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Design and Implementation of a Power Supervision Strategy for a Smart House in Libya: A Realistic Hybrid System Utilizing Solar Cells and Lithium Batteries

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Abstract- In the last few years, Libya has faced problems with electric power, the most important of which is the lack of maintenance of electrical stations, the failure to establish new stations, and the cutting of some electric tower wires that connect electricity to homes and institutions. To solve this problem, this paper focuses on helping establish a smart home in Libya powered by a hybrid system and the grid. This paper has dealt with two major steps: optimizing home appliance sizing and managing their control. The goal of this sizing is to determine the appropriate number of photovoltaic (PV) panels and batteries to be used while considering efficiency and costs. The PVsyst software is used to estimate the energy generated and consumed, the size of PV panels and batteries, and the best solar radiation angle annually. Secondly, the energy management system proposed in this paper has several main objectives: tracking the system through twelve modes, monitoring the connection between the home and the grid, supplying the home with electricity when the grid is interrupted by another source, controlling the battery charging, reducing the electricity tariff, achieving self-sufficiency in energy, and not relying solely on the government grid. This approach is applied to a real house in Zawiya City, Libya, and the practical results confirm the effectiveness of the proposed control strategy.

Keywords Smart home, hybrid system, PV panels, batteries, energy management system, optimizing home appliance sizing, PVSyst, grid connection, real house, practical result.

1. Introduction

The rise in crude oil prices, particularly in light of warnings about the depletion of fossil resources and the increasing impact of global warming and greenhouse gas emissions, underscores the importance of considering the use and development of renewable energy, diversifying energy sources, and optimizing consumption [1-5]. Many countries, including Libya, face significant challenges in meeting their energy needs despite having abundant solar radiation [6-10]. Libya has been grappling with prolonged and frequent power outages for over a decade, lasting from five to twenty hours per day in some cities, even in areas close to power stations. These outages have resulted in substantial damage to household appliances and equipment [11,12]. In remote and rural areas, power outages can last for days or weeks, particularly in southern Libya and desert regions, where electricity is provided through either traditional or renewable energy methods [13-18]. The significant growth in population in Libya, coupled with the lack of regular maintenance of government power stations and the failure to establish and develop new ones, has led to a drastic increase in electricity demand in recent years. Consequently, there is a rising demand for energy sources. Various scientific studies and research have been conducted to address the issue of power outages, including the proposal of independent systems relying on a single energy source [19]. However, these systems often come with high initial costs and their power production is intermittent [20-22]. A computational study was conducted, which can be applied to any household with renewable energy sources utilizing electric vehicle batteries. This study takes into account the timing of connections, as well as the duration of charging and discharging cycles. The advancements in smart home technology have played a crucial role in supporting the development of smart cities. As a result, there has been a notable evolution in the smart grid, often referred to as the "green transition," as mentioned in references [21,22]. In Reference [17], a study was conducted to model and analyse an energy system based on 100% renewable energy for the Middle East and North Africa region under the conditions projected for 2030. The study examined the integration of renewable energy sources with existing storage technologies, electricity trading between countries and regions, and the effects of photovoltaic (PV) energy consumers on the energy system. Similarly, in reference [23], a study was conducted in Nigeria with a primary focus on rural healthcare centers. The main objective of the study was to model and design affordable hybrid energy systems that utilize alternative energy sources, using HOMER software. Additionally, a risk and financial sensitivity analysis of the hybrid energy systems was performed. For a site located in the city of Kano in Nigeria, which benefits from abundant solar and wind energy potential due to its geographical location, the study investigated hybrid energy systems, incorporating one or more of these sources in conjunction with a diesel generator. Furthermore, a research study conducted in the Kingdom of Morocco, as mentioned in reference [24], had three objectives: to analyse the economics of large-scale solar farms' electricity generation based on cost assumptions spanning from 2020 to 2030, provide cost estimates for solar electricity, evaluate the economics of lead-acid battery storage, and discuss the implications of selecting solar energy technology for water desalination within the framework of Moroccan energy policy.

The research continued, and another study was conducted with the aim of modeling and multi-objective optimization to address the energy storage challenge in off-grid hybrid systems. This study specifically focused on the utilization of PV cells and two types of batteries, liquid batteries, and hydrogen batteries. The main emphasis of this study was placed on the energy storage system, which represents the largest cost component in this research [25]. The study explored various options for integration into a hybrid renewable energy system with a PV array, considering conventional electric vehicle batteries, lithium-iron phosphate batteries, and lead-acid batteries [26, 27]. On the other hand, there have been studies and works that have delved into hybrid combinations of renewable energy and traditional fossil fuel sources, such as diesel generators. However, it is important to note that these approaches have an unfavourable environmental impact, leading to increased pollution and carbon dioxide emissions, both in residential settings and public facilities, as stated in reference [28]. In contrast, in Libya, some individuals and groups prioritize clean energy production by utilizing solar cells or wind turbines to generate electricity, as mentioned in reference [29]. Moreover, various research efforts are currently directed towards energy optimization in hybrid systems, employing a range of innovative methods. For example, in reference [30], the study concentrates on achieving the optimal sizing of an off-grid photovoltaic (PV)/diesel/battery storage system using a specialized optimization technique known as the Gorilla Troops Optimizer. The primary goal is to determine the most efficient configuration for the system by considering factors such as renewable energy sources, diesel generators, and energy storage. This approach aims to establish sustainable and reliable power supply solutions for off-grid locations. Another notable example is presented in reference [31], where researchers investigate an optimal sizing and management technique for a hybrid renewable energy system specifically designed to power highway lighting. The study focuses on identifying the most suitable configuration of renewable energy sources, energy storage, and management strategies to efficiently provide electricity for the highway lighting infrastructure. The ultimate objective is to maximize the utilization of renewable energy while reducing dependence on conventional energy sources, thereby promoting environmentally-friendly and sustainable highway lighting solutions.

These studies are of high quality and have contributed valuable insights into the issue of electric power supply. However, it is important to acknowledge that these investigations are primarily based on research and simulation, which makes them hypothetical in nature. Furthermore, it should be noted that none of these studies focused specifically on the smart home concept, which entails the integration of both private and public electricity networks to enhance efficiency and sustainability. Moreover, some studies have used lead-acid batteries instead of lithium batteries, which are known to be more efficient. In addition, some studies focused on powering the system with a diesel generator while ignoring the use of a battery-based storage system. However, the use of diesel or gasoline generators poses disadvantages such as higher fuel costs, the need for frequent maintenance, and environmental pollution from exhaust gases and emissions. Thus, there is an opportunity for future research to explore and delve into the potential benefits and challenges associated with renewable hybrid systems and their integration with smart homes and broader electricity grid systems.

In this study, a hybrid system connected to the public electricity grid in the Libyan city of Zawiya is proposed to support and provide uninterrupted electricity to a smart home. The main sources of electricity in this project include the public grid, solar systems, and storage systems, which consist of lithium batteries. The focus of this study was on energy management and transmission systems between different sources and loads. The proposed strategy is divided into two parts: the first part involves sizing the system components and household appliances, while the second part focuses on controlling energy generation, consumption, and distribution among the loads and the hybrid system. To ensure an uninterrupted electricity supply, the algorithm used in this study cycles through twelve modes and monitors each

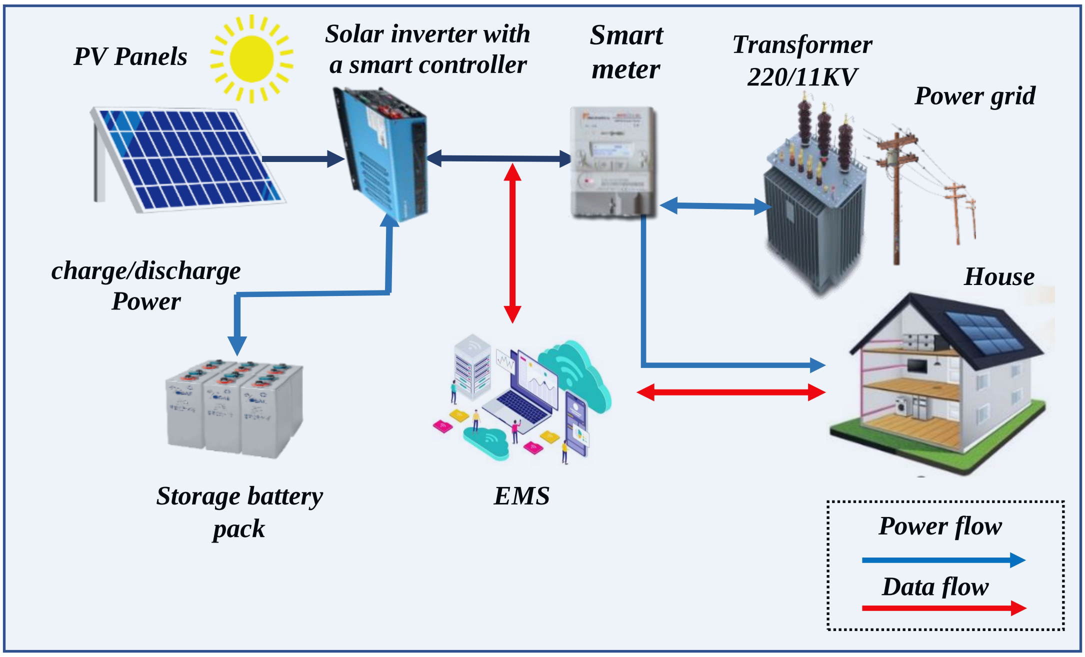


Figure. 1. Studied system architecture for the smart house.

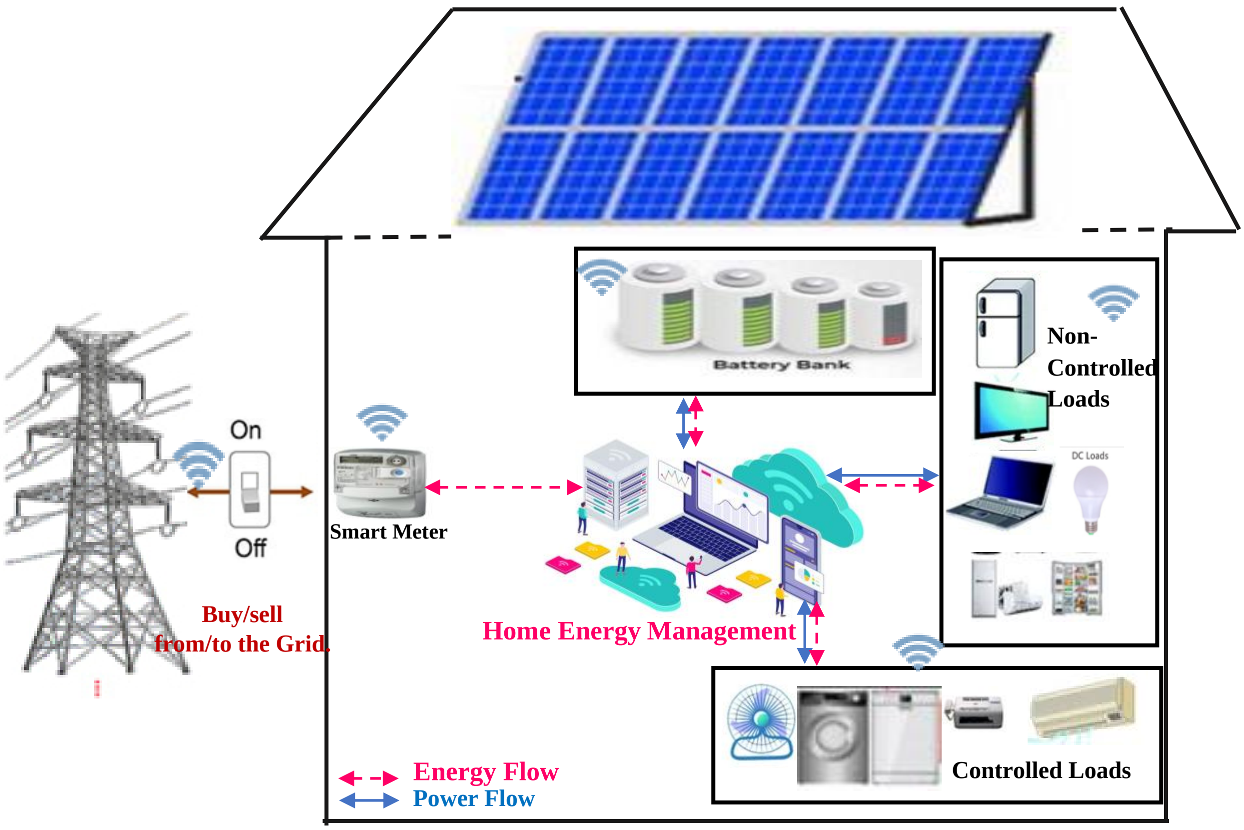


Figure. 2. Smart home control management.

case throughout the day and night. The contributions of this paper are as follows:

- Realistic and practical study conducted on an actual house in the city of Zawiya, Libya.
- Support and promotion of smart homes in Libya, where they are currently not widely available.
- Flexible and smooth electrical transformation through control of conversion between twelve modes, reducing power outages in the home.
- Effective control of lithium batteries' charging states (maximum and minimum).
- Maximum power point tracking in PV systems.
- Efficient management of energy production and consumption in a hybrid system.
- Control of power consumption for both priority and non-priority loads.
- This work serves as a model that can be applied to any home to address the issue of power outages in Libya.

This paper is divided into five sections: the first part is the introduction; the second part describes the study's system; the third part presents the proposed control strategy, which is further divided into two subsections: optimal sizing and energy management; the fourth part discusses the real-time implementation and presents practical results; and finally, the last part consists of the conclusion.

2. Study System Description

The system architecture under study, as depicted in Figure 1, consists of a smart house powered by a hybrid system comprising a solar generator, a lithium battery, and a general grid connection.

The smart house is linked to the grid via a 220/11 KV transformer. Additionally, the system incorporates a smart meter to measure the energy flow, enhancing residents' understanding of power sources and consumption. Furthermore, a PV inverter with an integrated controller is included in the system to manage energy within the smart house, utilizing twelve proposed modes for power consumption optimization and enhanced energy efficiency.

As depicted in Figure 2, the house under study comprises two types of household appliances categorized as priority and non-priority based on the residents' needs. The proposed energy management control system utilizes measurements from various detection sensors and the smart meter. Firstly, it establishes an energy balance for the house, leading to a significant reduction in the residents' electricity bills. Secondly, it manages the financial aspects between the residents and the government network.

3. Sizing Description Methodology

Optimal sizing plays a crucial role in maximizing the performance and efficiency of a hybrid system. It involves accurately determining the sizes of key components like solar panels, batteries, and inverters, ensuring they align with the energy demands of the system. This precision results in increased energy production, cost savings, and enhanced reliability. It also enhances the system's adaptability to changing energy requirements, bolstering overall resilience. In conclusion, optimal sizing is indispensable for achieving peak performance, cost-effectiveness, and sustainability in a hybrid system.

To meet the electrical requirements of the smart home with maximum flexibility, this section describes the optimal sizing methodology for the proposed hybrid system, which consists of a solar power system, storage batteries, and the general electricity grid. Figure 3 depicts the flowchart outlining the methodology. The first step of the algorithm involves determining the optimal location for the hybrid energy system and selecting the appropriate angle for installing the solar panels to maximize solar radiation capture. Additionally, the algorithm calculates the electrical energy required to operate appliances and materials, measured in watts, along with the daily working hours for each device.

Once the components of the hybrid system to be installed on the house roof are determined (e.g., solar panels, batteries, and inverters), the simulation is executed using the PVSyst program. The subsequent step in the algorithm involves comparing the energy produced by the system with the total energy demand of the devices. When the consumed and produced powers are in equilibrium, it indicates an optimal configuration, allowing the installation process to proceed. However, if the simulation does not align with the typical operating conditions of the house, further iterations of the simulation must be conducted, considering more efficient and reliable components. This iterative process continues until a satisfactory configuration meeting the energy demands is achieved.

By following this sizing methodology, the hybrid system can be designed to efficiently meet the electrical requirements of the smart home, considering factors such as location-specific solar irradiation, energy demand, and system component capabilities.

4. Smart Home Proposed Energy Management

To reduce the frequency of power outages at home, especially during peak hours, this paper investigates a three-source home energy management system in the context of a future smart grid. The objective is to enable the fulfilment of daily load requirements for residential applications, ensuring uninterrupted power supply.

Monitoring the effectiveness and performance of the photovoltaic system is crucial, as it involves assessing several factors, such as hourly output, maximum and minimum battery charge ratios (SOC max and SOC min), and the connection status to the public grid. The smart home's control management system incorporates twelve modes in its algorithm, including equal production and consumption.

The algorithm developed to manage the smart home in this project follows a series of twelve modes, as illustrated in Figure 4. This algorithm incorporates an advanced control management system, facilitating seamless transitions between energy sources as per specific requirements and time considerations. Its primary purpose is to ensure the continuous monitoring of home operations, daily energy demands, and sales management in collaboration with the General Electric Company. For that, this algorithm receives real-time information throughout the 24 hours regarding the grid status, PV production, battery state of charge, and home equipment demands as follows:

$P_{pv}(t)$	: PV Power
P_L (t)}	: Load Power of the studied system
SOC (t)	: Actual battery State Of Charge
SOC_{max}	: Maximum State Of Charge of the battery
SOC_{min}	: Minimum State Of Charge of the battery
G	: State of the Gird

The following paragraphs will provide a detailed explanation of each mode of home operation.

✧ **Mode 1**

{Ppv (t) = PL (t) }: Mode 1 is initiated when the power produced by the PV system matches the power consumed by the household. In this mode, the generated PV power is directly transmitted to the inverter and subsequently supplied to the house. This operation does not require the involvement of the public grid or batteries.

✧ **Mode 2**

{Ppv(t) > PL (t)} and {G = 1} and {SOC (t) ≥ SOCmax}: Mode 2 is activated when the power generated by the PV system surpasses the power consumed by the loads, and both the public grid and batteries are operational with the batteries fully charged. In this situation, the home switches to PV power as the primary source, and any surplus PV power is directed for sale to the public grid.

✧ **Mode 3**

{PPV(t) > PL (t) and {G = 0} and {SOC (t) ≥ SOC max}: Mode 3 is initiated when the power generated by the PV system exceeds the required power for the household, and both the batteries are fully charged, and the public grid is disconnected. In this situation, the home relies solely on PV power, and there is no option to sell the excess solar production to the public grid. Therefore, the energy management system sends a command to the inverter to limit PV energy production. The inverter is adjusted to maintain the PV power production at a level equal to the home power consumption, ensuring a balance between generation and consumption. This adjustment removes the PV system from the Maximum Power Point Tracking state.

✧ **Mode 4**

{PPV (t) > PL(t) } and {G = 0}and {SOC (t) < SOCmax}: Mode 4 is activated when the power generated by the PV system exceeds the household consumption value, the public grid is disconnected, and the batteries are not fully charged. In this scenario, the home operates solely on PV power, and the surplus power is utilized to charge the batteries simultaneously. The excess PV power is directed towards charging the battery capacity, allowing for energy storage for later use.

✧ **Mode 5**

{PPV (t) = 0}and {G = 1} and {SOC (t) ≥ SOCmax}: Mode 5 is activated when the General Electric grid is in an operational state, the PV power is zero, and the batteries are fully charged. In this situation, the household loads are solely operated by the grid, without the need for utilizing the batteries or PV power. The grid serves as the primary power source to meet the electricity demands of the home.

✧ **Mode 6**

{PPV (t) = 0} and {G = 0} and {SOCmin <SOC(t) <SOCmax}: Mode 6 is activated when the grid is disconnected, there is no PV power production, and the batteries are not empty. In this condition, the house loads are powered solely by the discharge of the batteries. The stored energy within the batteries is utilized to meet the power demands of the home, uninterrupted operation even when there is no grid power or PV production available.

✧ **Mode 7**

{PPV (t) < PL (t) } and {G = 1} and {SOC (t) ≥ SOCmax}: Mode 7 is activated when the solar energy production is insufficient compared to the household loads, the public grid is operational, and the batteries are fully charged. In this situation, the household loads are powered by a combination of solar energy and the public grid. The batteries are not utilized for charging or discharging during this mode. Instead, solar energy directly contributes to powering the household loads, while any additional power needed is supplemented by the public grid. The batteries remain idle during this mode.

✧ **Mode 8**

{PPV (t) < PL (t)} and {G = 0} and {SOCmin < SOC (t) < SOC max}: Mode 8 is activated when the public grid is disconnected, the performance of the PV system is insufficient to meet the home's consumption needs, and the batteries are not empty. In this scenario, the household loads are powered by a combination of PV power and the energy stored in the batteries. The PV system contributes its available power, while the batteries are discharged to provide additional energy required to operate the household loads. This mode ensures that the home's energy needs are met even when the PV system alone is unable to meet the demand, and the public grid is unavailable.

✧ **Mode 9**

{PPV (t) = 0} and {G = 1} and {SOC (t) < SOCmax}: Mode 9 is activated when the public grid is connected, there is no PV power production, and the batteries are not fully charged. In this scenario, the household loads are powered by the grid, and simultaneously, the batteries are being charged. The grid supplies the necessary power to operate the home loads and to charge the batteries, ensuring they are brought to their optimal capacity. This mode allows for the utilization of grid power while also charging the battery energy storage for future use.

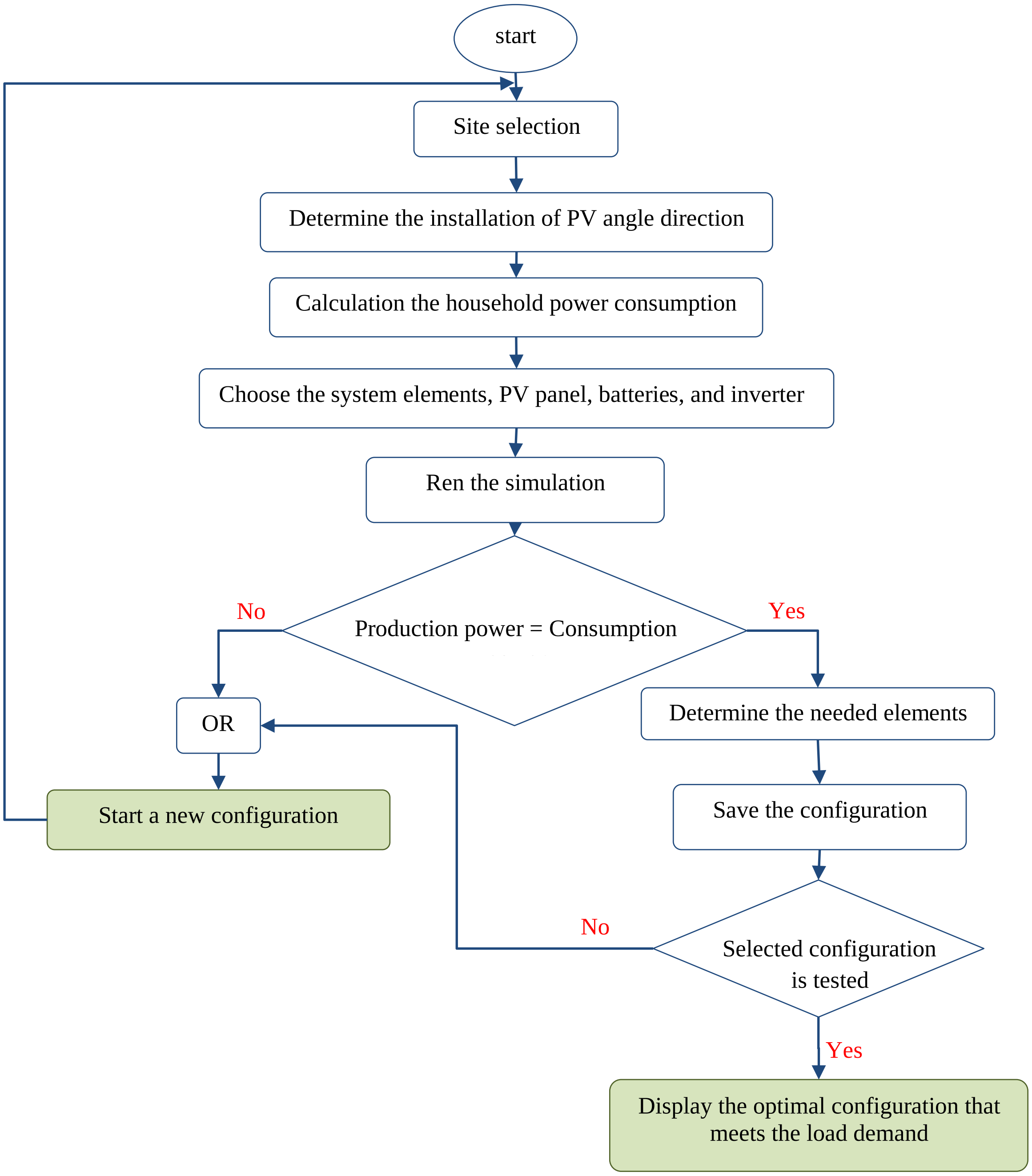


Figure 3. Sizing methodology flowchart using PVsyst software.

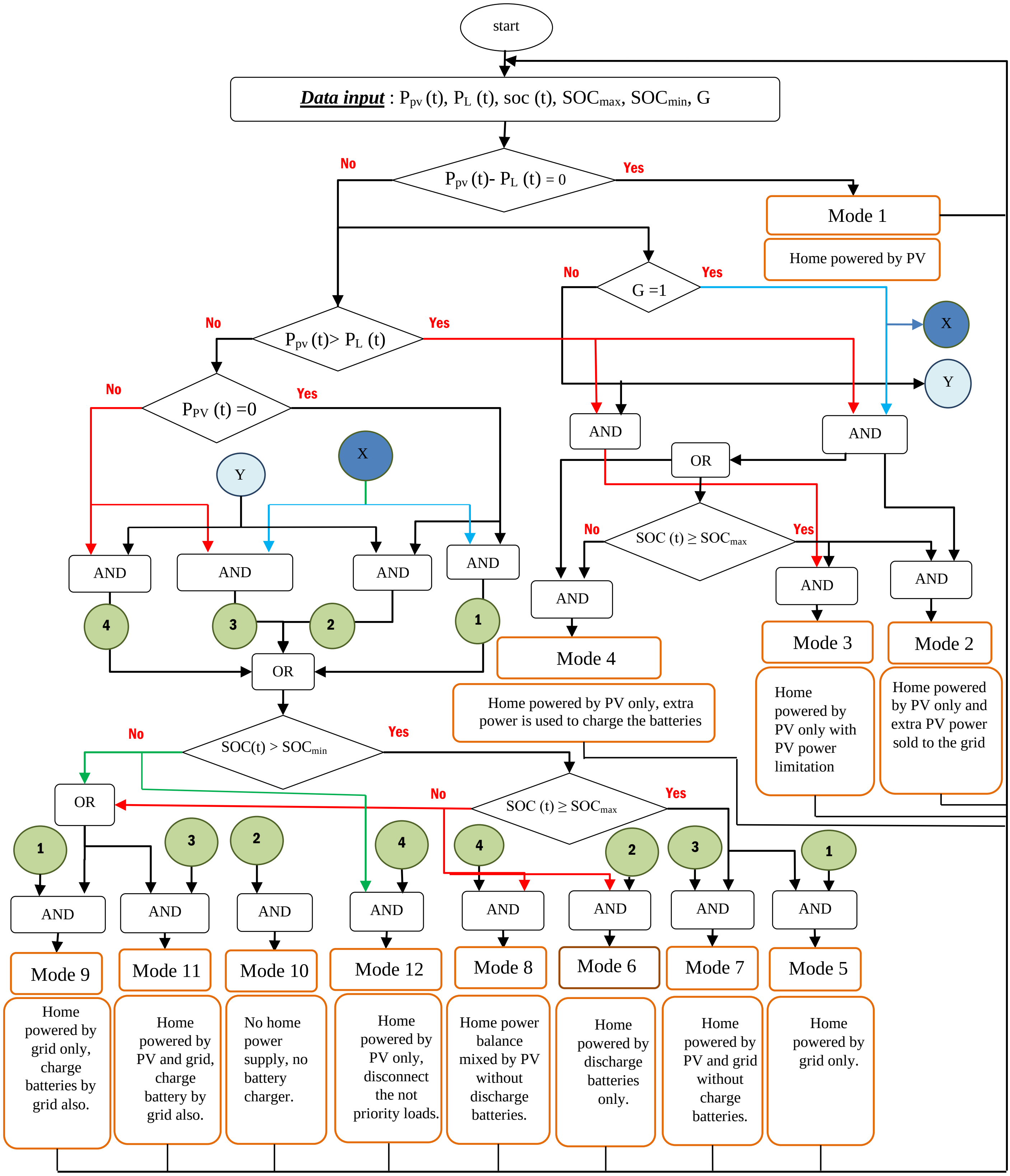


Figure 4. Smart home energy management flowchart.

✧ **Mode 10**

{PPV (t) = 0} and {G = 0} and {SOC(t) ≤ SOCmin}: Mode 10 is activated when there is no PV power generation, the public grid is disconnected, and the batteries are empty. In this situation, there is no available power source to operate any household loads. As a result, alternative solutions must be sought to meet the power requirements of the home.

✧ **Mode 11**

{PPV (t) < PL (t)} and {G = 1} and {SOC (t) < SOCmax}: Mode 11 is activated when the output of the PV system is limited, the public grid is connected, and the batteries are not fully charged. In this scenario, both the power generated by the PV system and the power imported from the public grid are utilized together to power the household loads. Simultaneously, the batteries are being charged to increase their energy storage capacity. This mode allows for the optimal utilization of both PV power and grid power, ensuring the operation of household loads while also recharting the battery storage for future use.

✧ **Mode 12**

{PPV (t) < PL (t) and {G = 0} and {SOC(t) ≤ SOCmin}: Mode 12 is activated when the public grid is disconnected, the batteries are empty, and the PV power is insufficient to power all the household loads. In this scenario, certain non-priority household loads are disconnected to maximize the utilization of the available solar energy for as long as possible. By selectively disconnecting non-critical loads, the PV power can be efficiently distributed to power essential and high-priority household loads, ensuring that the solar energy is used optimally until the batteries can be recharged or the grid power is restored.

5. Results and Discussions

The proposed control strategy was applied in two stages. Firstly, it was simulated using the PVSyst program. The results obtained from the simulation were then realistically implemented in a house located in Zawiya city, which is the target location. The global data used for this implementation was collected by NASA. The house is situated in the city of Zawiya, in the State of Libya. Its geographical coordinates are latitude 12.7362 and longitude 32.7523. The house is positioned at an altitude of 14 meters above sea level. The annual global horizontal radiation recorded at this location was 1943.2 kWh/m2/month, with a diffuse horizontal radiation of 522.5 kWh/m2/month. The solar panels were tilted at an angle of 300° towards the south, as depicted in Figure 5.

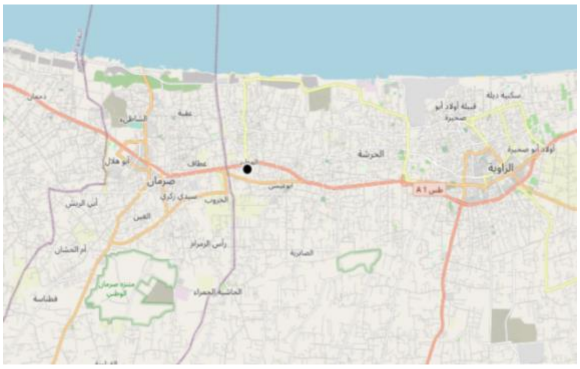


Figure.5. Home location by NASA using the PVsyst.

5.1. Pvsyst Result

Before implementing the hybrid system in the studied house, it is imperative to adhere to the sizing description methodology detailed in section 3. The initial and critical step involves determining the optimal inclination angle for installing the PV panels on the roof of the house. In this particular case, the chosen inclination angle was 30 degrees, facing south, as shown in Figure 6.

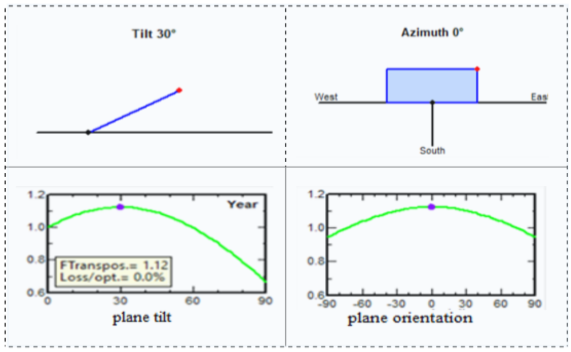
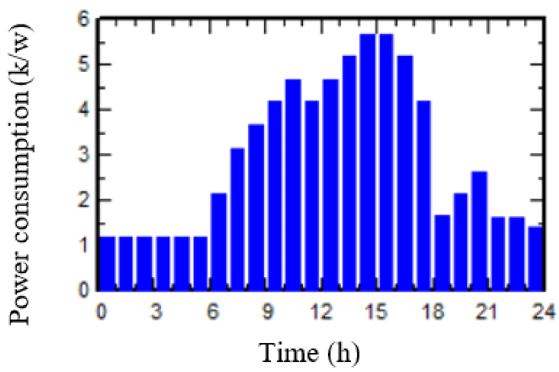


Figure.6. Shows the best direction and angle for solar radiation in the Zawiya house.

The parameters of the appliances used to determine the daily energy consumption of the Zawiya household under study are presented in Figure .7. Additionally, Figure .8. provides information about the working hours of each electrical device.



Figures.7. Daily energy consumption by the studied household.

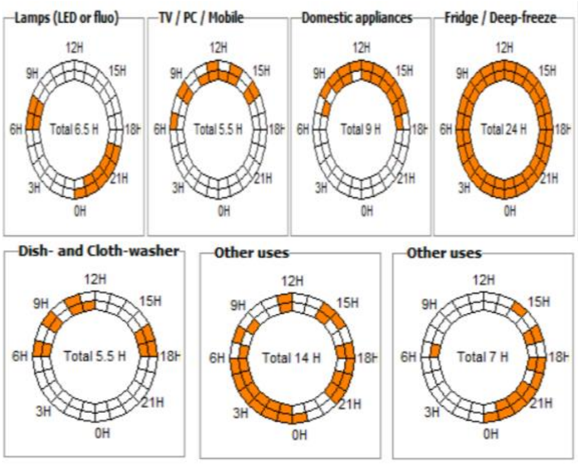


Figure.8. Shows the appliances working hours per day

The next step is to choose the components for the hybrid system, including the number and type of solar panels, batteries, and converters. This selection should consider factors such as cost, the roof area of the house, and the goal of achieving high capacity and efficiency to meet the electrical needs of the family. Choosing the types of solar cells to be installed on the roof of the house, as well as determining their production power, resulted in the selection of 8 solar panels with 450W/35V for each panel, as shown in Figure. 9.

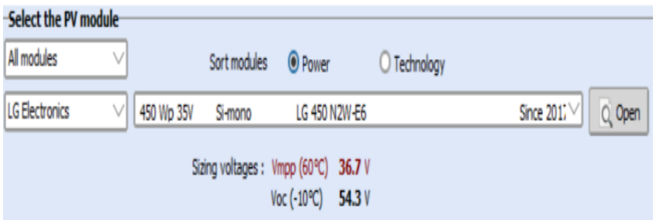


Figure.9. Select the PV module.

According to Figure 10, a total of 4 LG batteries with a capacity of 51.8V and a maximum capacity of 258Ah were used, making it the best type of battery to use under these conditions.

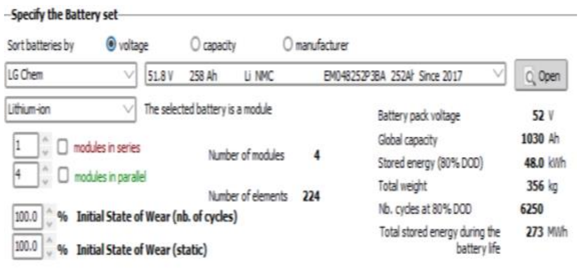


Figure.10. Specify the battery type.

The chosen inverter was a Generic type, selected to accommodate the different operating modes of the proposed energy management system and to include the Maximum Power Point Tracking function, as depicted in Figure.11.

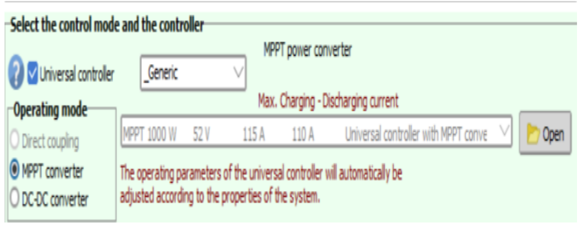


Figure.11. Selected the inverter.

5.2. Real Implementation

The hybrid system and its energy management are implemented in the Zawiya house, which is already connected to the grid. The intermittent power interruptions in the house at Zawiya City poses a significant problem. These disruptions not only cause damage to household equipment but also have a negative impact on the residents' overall comfort and well-being. Therefore, the primary goal of the proposed energy management plan is to attain self-sufficiency in electrical power for the household, reducing dependence on the government grid. Furthermore, the plan seeks to enhance the intelligence of the studied home by integrating an advanced home energy management system capable of monitoring the system in twelve distinct operating modes. In this study, the day-ahead information and results are verified each hour, and cases are tracked throughout the day and night to manage the production and consumption power between the loads and the hybrid system's considered sources, ensuring uninterrupted electrical power supply. The studied system and its management controller, installed in the Zawiya household, are shown in Figure.12.

Figure.12. The real hybrid system in the house

To address the issues with the government grid in Zawiya City and achieve electrical power self-sufficiency in the houses, the control strategy considers monitoring the entire system across twelve operating modes. The proposed energy management algorithm takes input parameters such as temperature, solar radiation, and the corresponding solar-generated power, which are depicted in Figure 13, Figure 14, and Figure 15, respectively.

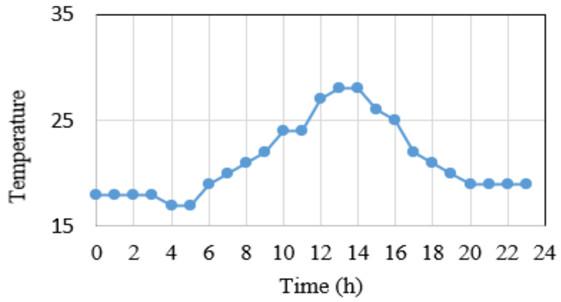


Figure 13. Temperature during the day

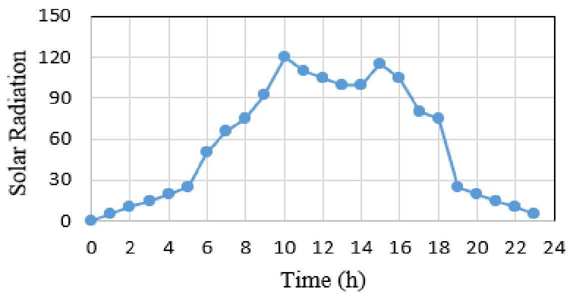


Figure.14: Solar radiation profile.

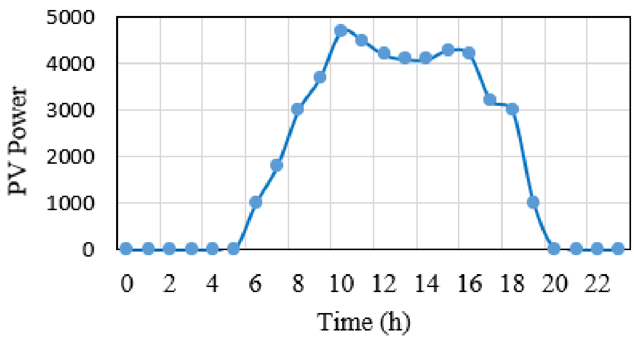


Figure.15. Power produced by the PV generator.

This algorithm also includes information regarding the connection state of the public grid and its availability to support the electrical consumption of the studied home, as depicted in Figure. 16. It is worth noting that the studied home is connected to the grid when the grid status indicates one (On). On the other hand, when the grid power is disconnected, the grid-status is specified as zero (Off).

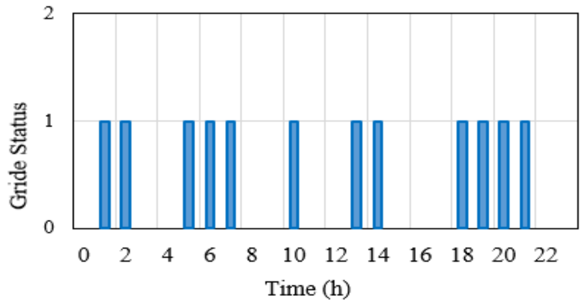


Figure 16: The public grid status (On/Off)

According to the proposed energy management algorithm described in this study, Figure. 17. illustrates the transitions between the twelve different modes of the proposed residential supervision strategy during a specific day. It is important to note that only one mode should be activated for each time interval of operation. Certainly, during the period [0, 1 h], the proposed algorithm operates in mode 10, indicating that there is no home power supply and no battery charging. In the intervals [1h, 3 h], [5h, 6h], and [20h, 20:30h], mode 9 is active. During this mode, the home is powered solely by the grid, and the battery charging is also done through the grid. In the intervals [3h, 5 h] and [22h, 24 h], mode 6 is active, indicating that the home is powered only by battery discharge. During the period [6h, 8 h], mode 1 is active, where the home is powered exclusively by PV panels. In the period [8h, 10 h], mode 4 is observed, in which the studied home is powered by PV generator alone, and the excess power is used to charge the battery. In the interval [10h, 11 h], mode 2 is activated, where the home is powered by PV generator alone, and the surplus power is sold back to the grid. During the period [11h, 13 h], mode 3 is applied, where the home is powered by PV generator alone with a limitation on the use of excess PV power. During the period [13h, 15 h], mode 7 is active, in which the home is powered by both PV generator and the grid, without battery charging. In the interval [15h, 17 h], mode 8 is applied, establishing the home power balance using PV power without discharging the battery. In the interval [17h, 18 h], mode 12 is implemented, where the home is powered solely by PV generator, with non-priority loads disconnected. In the interval [18h, 20 h], mode 11 is utilized, where the home is powered by both PV and the grid. Additionally, the battery charging operation is performed using the grid. During the period [20:30h, 22 h], mode 5 is activated, and the home is powered by the grid only.

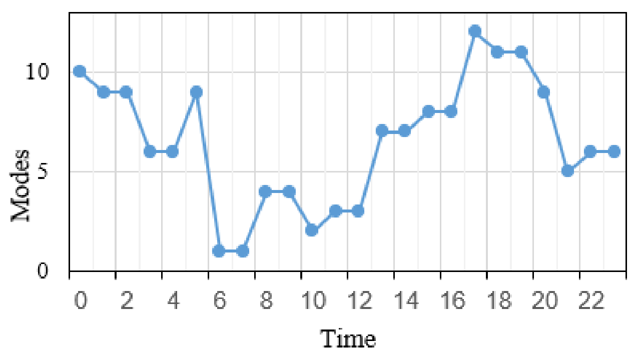


Figure 17: Different operating modes of the studied system

Once the proposed supervision strategy receives the necessary inputs, it initiates the process by calculating the power difference between the electricity generated by the PV generator and the domestic loads of the studied home, represented as Pdiff (t). Based on the corresponding operating mode, the evolution of the charging and discharging power profile of the domestic battery is illustrated in Figure 18. It's essential to note that negative powers indicate the charging process, during which the battery can store energy from the main grid or surplus power produced by the PV system. Conversely, positive powers indicate the discharging process, where the Li-ion battery functions to support the electrical power needs of the studied home.

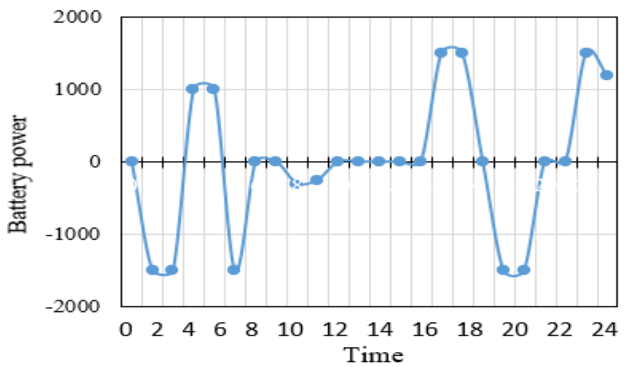


Figure 18: Domestic battery charging/discharging power

In the context of this study, the charging and discharging of the domestic battery can be observed through the evolution of the battery's State of Charge (SOC) profile for a day-ahead, as depicted in Figure. 19. The reduction in the battery's SOC value confirms the discharging operation. This validates the chosen convention, where the battery is charged (negative powers) or discharged (positive powers) as long as its SOC does not reach its maximum or minimum SOC value, respectively. Accordingly, the acceptable maximum and minimum values for the battery SOC are set to 0.8 and 0.6, respectively. Therefore, the proposed control algorithm not only ensures effective power management but also enhances the battery's autonomy and lifespan.

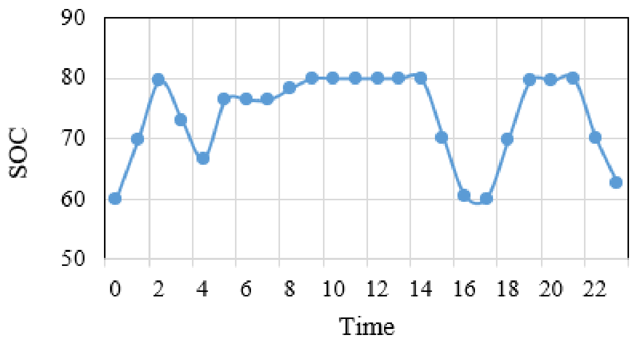


Figure. 19: State of charge of the studied battery.

In Figure 20, the power exchange between the public grid and the studied home is depicted for various operating modes, maintaining a balanced power supply for the household. The negative segment indicates the power being injected into the main grid, signifying that the home is exporting excess power. Conversely, the positive segment represents the power absorbed from the public grid, indicating that the home is importing power to fulfill its energy requirements.

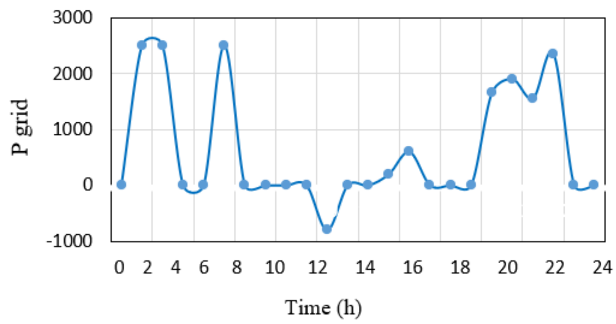


Figure. 20: Absorbed/injected power from/to the main grid.

Figure. 21. depicts the household equipment that is disconnected during mode 12, which is the mode where the home is powered solely by photovoltaic. It is important to note that these disconnected household loads are considered non-priority, and this disconnection is done to ensure the overall energy balance of the studied smart home.

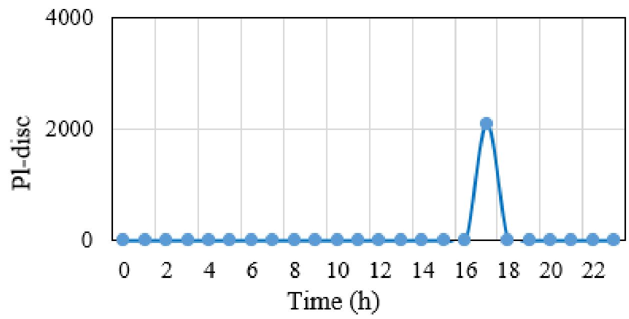


Figure. 21: Power of the no priority load disconnection.

The evolution of the energy balance of the studied smart house is clearly depicted in Figure. 22. Indeed, Pdiff1 which is exposed in green curve (Pdiff1 = PL -PPV) , illustrates the difference in power between the initial load power profile of the smart house in Zawiya city and the power generated by the PV system. Pdiff2 (Pdiff2 = PL – PPV – Pbatt), which is described in orange curve, shows the improvement of the daily home load power after the intervention of the domestic battery. Subsequently, the power demand of the smart home is further enhanced with the support of the public electricity grid. The difference in power between the initial daily household consumption, PV power, battery power, and the power supplied by the public grid is observed by Pdiff3 (Pdiff3 = PL – PPV – Pbatt – Pgrid), and this power gradually approaches zero. Finally, it is noteworthy that Pdiff4 the difference in power between the home power load, PV power, battery power, public grid power, and the disconnected non-priority loads (Pdiff4 = PL – PPV – Pbatt – Pgrid – PLdisc) is nearly zero. This indicates that the energy balance objective, in terms of the production and demand, has been successfully achieved. This confirms the effectiveness of our proposed control strategy.

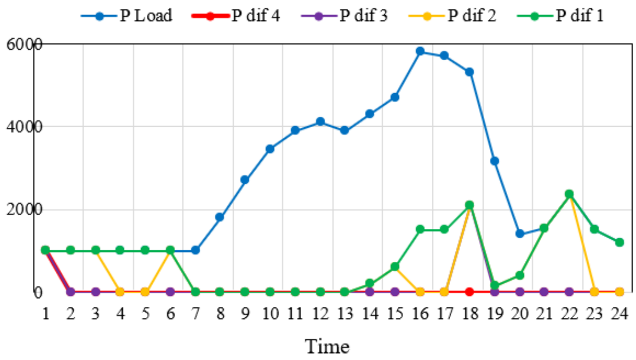


Figure. 22: Energy balance of the studied smart house.

6. Conclusion

Due to the challenging electricity situation in Libya, as discussed in this paper, a hybrid system consisting of solar cells, batteries, inverter, and charger controller was installed on the roof of a targeted house in Al-Zawiya City.

This installation effectively resolved the issue of power outages from the public grid. The methodology employed a precise flowchart using PVsyst software to accurately size all the components of the hybrid system. This ensured that the system could meet the electrical requirements of the household with maximum flexibility. Additionally, an energy management system was proposed to monitor the entire system in twelve different modes. This approach made the home smarter, achieving energy self-sufficiency, and enabling the household to remain unaffected by grid interruptions. The real-world results obtained from implementing this hybrid system demonstrated its success, effectiveness, and efficiency. This installation serves as a noteworthy example that can be replicated in other Libyan households to address the electricity problem and achieve greater energy independence.

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