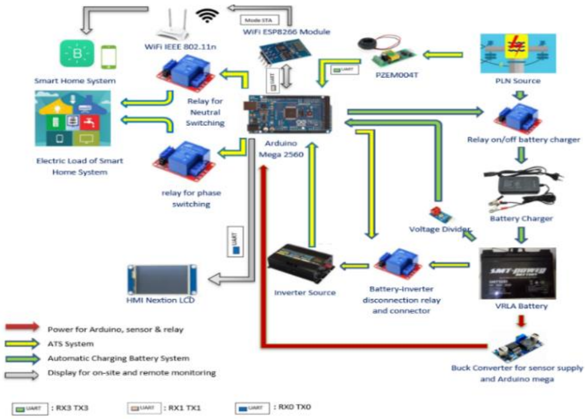


Fig. 4. Hardware system diagram

4. Results and Discussions

4.1 Smart Home Features

Figure 5 is the result of the design of the ATS system with the layout of the components where: a. Phase and neutral switch relay; b. Buck converter 5V; c. Grid AC voltage input; d. Inverter AC voltage input; e. PZEM004T Sensor; f. Arduino Mega 2560; g. Buck Converter LM296; h. Safe Relay. The load installed for the proposed smart home system prototype is listed in Table 2. When the inverter is working, socket I (for the battery charger) is always off due to the system design, making the battery automatically charged if there is electricity from the grid. In contrast, the battery will not be automatically charged when the inverter supplies the load. Therefore, the total loads when supplied from the grid and battery backup are 198W and 68W, respectively. Electrical wiring from the source to each load uses a 1.5 mm NYAF cable with a current-carrying capability of 15 A. This cable can transmit power up to 2244W so that socket II (to supply the fan) can be used for another load.

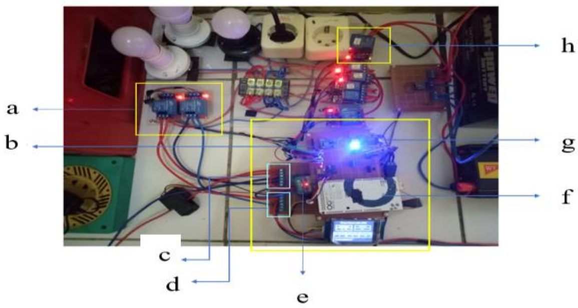
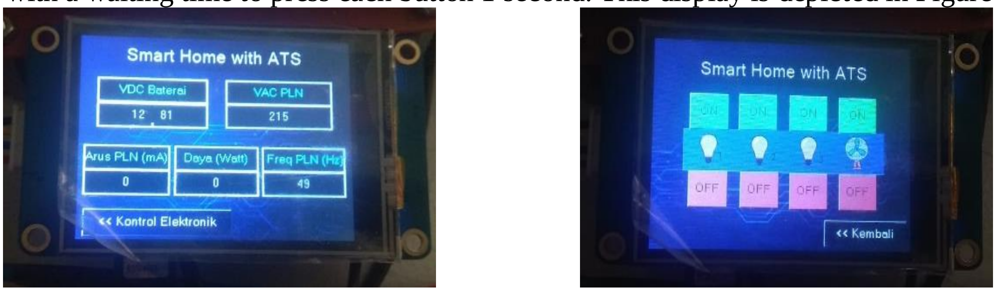


Fig. 5. Hardware realization of ATS

Table 2 - Load of the smart home system

Load	Power (W)
Lamp 1	3 Watt
Lamp 2	20 Watt
Lamp 3	15 Watt
Socket I for Battery Charger	130 Watt
Socket II for 30W Fan	30 Watt
Total Power	198 Watt

There are on-site and off-site monitoring and control for the proposed smart home. On-site control uses a 2.4-inch touchscreen Nextion LCD with a two-page interface. On the first page, there is information about the battery voltage, grid voltage, current, frequency, and power consumed. On the second page, there is on-off control where in this simulation is three lamp and a fan. Control of lights and sockets is successful with a delay of ±1 second per one piece of electronic equipment according to the program. Therefore, to turn on 2 lights, it takes a 2-second delay with a waiting time to press each button 1 second. This display is depicted in Figure 6.



(a) (b)

Fig. 6. On-site monitor and control display (a) power monitoring (b) control

The off-site control and monitoring are performed using IoT. The IoT platform used in this research is Blynk. Figure 7 shows the Blynk app interface for the control and monitoring of the proposed system. The detail of Figure 7 is (1) an indicator of system connectivity to the internet, (2) a monitoring display for PLN (the grid) power and batteries, (3) the on-off control of electrical equipment, (4) the display mode used, and (5) is a power monitoring graph.

The energy sensor (PZEM004T) accuracy test results are listed in Table 3. A significant error was obtained with a value of 33.06%, so the reading accuracy is only 66.94%. This large error occurs because the energy sensor has not been calibrated to adjust the current reading. Therefore, calibration is performed to reduce reading errors using a linear regression approach with the formula $y = a + bx$. The linear regression is based on the relation between power reading by the sensor and calculated energy which uses the data from voltage and current measurement using a multimeter. The linear regression for PZEM004T sensor calibration is shown in (3). After calibration, the energy reading accuracy level was tested for re-estimated costs. The error decreased from 33.06% to 9.79%, and the sensor accuracy level became 90.21%, as shown in Table 4. At the same time, the accuracy comparison graph is depicted in Figure 8.

The accuracy test was also performed for the DC voltage sensor, which senses the battery voltage. A multimeter was used for calibration. The results are shown in Figure 9, with the resulting accuracy being 99.20%. The accuracy tests for both AC energy and DC voltage sensors showed a good result of over 90%.

$$y = -4.45 * 10\text{-}3 + 1.96x$$

Table 3 - Accuracy test of PZEM004T sensor before calibration

No.	Average Load (W)	Energy from Calculation (kWh)	Energy from Sensor (kWh)	Error (%)
1	32.14	0.0064	0.0077	19.78
2	28.21	0.0056	0.0074	30.57
3	14.79	0.0030	0.0010	66.18
4	33.79	0.0068	0.0082	21.84
5	28.53	0.0057	0.0072	26.94
Average Error				33.06
Level of Accuracy				66.94

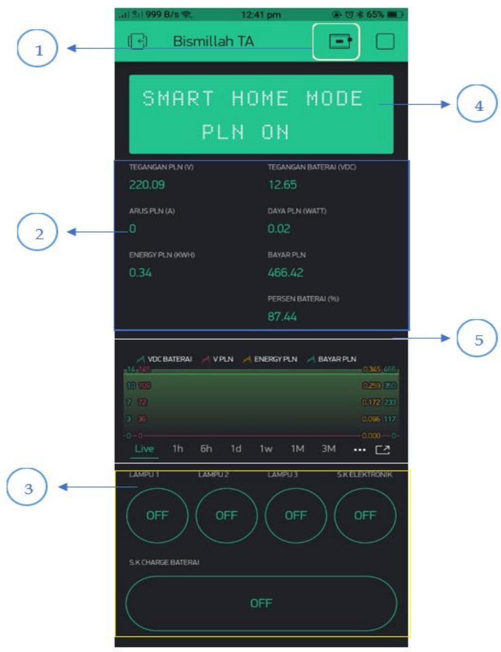


Fig. 7. Blynk app interface for control and monitoring

Table 4 - Sensor accuracy before and after calibration

Calibration	Energy (kWh)		Error (%)	Accuracy (%)
	Calculation	Sensor		

Before	0.0055	0.0063	33.0621	66.94
After	0.0066	0.0073	9.7931	90.21

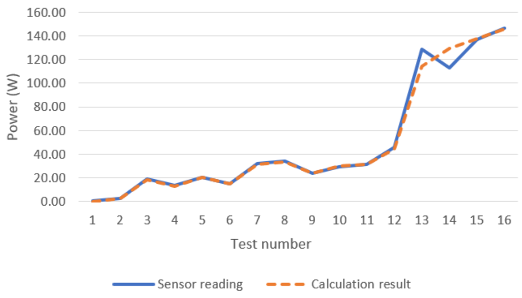


Fig. 8. Power sensor accuracy test

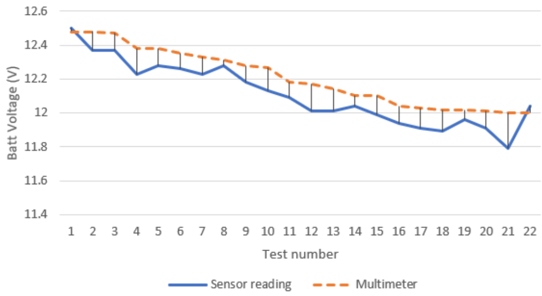


Fig. 9. DC voltage sensor accuracy test

4.2. Automatic Transfer Switch (ATS) Testing

ATS performance evaluation was done by setting up a grid voltage source and battery voltage. There are some schemes tested, which are: (1) both grid and inverter ON, (2) grid ON, inverter OFF, (3) both grid and inverter OFF, (4) grid OFF, inverter ON. The results are listed in Table 5, where 0V means the source is disconnected.

In switching performance evaluation, switching to a grid acquired a time delay of 1-3 seconds, while switching to the inverter acquired 2-4 seconds. Switching to the inverter has a longer delay than switching to the grid. The requirement checks for switching to a grid only had one condition: check whether there is a grid voltage. Meanwhile, switching to the inverter had two conditions: check whether there is no grid electricity supply, and check whether the battery voltage is >11.70V. Hence, the system process takes longer to switch to the inverter.

Table 5 - ATS system testing

Schemes tested	Grid voltage (V)	Battery Voltage (V)	Relay			Delay (s)
			Phase	Neutral	Safe	
1	>200	>11.7	Low	Low	High	1-3
2	>200	0	Low	Low	High	1-3
3	0	0	Low	Low	High	1-4
4	0	>11.7	High	High	Low	2-4

4.3. Battery Capacity Testing

The lower and upper limits of the battery are necessary to be defined to set the automatic charging system. The lower limit test was carried out by loading the battery to 3 lights and 1 fan (the total power base on the datasheet is 68W). The real power absorbed by the load detected by the power sensor is 47W. Since the inverter efficiency is 80%; therefore, the power absorbed from the battery is 58.75W or rounded as 59W.

Figure 10 shows that when the sensor reading is 10.66V, the inverter can no longer supply voltage to the load because the battery no longer carries current. When the load is turned off, the battery voltage is 11.16V. Therefore, it can be determined that the lower limit of the battery is 11.16V. The difference between battery voltage before loaded and after loaded is 0.49V.

The determination of the upper limit is done by charging the battery until it is fully charged. The VRLA SMT1233 battery has constant voltage charging characteristics so that when charging, the charger must provide a charging voltage between 14.50V and 14.90V, based on the battery specifications. When the battery charging process is from the lower limit, the battery charging current is about 8.60A which then decreases when the battery starts to be fully charged. In a full-charged condition, the current flowing in the battery becomes 1A, then switches to float charging mode.

Figures 11 (a) and (b) show the charging process to find the battery's upper limit, which is done for three hours per day on two separate days. The total time needed for charging from the lower limit to the upper limit is about 5 hours and 50 minutes. Meanwhile, according to the specification, the required charging time is 3 hours 48 minutes if the charging current is constant at 8.60A, as calculated in (4). The difference between the real charging time and the calculated time is 2 hours and 2 minutes. The difference is quite far because the charging current in the calculation is always constant, while in actual conditions, the current gradually decreases when the battery goes fully charged. The upper limit of the battery is 12.90V.

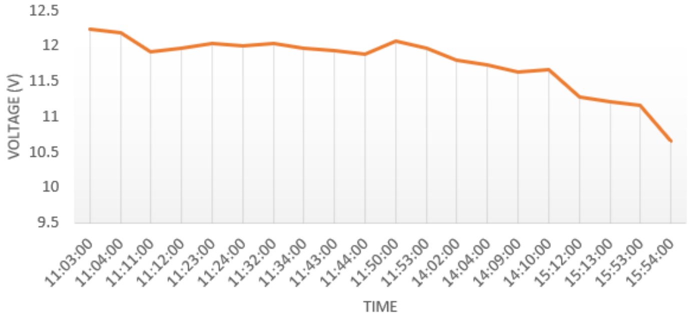
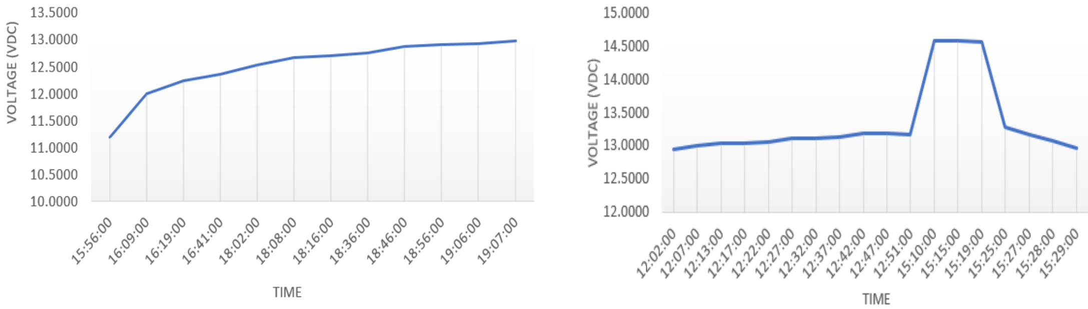


Fig. 10. Load test to get the lower limit of the battery



(a) (b)

Fig. 11. Battery charging for upper limit determination (a) first day (b) second day

$$\textit{Charging time} = 33Ah/\ 8.60\ A = 3\ \textit{hours}\ 48\ \textit{minutes}$$

In determining the cut-off of the upper limits of the ABC, based on the charging graph of Figure 11(b), the highest voltage during charging is 14.6V; therefore, it is set as the cut-off of the upper limit voltage. In comparison, the cut-off lower limit is determined by calculating the SoC and DoD of the battery. In this study, the DoD of the battery was set at 70%, so the SoC was set at 30%. Based on Figure 12, the battery usage time is tested for a 59W power load, and the SoC graph of the battery is obtained, as shown in Figure 13. The test starts at a battery voltage of 12.40V, with the battery's SoC at 72.95%. The test is completed when the battery voltage is 11.99V at 48.65% SoC. Meanwhile, 100% SoC is when the battery is at a maximum voltage of 12.90V, then 30% SoC is set at 11.70V as the lower limit of the battery to activate the ABC. In Figure 12, with a 59W battery load, the 12.40V battery voltage is reduced to 12V in 1 hour 30 minutes with a voltage difference of 0.40VDC. Hence, if the battery load is constant at 59W, assuming linear condition, the battery can supply power for 4 hours 30 minutes (12.90V – 11.70V = 1.20 V; (1.20V/ 0.40V) *1.5h = 4 h 30 min) in the range SoC of 30-100%. From the battery capacity test results, the battery capacity can be used for the battery presentation feature, where this percentage feature is obtained from the SoC OCV formula. The error value for the battery percentage feature is 0.52%, so the accuracy is 99.44%, as listed in Table 6.

4.4. Automatic Battery Charging (ABC) Testing

The Battery auto-charging is performed when the battery's voltage is below the lower limit. When the charger has switched to float charging mode, the ABC System performs a cut-off at a voltage of 14.60V. In actual conditions, the voltage of a fully charged battery is < 14.60V, but in this system, the cut-off upper limit specified is 14.60V because the charger is a smart charger that can switch modes automatically from deep cycle charging to float charging.

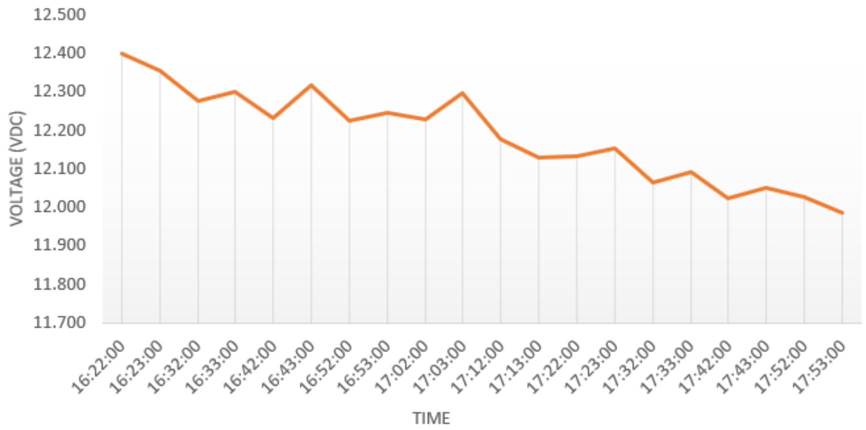


Fig. 12. Battery usage time graph

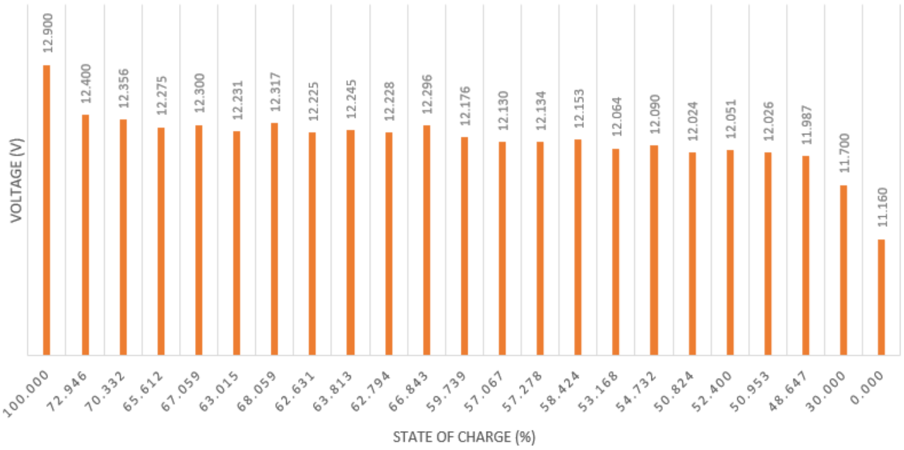


Fig. 13. SoC percentage according to battery voltage characteristics

Table 6 - Battery percentage accuracy testing

Mode	No	Voltage (V)	Percentage in Blynk (%)	Percentage with calculation (%)	Error (%)
Charging	1	13.40	55.68	55.56	0.22
	2	13.48	58.39	58.52	0.22
	3	13.52	60.20	60.00	0.33
	4	13.57	62.91	61.85	1.71
	5	13.60	63.82	62.96	1.36
Not-charging	1	12.40	71.40	71.26	0.19
	2	12.45	74.21	74.14	0.10
	3	12.55	79.82	79.89	0.08
	4	12.57	81.22	81.03	0.23
	5	12.62	84.03	83.91	0.15

When the safe relay condition is HIGH, the voltage from the battery to the inverter is cut. When charging, the battery does not supply voltage to the inverter. According to ATS switching, the delay in switching conditions between ON and OFF charging relays is ±2s while the delay for safe relays from HIGH to LOW states is around 2-4s. Both delays do not come from programming but from system performance. Safe relay in condition No.2 remains HIGH because even though there is no grid voltage, the battery voltage is <11.70V. When charging is running, and the battery voltage is >11.70V, but suddenly the grid electricity goes out, charging will stop so that the battery is not charged from the inverter source. The test results are listed in Table 7.

Table 7 - Automatic charging battery testing

No	Battery Voltage (V)	Grid Voltage (V)	Charging Relay	Safe Relay	Delay relay charging (s)
1	< 11.70	Exist	ON	HIGH	± 2

2	< 11.70	None	OFF	HIGH	± 2
3	≥ 14.60	Exist	OFF	HIGH	± 2
4	≥ 14.60	None	OFF	LOW	± 2

4.5. Result Comparison

According to Indonesia National Standard (SNI) 0225, about General Electrical Installation Requirements (PUIL) 2011, the power plant for emergency service needs to be able to carry a load within 15s, and the entire load needs to be switched within the next 30s, or a total duration of 45s (National Standardization Body (BSN), 2011). Based on this standard, Syah et al. (2021) proposed Arduino-based ATS which can switch from main to backup supply within 15.13s. Our proposed ATS can switch to the backup supply with the time only 4s. The faster time is not only affected by ATS processing time but also by the backup supply used. The standard is based on a Generator-Set whereas the proposed method used battery based. The battery base has a better response time since it is in the standby position.

Hasanah, et al. (2018) also, develop an Arduino-based ATS which controls power from the grid and the Genset. From the experimental testing, they conclude that the time required to switch all the load to the Genset is 37.8s. While the time to reconnect to the grid is 2.8s. This result still matches the PUIL 2011 standard. On the other hand, our proposed system with battery backup can give faster electricity recovery since there is no time required to turn it on.

Table 8 resumes the estimated cost of the proposed system. Compared to the system proposed by Venancio and Chua (2020) which uses PLC as a controller and an MCB ATS which is available in the market with a total cost of USD $724.56, the proposed system is cheaper. In the proposed system, the solar panel system is not used, this also can reduce the total cost.

Table 8 - Estimated cost of the proposed system

No	ATS Components	Cost (IDR)
1	Arduino Mega & ESP8266	225,000
2	Sensor PZEM004T	165,000
3	Voltage sensor DC	5,000
4	Buck converter 12v to 5v	100,000
5	Relay 5v DC	184,000
6	Nexion LCD 2.4	400,000
7	Electronic component and cable	100,000
8	Blynk IoT package	100,000
	Backup Supply Components	
9	Battery VLRA SMT 1233	734,000
10	Battery charger	400,000
11	Inverter 500W	240,000
	TOTAL Cost	2,653,000
	TOTAL Cost in USD	$183.97

The findings hold practical implications for various applications. The rapid response of our battery-based ATS not only meets standards but also offers enhanced power continuity during outages. This has practical implications for critical facilities, ensuring uninterrupted operations in emergency scenarios. Additionally, the cost-effectiveness of our system, compared to alternatives, makes it an attractive solution for a range of settings, from residential homes to small businesses.

5. Conclusion

The Smart Home System with battery backup was successfully designed and tested. The system has on-site and off-site control and monitoring using an HMI and IoT. An Automatic Transfer Switch (ATS) is used to switch the power from grid to battery backup and vice versa. There is also an Automatic Battery Charging (ABC) system to charge the battery backup. The proposed system also provides electric tax prediction. The test shows that the power sensor, DC voltage sensor, and SoC calculation accuracies are 90.21%, 99.20%, and 99.44%, respectively. ATS and ABC systems can perform well. Switching to the inverter only took a 2-4s delay, while switching to the grid had a 1-3s delay. The automatic charging can perform at a predetermined minimum battery voltage with a delay of ± 2s. Compared to the previous research results, the proposed system has faster responses times and lower prices. The seamless integration of ATS and ABC systems, coupled with IoT capabilities, empowers homeowners to maintain uninterrupted power supply, especially during grid disruptions, fostering energy resilience and convenience.

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References

Adiono, T., Manangkalangi, B. A., Muttaqin, R., Harimurti, S., & Adijarto, W. (2017). Intelligent and secured software application for IoT based smart home. *2017 IEEE 6th Global Conference on Consumer Electronics, GCCE 2017*, *2017-Janua*, 1–2. https://doi.org/10.1109/GCCE.2017.8229409

Agarwal, K., Agarwal, A., & Misra, G. (2019). Review and Performance Analysis on Wireless Smart Home and Home Automation using IoT. *Proceedings of the 3rd International Conference on I-SMAC IoT in Social, Mobile, Analytics and Cloud, I-SMAC 2019*, 629–633. https://doi.org/10.1109/I-SMAC47947.2019.9032629

Ahmad, I., Niazy, M. S., Ziar, R. A., & Khan, S. (2021). Survey on IoT: Security Threats and Applications. *Journal of Robotics and Control (JRC)*, *2*(1), 42–46. https://doi.org/10.18196/JRC.2150

Antão, L., Pinto, R., Reis, J., & Gonçalves, G. (2018). Requirements for testing and validating the industrial internet of things. *Proceedings - 2018 IEEE 11th International Conference on Software Testing, Verification and Validation Workshops, ICSTW 2018*, 110–115. https://doi.org/10.1109/ICSTW.2018.00036

Asghar, M. H., Negi, A., & Mohammadzadeh, N. (2015). Principle application and vision in Internet of Things (IoT). *International Conference on Computing, Communication and Automation, ICCCA 2015*, 427–431. https://doi.org/10.1109/CCAA.2015.7148413

Asman, F. F., Permata, E., & Fatkhurrokhman, M. (2020). Prototype of Smart Lock Based on Internet Of Things (IOT) With ESP8266. *Jurnal Ilmiah Teknik Elektro Komputer Dan Informatika*, *5*(2), 101–111. https://doi.org/10.26555/jiteki.v5i2.15317

Atmaja, A. P., Hakim, A. El, Wibowo, A. P. A., & Pratama, L. A. (2021). Communication Systems of Smart Agriculture Based on Wireless Sensor Networks in IoT. *Journal of Robotics and Control (JRC)*, *2*(4), 297–301. https://doi.org/10.18196/JRC.2495

Azman, N., Habiburrohman, M., & Nugroho, E. R. (2023). Development of a Remote Straw Mushroom Cultivation System Using IoT Technologies. *Jurnal Ilmiah Teknik Elektro Komputer Dan Informatika*, *9*(3), 872–894. https://doi.org/10.26555/jiteki.v9i3.26280

Brundha, S. M., Lakshmi, P., & Santhanalakshmi, S. (2018). Home automation in client-server approach with user notification along with efficient security alerting system. *Proceedings of the 2017 International Conference On Smart Technology for Smart Nation, SmartTechCon 2017*, 596–601. https://doi.org/10.1109/SMARTTECHCON.2017.8358441

Dev, M. A., Beevi, P. F., Abhinshan, K., Kumar, K. S., & Safvan, K. M. (2020). Three Mode Single Phase Automatic Changeover Controller. *International Conference on Futuristic Technologies in Control Systems and Renewable Energy, ICFCR 2020*. https://doi.org/10.1109/ICFCR50903.2020.9249997

Dey, S., Roy, A., & Das, S. (2016). Home automation using Internet of Thing. *2016 IEEE 7th Annual Ubiquitous Computing, Electronics and Mobile Communication Conference, UEMCON 2016*. https://doi.org/10.1109/UEMCON.2016.7777826

Farahiyah, D., & Purnama, B. W. (2021). Design Prototype of Temperature and Humidity Control and Monitoring on Weaver Ant Cage based on Internet of Things. *Jurnal Ilmiah Teknik Elektro Komputer Dan Informatika*, *7*(2), 326–337. https://doi.org/10.26555/JITEKI.V7I2.21438

Farmann, A., & Sauer, D. U. (2017). A study on the dependency of the open-circuit voltage on temperature and actual aging state of lithium-ion batteries. *Journal of Power Sources*, *347*, 1–13. https://doi.org/10.1016/J.JPOWSOUR.2017.01.098

Fikri, N. I., Nathaniel, V. L., Gunawan, M. S., & Abuzairi, T. (2021). Design of Real-Time Aquarium Monitoring System for Endemic Fish on the Smartphone. *Jurnal Ilmiah Teknik Elektro Komputer Dan Informatika*, *7*(2), 269–276. https://doi.org/10.26555/JITEKI.V7I2.21137

Haque, M. E., Islam, M. R., Fazle Rabbi, M. T., & Rafiq, J. I. (2019). IoT based home automation system with customizable GUI and low cost embedded system. *2019 International Conference on Sustainable Technologies for Industry 4.0, STI 2019*. https://doi.org/10.1109/STI47673.2019.9068035

Hasanah, R. N., Soeprapto, & Adi, H. P. (2018). Arduino-based Automatic Transfer Switch for Domestic Emergency Power Generator-Set A must for an area with frequent electricity service interruption. *2018 2nd IEEE Advanced Information Management,Communicates,Electronic and Automation Control Conference (IMCEC)*, *Imcec*, 742–746.

Hermanu, C., Maghfiroh, H., Santoso, H. P., Arifin, Z., & Harsito, C. (2022). Dual Mode System of Smart Home Based on Internet of Things. *Journal of Robotics and Control (JRC)*, *3*(1), 26–31. https://doi.org/10.18196/JRC.V3I1.10961

Hisham Che Soh, Z., Azeer Al-Hami Husa, M., Afzal Che Abdullah, S., & Affandi Shafie, M. (2019). Smart waste collection monitoring and alert system via IoT. *ISCAIE 2019 - 2019 IEEE Symposium on Computer Applications and Industrial Electronics*, 50–54. https://doi.org/10.1109/ISCAIE.2019.8743746

Husni, M., Ginardi, R. V. H., Gozali, K., Rahman, R., Indrawanti, A. S., & Senoaji, M. I. (2021). Mobile Security Vehicle ' s based on Internet of Things. *Journal of Robotics and Control (JRC)*, *2*(6). https://doi.org/10.18196/jrc.26135

Indikawati, F. I., & Zamroni, G. M. (2019). Household Power Consumption Forecasting using IoT Smart Home Data. *Jurnal Ilmiah Teknik Elektro Komputer Dan Informatika*, *5*(1), 8–15. https://doi.org/10.26555/jiteki.v5i1.13184

Kim, J. Y., Lee, H. J., Son, J. Y., & Park, J. H. (2015). Smart home web of objects-based IoT management model and methods for home data mining. *17th Asia-Pacific Network Operations and Management Symposium: Managing a Very Connected World, APNOMS 2015*, 327–331. https://doi.org/10.1109/APNOMS.2015.7275448

Kumar, S., & Lee, S. R. (2014). Android based smart home system with control via Bluetooth and internet connectivity. *Proceedings of the International Symposium on Consumer Electronics, ISCE*. https://doi.org/10.1109/ISCE.2014.6884302

Kurniawan, N. (2020). Electrical Energy Monitoring System and Automatic Transfer Switch (ATS) Controller with the Internet of Things for Solar Power Plants. *Journal of Soft Computing Exploration*, *1*(1), 16–23. https://doi.org/10.52465/JOSCEX.V1I1.2

Mbonu Nkemjika, B., Usikalu Mojisola, R., Ayara Williams, A., & Obafemi Leke, N. (2019). Design and construction of automatic transfer switch. *ARPN Journal of Engineering and Applied Sciences*, *14*(22), 3906–3909.

Mohamed, A. A. S., Zulkefli, A. M., Sagar, S. M. V., Gajjarapu, U. M., Thomas, A., & Bhavaraju, V. (2023). Smart Vehicle-To-Home (V2H) Platform Enabled Home Energy Management System (HEMS) for Backup Supply. *IEEE Green Technologies Conference*, *2023-April*, 73–77. https://doi.org/10.1109/GreenTech56823.2023.10173790

Naresh, D., Chakradhar, B., & Krishnaveni, S. (2013). Bluetooth Based Home Automation and Security System Using ARM9. *International Journal of Engineering Trends and Technology (IJETT)*, *4*(9), 4052–4058.

National Standardization Body (BSN), S. 0225. (2011). General electrical installation requirements (PUIL) 2011, 8-21: Emergency (genset) generator installation. In *DirJen Ketenagalistrikan* (Vol. 2011, Issue PUIL).

Panduardi, F., Haq, S., Studi, P., Informatika, T., & Banyuwangi, P. N. (2016). Wireless Smart Home System Menggunakan Raspberry Pi Berbasis Android. *Jurnal Teknologi Informasi Dan Terapan*, *3*(1), 320–325.

Prasetia, Y., Putrada, A. G., & Rakhmatsyah, A. (2021). Evaluation of IoT-Based Grow Light Automation on Hydroponic Plant Growth. *Jurnal Ilmiah Teknik Elektro Komputer Dan*

Informatika, *7*(2), 314–325. https://doi.org/10.26555/JITEKI.V7I2.21424

Purnomo, P., Aripriharta, A., Handayani, A. N., Hasanah, R. N., Rosmin, N., & Horng, G.-J. (2021). Realtime IoT based Harmonics Monitoring System Review with Potential Low-Cost Devices with Experimental Case Study. *Jurnal Ilmiah Teknik Elektro Komputer Dan Informatika*, *7*(2), 259–268. https://doi.org/10.26555/JITEKI.V7I2.21166

Putra, J. M., Misbahuddin, M., & Al Sasongko, S. M. (2022). Multi-hop ESP-Mesh Network and MQTT Protocol for Smart Light Systems in High-Rise Buildings. *Jurnal Ilmiah Teknik Elektro Komputer Dan Informatika*, *8*(1), 51. https://doi.org/10.26555/jiteki.v8i1.22535

Rahmaniar, F. D., Endri, J., & Salamah, I. (2023). Design of Automatic Organic Fertilizer Processing Tools by Utilizing the Internet of Things (IOT) as a Monitoring System. *Jurnal Ilmiah Teknik Elektro Komputer Dan Informatika*, *9*(3), 684–692. https://doi.org/10.26555/jiteki.v9i3.26528

Rahmaniar, W., & Rakhmania, A. E. (2021). Online Digital Image Stabilization for an Unmanned Aerial Vehicle (UAV). *Journal of Robotics and Control (JRC)*, *2*(4), 234–239. https://doi.org/10.18196/jrc.2484

Rahmatullah, R., Kadarina, T. M., Irawan, B. B., Septiawan, R., & Rufiyanto, A. (2023). Design and Implementation of IoT-Based Monitoring Battery and Solar Panel Temperature in Hydroponic System. *Jurnal Ilmiah Teknik Elektro Komputer Dan Informatika*, *9*(3), 810–820. https://doi.org/10.26555/jiteki.v9i3.26729

Ransing, R. S., & Rajput, M. (2015). Smart home for elderly care, based on wireless sensor network. *2015 International Conference on Nascent Technologies in the Engineering Field, ICNTE 2015 - Proceedings*. https://doi.org/10.1109/ICNTE.2015.7029932

Riadi, I., & Syaefudin, R. (2021). Monitoring and Control Food Temperature and Humidity using Internet of Things Based-on Microcontroller. *Jurnal Ilmiah Teknik Elektro Komputer Dan Informatika*, *7*(1), 108–117. https://doi.org/10.26555/JITEKI.V7I1.20213

Sabry, A. H., Wan Hasan, W. Z., Alkubaisi, Y., & Ab-Kadir, M. Z. A. (2019). Battery Backup Power System for Electrical Appliances with Two Options of Primary Power Sources. *2018 IEEE 5th International Conference on Smart Instrumentation, Measurement and Application, ICSIMA 2018*. https://doi.org/10.1109/ICSIMA.2018.8688757

Saleh, N. H., Mubdir, B. A., M. Al-Hindawi, A. M., & Ahmed, A. H. (2017). Design and Implementation of Aurdino Based Smart Home Energy Management System Using Renewable Energy Resources. *Kurdistan Journal of Applied Research*, *2*(3), 202–211. https://doi.org/10.24017/science.2017.3.40

Salman, L., Salman, S., Jahangirian, S., Abraham, M., German, F., Blair, C., & Krenz, P. (2017). Energy efficient IoT-based smart home. *2016 IEEE 3rd World Forum on Internet of Things, WF-IoT 2016*, 526–529. https://doi.org/10.1109/WF-IOT.2016.7845449

Saputro, J. S., Maghfiroh, H., Adriyanto, F., Darmawan, M. R., Ibrahim, M. H., & Pramono, S. (2023). Energy Monitoring and Control of Automatic Transfer Switch between Grid and Solar Panel for Home System. *International Journal of Robotics and Control Systems*, *3*(1), 59–73. https://doi.org/10.31763/ijrcs.v3i1.843

Senen, A., Widyastuti, C., Handayani, O., Pln, T., Lingkar, J., Barat, L., & Kosambi, D. (2022). Master Plan for Electricity Distribution Networks Based on Micro-Spatial Projection of Energy Demand. *Jurnal Ilmiah Teknik Elektro Komputer Dan Informatika*, *7*(3), 503–511. https://doi.org/10.26555/JITEKI.V7I3.22244

Shahadi, H. I., Kadhim, M. K., Almeyali, N. M., & Hadi, A. T. (2021). Design and Implementation of a Smart, Interactive, and Portable System for Monitoring of Human Vital Signs. *Jurnal Ilmiah Teknik Elektro Komputer Dan Informatika*, *7*(1), 30–42. https://doi.org/10.26555/jiteki.v7i1.20209

Shin, H., & Baldick, R. (2017). Plug-In Electric Vehicle to Home (V2H) Operation under a Grid Outage. *IEEE Transactions on Smart Grid*, *8*(4), 2032–2041. https://doi.org/10.1109/TSG.2016.2603502

Singh, H. K., Verma, S., Pal, S., & Pandey, K. (2019). A step towards Home Automation using IOT. *2019 12th International Conference on Contemporary Computing, IC3 2019*. https://doi.org/10.1109/IC3.2019.8844945

Somani, S., Solunke, P., Oke, S., Medhi, P., & Laturkar, P. P. (2018). IoT Based Smart Security and Home Automation. *Proceedings - 2018 4th International Conference on Computing, Communication Control and Automation, ICCUBEA 2018*. https://doi.org/10.1109/ICCUBEA.2018.8697610

Suesaowaluk, P. (2020). Home Automation System Based Mobile Application. *2020 2nd World Symposium on Artificial Intelligence, WSAI 2020*, 97–102. https://doi.org/10.1109/WSAI49636.2020.9143317

Suryanto, A. T., Aprillia, B. S., & Putri, C. E. (2020). Control System for Smart Home Energy Management. *IOP Conference Series: Materials Science and Engineering*, *982*(1), 012017. https://doi.org/10.1088/1757-899X/982/1/012017

Syah, K. S., Saodah, S., & Nataliana, D. (2021). Arduino Uno-Based Automatic Transfer Switch. *Rev. Roum. Sci. Techn.– Électrotechn. et Énerg.*, *66*, 219–224.

Tharaniya Soundhari, M., & Brilly Sangeetha, S. (2015). Intelligent interface based speech recognition for home automation using android application. *ICIIECS 2015 - 2015 IEEE International Conference on Innovations in Information, Embedded and Communication Systems*. https://doi.org/10.1109/ICIIECS.2015.7192988

Vaidya, V. D., & Vishwakarma, P. (2018). A Comparative Analysis on Smart Home System to Control, Monitor and Secure Home, based on technologies like GSM, IOT, Bluetooth and PIC Microcontroller with ZigBee Modulation. *2018 International Conference on Smart City and Emerging Technology, ICSCET 2018*. https://doi.org/10.1109/ICSCET.2018.8537381

Venancio, L. A., & Chua, A. Y. (2020). A novel low cost automation of transfer switch control for a hybrid solar power system with simulation. *International Journal of Mechanical Engineering and Robotics Research*, *9*(7), 987–997. https://doi.org/10.18178/ijmerr.9.7.987-997

Vishwakarma, S. K., Upadhyaya, P., Kumari, B., & Mishra, A. K. (2019). Smart Energy Efficient Home Automation System Using IoT. *Proceedings - 2019 4th International Conference on Internet of Things: Smart Innovation and Usages, IoT-SIU 2019*. https://doi.org/10.1109/IOT-SIU.2019.8777607

Wardana, H., Salamah, I., & Taqwa, A. (2023). Cat Feeding Using Microcontroller Arduino Uno TCS3200 Sensor and Internet of Things. *Jurnal Ilmiah Teknik Elektro Komputer Dan Informatika*, *9*(3), 758–767. https://doi.org/10.26555/jiteki.v9i3.26529

Wicaksono, M. F., & Rahmatya, M. D. (2022). IoT for Residential Monitoring Using ESP8266 and ESP-NOW Protocol. *Jurnal Ilmiah Teknik Elektro Komputer Dan Informatika*, *8*(1), 93. https://doi.org/10.26555/jiteki.v8i1.23616

Wicaksono, M. F., Syahrul, S., & Rahmatya, M. D. (2021). Development of Laboratory Equipment Inventory System Using Radio Frequency and Internet of Things. *Jurnal Ilmiah Teknik Elektro Komputer Dan Informatika*, *7*(2), 249–258. https://doi.org/10.26555/JITEKI.V7I2.21114

Withanage, C., Ashok, R., Yuen, C., & Otto, K. (2014). A comparison of the popular home automation technologies. *2014 IEEE Innovative Smart Grid Technologies - Asia, ISGT ASIA 2014*, 600–605. https://doi.org/10.1109/ISGT-ASIA.2014.6873860

Yang, L., Ji, M., Gao, Z., Zhang, W., & Guo, T. (2009). Design of home automation system based on ZigBee wireless sensor network. *2009 1st International Conference on Information Science and Engineering, ICISE 2009*, 2610–2613. https://doi.org/10.1109/ICISE.2009.481

Zhang, M., & Fan, X. (2020). Review on the State of Charge Estimation Methods for Electric Vehicle Battery. *World Electric Vehicle Journal 2020, Vol. 11, Page 23*, *11*(1), 23. https://doi.org/10.3390/WEVJ11010023