On-Grid Photovoltaic (PV) - Battery - PLN for Smart Home System

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Abstract **– Electricity is one of basic human needs. However, PLN's ability to meet customer demands is hampered by its limitations. On the other hand, the sunny geographical advantage of Makassar city can be utilized as a new renewable and environmentally friendly energy source in a smart home. Smart house is a family residence that is able to synergize electricity usage based on the habits of its residents with the help of smart technology so that comfort, safety and efficiency of using electrical energy are obtained. The utilization of solar cell hybrid power – battery – PLN can be implemented in addition to meeting the needs of electricity load in the smart home, it can also contribute excess energy to fulfill off-grid building load. Monte Carlo Simulation (MCS) is carried out at the beginning of data processing by randomly generating 24-hour models of solar irradiance and smart home load requirements along with weather conditions. PLN not only takes over fulfilling the needs of the smart home load when there is less and or no sunlight and minimum battery capacity conditions, but also it will charge the battery capacity up to 100% every midnight. On average, the daily load requirement for a smart home is almost half the energy produced by PVs, which are 12,439 kW and 24,509 kW respectively. Furthermore, the smart home hybrid power is capable of producing 8,946 MW of excess energy in a year to serve the off-grid building load needs.**

Keywords: MCS, on-grid, PV, Battery, Smart Home.

I. INTRODUCTION

The increasing number of housing, offices and industries demands higher electricity needs. This is inversely proportional to the availability of the number and capacity of power plants operated by PT. PLN which is the sole electricity supplier in Indonesia. Meanwhile, the geographical position of Indonesia in the equator has abundant sunlight and can be converted using Photovoltaic (PV) power plant. The combination of PV power and battery storage capacity that remains connected to the PLN distribution line can be a solution to this problem to fulfill the load of smart homes.

Tamer [1] believes that although Photovoltaic PVs are a safe energy source and have environmentally friendly technology, they require initial installation costs which are quite expensive compared to conventional energy sources at the same power capacity. Moreover, research conducted by Abdullah [2] on the use of hybrid power in water pump applications shows that in general during the day the excess power produced by PVs is abundant, and unfortunately must be disposed off after previously supplying water pump and fully charging the battery. Several studies have been carried out on optimizing the size of hybrid power Photovoltaic (PV) components [1]-[11]. Furthermore, Roberto uses MCS to process solar cell power generator uncertainties, State of Charge (SoC) initials of battery, real time costs, weather conditions, and load shifts based on a priority scale. Other previous researchers have also used MCS to analyze electrical energy due to uncertainties in certain variables such as sunlight and wind [10], [12], and [13].

A smart home is a residential which able to follow the habits of the people who live in it in term of electricity and information technology usage. Several studies on smart homes have been carried out. To name a few, Roberto [14] has researched electrical energy management systems in smart houses using a PV-battery combination by applying load settings and priority scales using a micro-computer system to control the transfer of electrical loads, a solar cell-battery hybrid system and electrical energy consumption through a set of sensors are connected using Z-wave technology. These smart residences are not connected to an integrated electricity supply from an external electricity network (stand-alone/off-grid). So, they are very dependent on the presence of sunlight. If the Photovoltaic (PV) power produced is minimal and the battery is in minimal SoC condition, the smart house's electricity demands cannot be met.

Another research conducted by the Belgium GfK consortium [15] discusses on methodology, surveys, scenarios, economics, technicalities and regulations for the application of producer and consumer (prosumer) housing in European countries by employing renewable energy, especially PV. The residential covered were public housing that did not apply information technology in its energy management. Many previous studies regarding energy management in smart homes have been carried out [11], [14], [16]-[19]. This research offers an energy management system to supply the electrical energy for smart houses applying a combination of PV and batteries as energy storage connected to PLN electricity by implementing settings and scheduling the operation of the electronic devices contained in it.

II. METHOD AND DESIGN

A. Load of Smart Home

The Smart Home uses electrical devices needs power varies from 2 W to 500 W. The existing device loads are shown in table 1.

Table1. The amount of load for each equipment

No	Electrical Device	Load (W)
1	Lamp	2 – 20
2	AC	250 – 320
3	Fan	50
4	Refrigerator	140
5	TV	80
6	PC	125
7	Washing Machine	350
8	Steam iron	450
9	Water pump	125
10	Rice cooker	500
11	Vacuum cleaner	400
12	Laptop charger	60
13	Cell phone charger	25
14	Security equipment (8 CCTV camera, sensor, etc.)	50

The usage of electronic devices in smart home is regulated according to the activities of its residents. Activation of some electrical devices is by using sensors and setting their operation time. A 24-hour weekdays and weekends load profile for a typical home is shown in Figure 1.

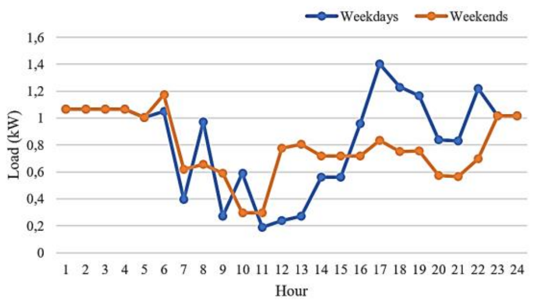

Figure 1. Typical 24-h home load profile

B. Hybrid Power Model PV–Battery–PLN

The power sources designed to meet the electrical load needs of this smart home depend on a combination of power produced by PV and PLN and stored in batteries which is expressed in the equation below.

$$P_k^{dem} = P_k^{PV} + P_k^{batt} - P_k^{load} \qquad (1)$$

with k = 1, 2, 3, ..., 24

where P_k^{dem}, P_k^{PV}, P_k^{batt}, and P_k^{load} are the total demand power, the power produced by the PV, the power stored in the battery, and the smart home load for 24-hour, respectively.

C. Photovoltaic (PV) Power

The calculation solar panel capacity is based on the electrical load required by the smart home between 8 am and 6 pm. The Peak Sun Hour (PSH) in Makassar is taken 5 hours where the PV efficiency 16%. The research scenario is PV will cover almost half of the smart home total daily load, since it is still connected to PLN grid.

Tamer [1] stated that the power generated by PV follows the equation,

$$P_{PV} = \frac{E_L}{\eta \cdot PSH} \cdot S_f \qquad (2)$$

where E_L is the daily energy consumption around 10,420 kWh, η is the PV's efficiency 16%, and S_f is the safety factor between 1.25 – 1.75. Therefore, a smart home requires 18 solar cell modules with a power of 500 Wp and connected in parallel fashion.

Furthermore, Tamer [1] showed the electrical energy produced by PV depending on the total efficiency of PV, inverter, and cables (η_{total}), the PV area (A_{PV}), and solar irradiance (E_{sun}) as

$$E_{PV} = \eta_{total} A_{PV} E_{sun} \qquad (3)$$

The PV power produced for 24 hours is depicted in Figure 2 below.

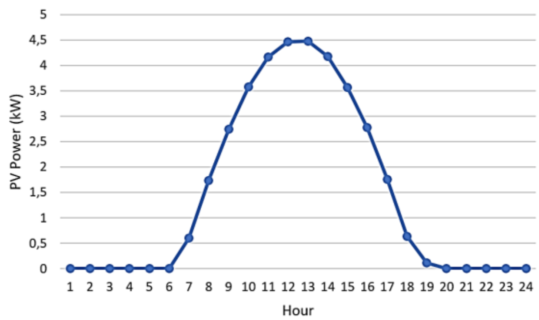

Figure 2. Energy produced by typical PV series in 24 hours

D. Battery Capacity

Batteries are used as auxiliary power when PV is unable to serve the load requirements for operating electrical equipment in the smart home. For maintenance, Deep of Discharge (DoD) of battery is taken 50%. The battery capacity in watt-hour required follows the formula described by Khatib below

$$C_{wh} = \frac{E_L \times AutDay}{V_{batt} \times DoD \times \eta_{batt}} \qquad (4)$$

where AutDay is Autonomous Day set in three days, V_{batt} is battery voltage, DoD is Depth of Discharge, and η_{batt} is the battery efficiency around 0.95.

This smart home with a hybrid power system uses 2 of 200 Ah batteries which work at 12 V. The battery condition in the smart home is set to the maximum position when the sun is not shining.

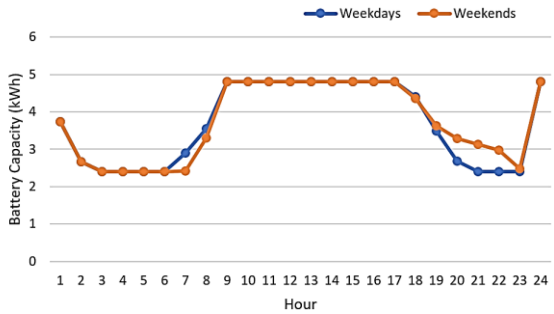

Figure 3. Battery storage capacity in 24-hour

The energy stored in the battery in a smart home can be seen in Figure 3.

E. Producer and Consumer Power

The PLN distribution line that is connected to the smart home will supply its electrical energy if PV and battery capacity cannot fulfill its load demands. This state is smart home consumer. On the other hand, if after meeting the needs of the load and fully charging the battery, surplus power generated by the solar power system installed in the smart home will power the off-grid building and/or its battery. This smart home acts as electricity producer. Therefore, the smart home becomes an electricity prosumer. This condition can be seen in the following statement

$$P_k^{SH(produced)} if P_k^{dem} > 0, \text{ and}$$
$$P_k^{SH(consumed)} if P_k^{dem} < 0 \qquad \text{.......................(5)}$$

where P_k^{SH} is the power received from PLN line and sent to off-grid building.

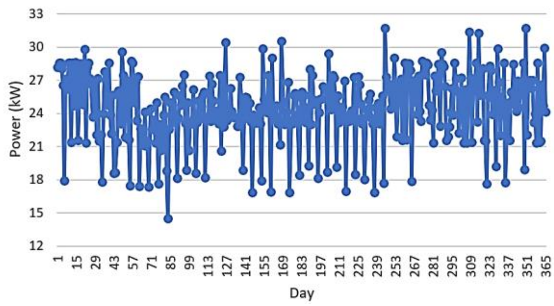

Figure 4. PV Power for off-grid building

F. Smart Home Energy Management Design

A design of smart home energy management can be shown in figure 5.

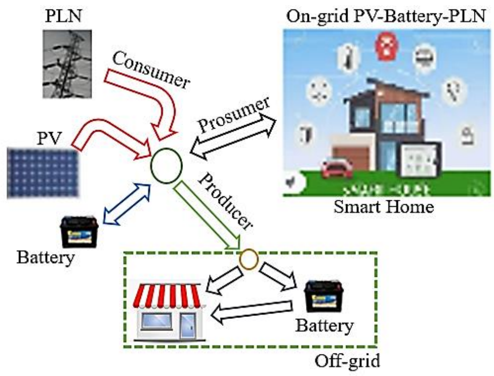

Figure 5. Smart Home Energy Setting.

The power produced by PVs will supply electricity to the smart home. If there is excess PV power, it will charge the battery, and if there is still excess power available, the excess power will be injected into the off-grid building and/or its battery. The battery will be discharged to a minimum capacity of 50% if the PV power is not sufficient enough for the smart house's or the off-grid building needs. The last design is the power will be supplied by PLN if the combination of PV power and batteries is deficit to meet the power required by the smart residence. PLN also recharges smart home's batteries to their maximum capacities at the end of the day, at 11.00 pm. Meanwhile, when there is no sunlight or the sun is not shine enough, PLN will take over to meet the load needs of the smart home.

MCS is carried out at the beginning of data processing which refers to 24-hour models of solar irradiance, weather (sunny, cloudy, rainy) and the use of electrical devices in the smart home. Furthermore, the process of calculating the load power of the smart home, PV, battery, producer and consumer powers of the house is every hour for a period of 365 days.

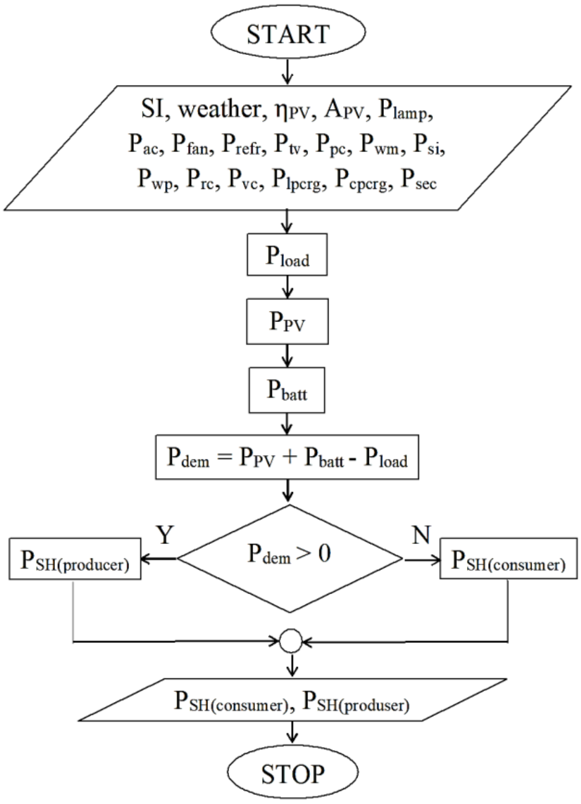

Figure 6. Smart Home Hybrid Power Flowchart

Firstly, the use of smart home loads depending on the resident habits. On weekdays, the load required during the day is less than at night. Every morning until evening, they do activities outside the house and rest at home afterwards. Meanwhile on weekends, they tend to spend time at home in the morning and set out to find entertainment during the day and return home before the turn of the day. This load is a matrix of 24 x 365. A 24-hour load profile can be seen in figure 1. The PV power is then obtained by focusing on the maximum load that the smart home requires in a day. This performance is also expressed in a 24 x 365 matrix. Figure 2 represents PV Power in a day. Furthermore, battery capacity takes into account not only the maximum daily load, but also the minimum capacity allowed to sustain continuous use. The battery undergoes a charging and discharging process depending on the ability of the PV power to supply the smart home loads. The process of charging and discharging is in figure 3. The battery capacity condition is also represented by a matrix of 24 x 365. Finally, a smart home requires electricity supply from PLN or provides it to the off-grid building depending on whether the PV power and/or installed battery capacity can accommodate the load required by the smart house or not. If surplus power is generated by the PV after charging the battery to maximum capacity and serving all load demands, the excess is used to serve the off-grid building load and/or its battery. This situation turns the smart home into electricity producer. In contrast, the battery is first discharged up to 50% of its capacity to help PV meet the load needs of the smart home. If the combination of PV and 50% battery capacity cannot handle the smart home load, PLN will inject power to address the shortfall. Smart home is now becoming consumers of electricity. Therefore, this smart home hybrid power connected to PLN can be an electricity prosumer. These smart home power producer and consumer are also presented in 2 x 365 matrix.

III. RESULTS AND DISCUSSION

Apart from following the habits of the occupants, the electricity load requirements in smart homes also regulate the use of several existing electrical devices by using sensors to activate, deactivate and reduce the intensity of lighting, air conditioning and entertainment equipment. In addition, scheduling the time of use of water pumps, washing machines, steam iron dan vacuum cleaner is also carried out. Meanwhile, other devices are not regulated but adapted to use.

Furthermore, batteries that are set to be fully charged earlier in the day, will undergo two discharges to help PV serve the needs of the smart home until it remains at half its capacity. The discharging process occurs in the early morning at 00.00 – 03.00 and 17.00 – 20.00. PVs, in the morning at 06.00 – 08.00 am, not only serve smart home loads but also charges the battery to maximum capacity at the same time. The battery charging process also occurs at the end of the day, which is at 23.00 with the help of PLN supply.

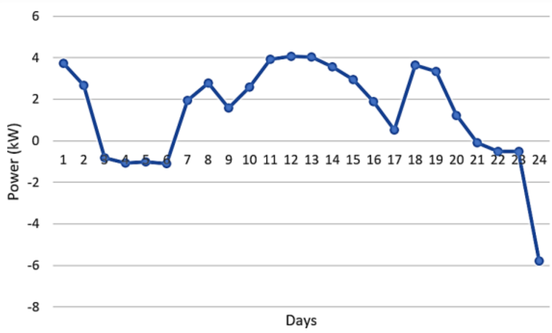

Figure 7. 24-hour smart home producer-consumer power

Moreover, PLN will serve all smart home electricity needs if PV power and batteries are not able to serve smart house loads anymore. The battery is in the idle position when it is fully charged and all smart home electricity needs are served by PV. On average, the smart home contributes 24,509 kW of electricity during the day and require 12,432 kW of electricity supply at night.

This smart house hybrid power system is not only able to serve the needs of its load based on the habits of its occupants, but also capable of serving the off-grid building of 14,518 – 31, 746 kW every day or in a year capable of providing power of 8,946 MW. In other words, on average in 24 hours the building that is not connected to the PLN distribution gets a power supply of 24,509 kW. However, smart home still requires a daily supply of 8,486 – 13,564 kW per day, or an average of 12,432 kW per day. Thus, in one year PLN injected 4,538 MW of electricity into smart home.

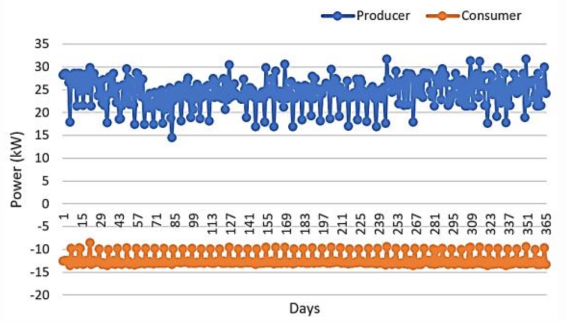

Figure 8. Smart home producer-consumer for 365 days

IV. Conclusion

Hybrid power system for smart home can be applied by using smart technology that adjusts energy consumption based on resident activities to achieve a sense of comfort, safety, and efficient power consumption. In order to implemented it, this smart home installs 18 solar cell modules with a power of 500 Wp and has 2 batteries with a capacity of 200 Ah. In addition to requiring electricity supply from PLN, this hybrid system is able to provide excess power to building that is not connected to PLN's distribution lines. PV power installed is able to make smart homes as producers and consumers of electricity. On average, this smart home produces excess electricity almost twice as high as its needs. Thus, for 365 days this smart home is able to inject power of 24,509 MW to the off-grid building and requires PLN's supply of 12,432 MW to serve its electricity needs. The development of this research can be done by taking into account the load power and battery capacity needed by the off-grid building, optimizing the system, using other renewable energy, expanding the scope of user loads, and other methods.

V. Acknowledgments

Authors thanks to Indonesian Muslim University for its financial support.

References

[1] Tamer Khatib, Azah Mohamed, K. Sopian, M. Mahmoud, 2013, *Optimal Sizing of The Energy Sources in Hybrid PV/Diesel Systems: A case Study for Malaysia, International Journal of Green Energy,* Volume 10, p 41 – 52.

[2] Abdullah Basalamah, Tanridio SDA, Saidah Suyuti, 2020, Penggunaan Metode *Linear Programming* pada Optimasi Pompa Bertenaga Hybrid Generator Diesel – Sel Surya - Baterai, Jurnal Instek, Vol 5, No 1, p 121 – 128

[3] Abdelhamid Kaabeche, Rachid Ibtiouen, 2014, *Techno-Economic Optimization of Hybrid Photovoltaic/Wind/Diesel/Battery Generation in A Stand-Alone Power System, ScienceDirect, Solar Energy,* Volume 103, p 171 – 182.

[4] Amos Madhlopa, Debbie Sparks, Samantha Keen, Mascha Moorlach, Pieter Krog, Thuli Dlamini, 2015, *Optimization of a PV–wind hybrid system under limited water resources, Renewal and Sustainable Energy Review,* Volume 47, p. 324 – 331.

[5] Hicham Fakham, Di Lu, Bruno Francois, 2011, *Power Control Design of a battery charger in a Hybrid Active PV generator for load-following applications, IEEE Transaction on Industrial Electronics*, Vol. 58, Issue. 1, p 85-94.

[6] H. Ren, Q. Wu, W. Gao, and W. Zhou, 2016, *Optimal operation of a grid-connected hybrid PV/fuel cell/battery energy system for residential applications, Energy,* vol. 113, p 702-712.

[7] Kanwarjit Singh Sandhu and Aeidapu Mahesh, 2018, *Optimal sizing of PV/wind/battery Hybrid Renewable Energy System Considering Demand Side Management*, *International Journal on Electrical Engineering and Informatics*, Volume 10, No 1.

[8] K. Karakoulidis, K. Mavridis, D. V. Bandekas, dkk, 2011, *Techno-Economic Analysis of A Stand-Alone Hybrid Photovoltaic-Diesel-Battery-Fuel Cell Power System, Renewable Energy,* Volume 36, p 2238 – 2244.

[9] Lin Xu, Xinbo Ruan, Chengxiong Mao, Buhan Zhang, and Yi Luo, 2013 *An improved optimal sizing method for wind-solar-battery hybrid power system, IEEE Tranaction. on Sustainable Energy,* 4(3):774–785.

[10] M. Bashir dan J Sadeh, 2012, *Optimal sizing of hybrid wind/photovoltaic/battery considering the uncertainty of wind and photovoltaic power using Monte Carlo Simulation,* IEEE.

[11] Y Nurfaidah, I P D Wibawa, dkk, *Analysis of Smart House Power Savings with on-grid Photovoltaic Power System, International Conference on Engineering Technology and Innovative Researchers,* IOP Publishing Ltd.

[12] Gonzalo E. Constante-Flores dan Mahesh Illindala, 2018, *Data-driven probabilistic power flow analysis for a distribution system with renewable energy sources using Monte Carlo Simulation, IEEE Transaction on Industry,* Volume 55, Issue 1.

[13] Rodolfo Dufo-Lopez, Eduardo Perez-Cebollada, dkk, 2016, *Optimisation of energy supply at off-grid healthcare facilities using Monte Carlo Simulation, Energy Conversion and Management,* Volume 11, p 321 – 330.

[14] Roberto Romano, Pierluigi Siano, Mario Acone dan Vincenzo Loia, 2017, *Combined Operation of Electrical Loads, Air Conditioning and Photovoltaic – Battery Systems in Smart Houses, MDPI, Aplied Science,* 7, 525.

[15] GfK Belgium Consortium, 2017, *Study on residential prosumers in the European Energy Union.*

[16] Baoan Li dan Jinajun Yu, 2011, *Research and Application on The Smart Home based on Component Technologies and Internet of Things, SciVerse ScienceDirect*, Elsevier Ltd, 15, p 2087 – 2092.

[17] Gerhard Leitner, Felice Ferrara, dkk, 2014, *Decision Support in the Smart Home,* *https://www.researchgate.net/figure/Actors-and-components-in-the-smart-home_fig1_245031171*, seen 23th August 2023.

[18] Hussain Shareef, Maytham S Ahmed, dkk, 2017, *Review on Home Energy Management System Considering Demand Responses, Smart Technologies, and Intelligent Controllers*, IEEE Translation, doi : 10.1109/ACCESS.2018.2831917.IEEE Access

[19] M. Kasif Rafique, Saad Ullah Khan, dkk, 2019, *An Intelligent Hybrid Energy Management System for a Smart House Considering Bidirectional PowerFlow and Various EV Charging Technique*, MDPI, *Applied Sciences*,9, 1658.