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Analysis of Battery Technologies for Use as Battery Management Systems in a Simple Solar Power Plant

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Abstract

A solar power plant is a device that uses solar radiation to generate electricity. However, a dependable energy storage system is essential to effectively operating solar power plants. This study aims to examine how battery technology is used in solar power plants as a voltage storage. Specifically, the performance of lithium-ion and lead acid batteries, known as valve-regulated lead acid (VRLA), will then be compared. The findings demonstrate that Lithium-ion Batteries are better at keeping a steady voltage in no-load situations. The highest voltage value was recorded at 13:79 V at a 90° tilt angle and 13:00 Indonesia time. At the same hour, the VRLA Battery recorded the lowest voltage of 12.08 V with a 0° tilt angle. Under load conditions, the Lithium-ion Battery performed better with a more moderate voltage drop, achieving the lowest voltage of 12.68 V at an inclination angle of 165° and 14:00 Indonesia time, compared to the VRLA Battery's lowest value of 12.08 V under comparable conditions. Thus, Lithium-ion Batteries are thought to be more efficient and stable than VRLA Batteries in solar power plant applications, particularly in terms of voltage stability under changing operating conditions. Furthermore, battery selection should still take into account the initial investment cost and the unique requirements of the solar power plant system to be deployed.

Keywords

Solar Power Plant, Lithium-ion Battery, VRLA Battery, Battery Management System, Voltage Stability.

Introduction

Solar power plants utilizing photovoltaic technology, which directly converts solar radiation into electrical energy using solar cell semiconductor devices also referred to as solar panel technology allow for the use of solar energy as a power plant. A dispersed system (off-grid or stand-alone), a hybrid system, or a centralized system can be used for power plants. Solar power plants are used in conjunction with other power-producing methods in the hybrid system. This hybrid system is sometimes dubbed an on-grid system since, in general in Indonesia, the hybrid solar power plant system is connected to the Indonesia national grid power network, better known as PLN. Batteries, inverters, solar charger controllers (SCC), and solar panels are the parts that make up the solar power plant system according to Fedorova in his study (Fedorova, et al., 2020). Additionally,

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according to the Medco Power Indonesia Report in 2021, (Medco, 2021), the most effective way to supply electricity to isolated locations is through off-grid solar power plant systems. These systems use solar energy that is transformed into electrical energy and can meet the population's electricity needs while having an extremely simple system to operate and maintain. Off-grid solar power system selection considers several factors, including dispersed residential settlement patterns, land transportation challenges, the need for no plant integration, modularity and ease of development, and small capacity for user-friendliness. installation, a reasonable cost, enough solar radiation to serve as an energy source, and fuel oil independence. In simple terms, the energy produced in the solar power plant system comes from solar radiation received by solar panels causing electrons in solar cells to flow from negative to positive. As a result, electrical energy is produced. The result of this operation is direct current (DC), the quantity of which is determined by the number of solar cells that are mounted on the panel. The amount of electricity produced increases with the number of solar cells deployed. This solar panel's output can be utilized directly to loads with a DC voltage rating and a modest current. Solar power plants only generate electricity during the day; at night, they draw their energy from energy storage (Noussan, 2022).

Solar power plants rely heavily on battery technology to store energy from solar panels. It enables the usage of the generated solar energy at the appropriate time, even when the sun is not shining. Battery pack supervision technology refers to battery cell assemblies that are electrically structured in a row x column matrix format to supply specified voltage and current ranges overtime against an expected load scenario. As stated by (Andrea, 2010), a battery management system (BMS) is any electronic device that manages a rechargeable battery pack. The BMS monitors the battery pack's state, calculates secondary data, offers protection, and controls its environment. This timely book provides a solid understanding of battery management systems (BMS) in large Li-Ion battery packs, describing the important technical challenges in this field and exploring the most effective solutions. Professionals find in-depth discussions on BMS topologies, functions, and complexities, helping them determine which permutation is right for their application. Packed with numerous graphics, tables, and images, the book explains the 'why(s)' and 'how(s)' of Li-Ion BMS design, installation, configuration, and troubleshooting. This hands-on resource includes an unbiased description and comparison of all the off-the-shelf Li-Ion BMSs available today. Moreover, it explains how using the correct one for a given application can help get a Li-Ion pack up and running quickly at a low cost. Also, in Tan's book, the information on the core and basic concepts of BMS, the performance testing and battery modeling, the basic functions and topologies of BMS, and several advanced functions of BMS have been given (Tan, et al., 2022). Several functions of battery as BMS are mentioned in (Rosen and Farsi, 2023):

i) Prevents the battery from being overcharged,
ii) Calculates the state of charge,
iii) Monitors battery health and safety by constantly checking cables and loose connections, damaged cable insulation, and the need to replace damaged batteries.

How the BMS works is also simply defined in the study that has been developed by Rosen and Farsi. A battery management system typically is an electronic control unit that regulates and monitors the operation of a battery during charge and discharge. In addition, the battery management system is responsible for connecting with other electronic units and exchanging the necessary data about battery parameters. The voltage, capacity, temperature, power consumption, state of charge and health, charging cycle, and other characteristics of the battery are controlled and monitored by the battery management system. The battery management system uses these data for estimation of the state of charge and state of health of a battery pack. The battery's state of health is an indicator of the present battery capacity compared to the capacity at the beginning of its life. This indicator can be used to predict the end of life of a battery. The state of charge (SOC) represents the ratio of available capacity at a given time to the maximum possible charge that can be stored in the battery. Each battery should be maintained between the minimum and maximum state of charge defined in the battery profile.

Two kinds of batteries are commonly used in the solar power plant, namely Valve Regulated Lead Acid (VRLA) and Lithium-ion. Those two batteries have their characteristics to optimize the power plant. Several studies by (Suyanto, et al., 2022) discussed the optimization of VRLA and Lithium-ion batteries for linear and nonlinear load consumption. As in the white report (Legrand, 2022), the pros and cons. of VRLA and Lithium-ion batteries are discussed. Studies that mitigated and discussed the utilization of VRLA (Utomo, et al., 2023) and Lithium-ion (Martahang, et al., 2024) as energy storage at the lab-scale level. The comparison of both batteries discussed by (Ayeng'o, et al., 2018). The comparison of VRLA and Lithium-ion batteries in the solar power plant system, when addressing their durability, compact and lightweight form factors, fast charge/discharge rate, and higher efficiency, is discussed by (Keshan, et al., 2016).

This study examines and compares two commonly used batteries in solar power systems as BMS, namely VRLA and Lithium-ion. We designed and constructed a simple off-grid solar power plant, which is not only used as a mini power plant but also as the practice object at the Power Plant Laboratory of the Electrical Engineering Department, Politeknik Negeri Lhokseumawe. Sections of this paper are arranged as follows. The introduction discusses the solar power plant and battery as the BMS and two kinds of batteries commonly used in the solar power system, namely VRLA and Lithium-ion. The methodology section discussed how both batteries are used in the developed solar power plant, and the results and discussion section explained the measured parameters and the optimization of each battery. Finally, the conclusion section concludes how the work has been done.

Material and Methods

The methodology is written systematically. The design and model of the developed solar power plant, including the specifications of the solar power plant components, are clearly stated. The solar power plant system was developed as a simple off-grid system that uses two types of batteries, namely VRLA and Li-ion batteries. Figure 1 shows the system. The configuration of the solar power plant system consists of a 160Wp monocrystalline solar panel with the dimensions 1480x670x35 mm and an output guarantee of 10 years. It also consists of a 10A Solar Charger Controller, VRLA VOZ Battery 12V-100Ah, Lithium-ion VOZ Battery 12V-100Ah, STEC 12V-300W Inverter, MC4 Connector, 2x4mm solar panel cable and a SCC-Battery cable.

Figure 1: Simply solar power plant

Due to operating the developed simple solar power plant with both VRLA and Lithium-ion batteries, the control system is designed. Figure 2 illustrates the mechanism of the control system. This solar power plant system uses two types of batteries to store the DC voltage that was generated by the solar panels. Battery use can be switched using a switch (in this case an MCB) if the system runs separately on a VRLA battery or Lithium-ion battery. Furthermore, if the voltage produced exceeds the capacity of each type of battery utilized, the two types of batteries can be combined in use.

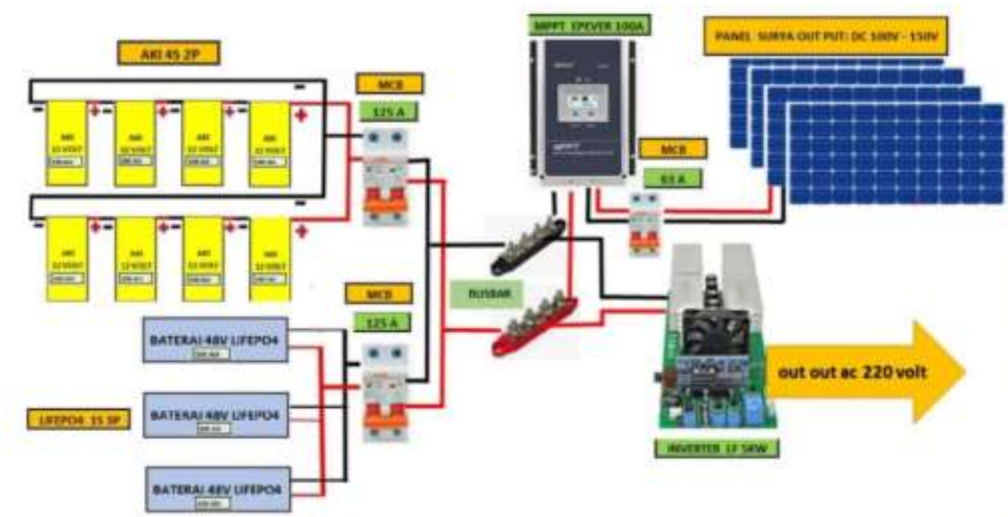


Figure 2. Control switch design of the batteries in use in solar power plant

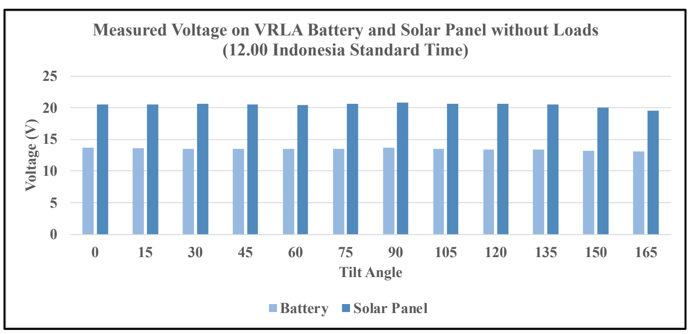
Results and Discussion

Results were tied to the methodology and objectives are achieved. The output voltage of the solar power plant system's batteries, inverters, and solar panel modules was measured both when the system was under no-load and when loads were applied. The system was developed using two different types of batteries: VRLA and Lithium-ion on Thursday, July 25, 2024, the test was conducted during midday within two hours (12.00-14.00 Indonesia Standard Time). At that moment, the recorded temperature was 34°C, but it felt like 42°C. A solar power meter is used to measure the amount of solar radiation that the solar panel cells are exposed to at each tilt angle, which ranges from 0 to 165 degrees.

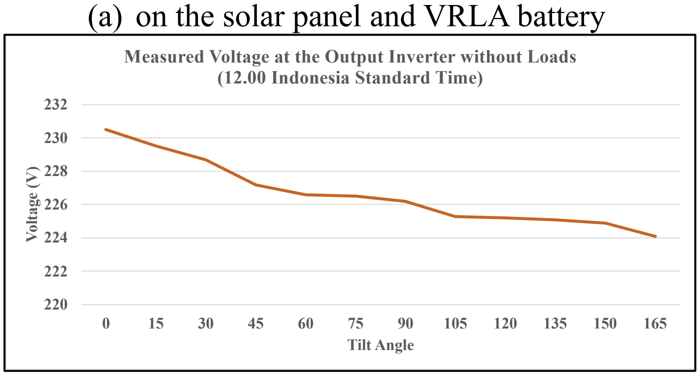
Voltage measurements on solar power plant components using VRLA batteries are performed by charging the battery and then performing test steps. The instructions are as follows.

a) Prepare the measuring tools to be used (digital multimeter and solar power meter).
b) Inspect and calibrate all measuring tools.
c) Testing is conducted from 12.00-14.00 Indonesia Standard Time.
d) Data is collected every time the solar panel tilt angle changes by 15 degrees.
e) Retrieve data such as solar panel output voltage, VRLA battery output voltage, and inverter output voltage.

Changes in voltage during the measurement time can be seen in Figure 3 (a) voltage output on the solar panel and VRLA battery and Figure 3 (b) inverter output as follows.



(a) on the solar panel and VRLA battery



(b) at the inverter output

Figure 3. Measured Voltage, type of used battery: VRLA

Table 1 summarizes the findings of monitoring the output voltage of the solar panel components, VRLA battery, and inverter under no-load and loaded conditions.

Measurement of the Simply Solar Power Plant
Thursday, 25 July 2024 Temperature 34˚C
Type of Battery: VRLA

No Load Circumtances					Loads Circumtances				
Hour	Tilt Angle	Measured Voltage on (V)			Hour	Tilt Angle	Measured Voltage on (V)		
		Battery	Solar Panel	Output Inverter			Battery	Solar Panel	Output Inverter
12.00	0	13,70	20,53	230,5	12.00	0	13,76	15,99	224,9
	15	13,62	20,50	229,5		15	13,68	16,13	223,9
	30	13,50	20,66	228,7		30	13,60	16,28	222,7
	45	13,53	20,48	227,2		45	13,55	16,16	224,1
	60	13,47	20,45	226,6		60	13,60	15,68	224,8
	75	13,52	20,60	226,5		75	13,68	15,01	224,2
	90	13,67	20,80	226,2		90	13,79	16,68	225,0
	105	13,53	20,64	225,3		105	13,60	15,52	224,1
	120	13,44	20,60	225,2		120	13,59	15,26	225,7
	135	13,37	20,51	225,1		135	13,56	14,49	225,6
	150	13,23	20,04	224,9		150	13,51	13,31	223,2
	165	13,12	19,50	224,1		165	13,50	13,05	223,6
Hour	Tilt Angle	Measured Voltage on (V)			Hour	Tilt Angle	Measured Voltage on (V)		
		Battery	Solar Panel	Output Inverter			Battery	Solar Panel	Output Inverter
13.00	0	13,80	18,52	227,7	13.00	0	13,67	15,85	223,9
	15	13,79	18,58	226,5		15	13,64	15,42	223,9
	30	13,79	18,60	225,5		30	13,60	14,98	222,7
	45	13,79	18,50	226,4		45	13,56	17,03	222,1
	60	13,79	18,57	225,8		60	13,60	16,92	221,8
	75	13,78	18,44	225,4		75	13,65	16,32	222,2
	90	13,74	19,18	225,3		90	13,79	17,68	224,0
	105	13,62	19,36	225,0		105	13,60	16,13	223,7
	120	13,62	19,51	224,9		120	13,56	15,86	223,1
	135	13,63	18,54	224,4		135	13,56	15,68	222,6
	150	13,63	18,45	224,3		150	13,50	15,37	222,2
	165	13,63	18,34	224,3		165	13,45	14,44	221,6
Hour	Tilt Angle	Measured Voltage on (V)			Hour	Tilt Angle	Measured Voltage on (V)		
		Battery	Solar Panel	Output Inverter			Battery	Solar Panel	Output Inverter
14.00	0	12,93	16,97	225,7	14.00	0	12,08	12,87	222,9
	15	12,88	15,94	225,6		15	12,79	12,85	221,6
	30	12,99	15,05	223,7		30	12,87	12,94	221,3
	45	13,14	14,21	223,9		45	13,00	13,11	221,0
	60	13,20	14,33	225,7		60	13,03	13,15	220,8
	75	13,00	15,00	225,6		75	13,43	13,14	221,1
	90	13,18	16,31	225,7		90	13,98	13,10	221,0
	105	13,26	15,39	225,7		105	13,61	13,27	220,8
	120	13,26	15,28	225,7		120	13,34	13,31	220,7
	135	13,23	14,34	225,6		135	13,11	13,19	220,6
	150	13,09	14,16	222,6		150	13,00	13,17	220,2
	165	13,70	13,13	218,5		165	12,68	13,09	220,0

The output voltage measurement findings for the solar panel, Lithium-ion battery, and inverter components are summarized in Table 2 for both no-load and load scenarios using the same test procedures as when charging the battery. Figure 4 illustrates the variations in output voltage during the testing period. (a) The voltage output on the solar panel and Lithium-ion battery; and (b) The subsequent inverter output.

Table 2
Measurement of the Simply Solar Power Plant
Thursday, 25 July 2024 Temperature 34˚C
Type of Battery: Lithium-ion

No Load Circumtances

Hour	Tilt Angle	Measured Voltage on (V)		
		Battery	Solar Panel	Output Inverter
12.00	0	13,53	20,53	226,1
	15	13,47	20,70	226,1
	30	13,40	20,66	226,1
	45	13,42	20,08	226,2
	60	13,44	20,45	226,5
	75	13,45	20,60	225,7
	90	13,46	20,80	226,9
	105	13,45	20,74	226,4
	120	13,40	20,64	226,4
	135	13,36	20,61	225,4
	150	13,33	20,54	225,2
	165	13,30	20,50	224,8
Hour	Tilt Angle	Battery	Solar Panel	Output Inverter
13.00	0	13,33	18,52	224,9
	15	13,37	18,58	224,6
	30	13,40	18,60	224,0
	45	13,42	18,50	224,0
	60	13,44	18,57	224,9
	75	13,45	18,44	224,6
	90	13,46	19,18	224,2
	105	13,45	19,36	223,5
	120	13,40	19,51	223,1
	135	13,37	18,54	222,3
	150	13,33	18,45	222,1
	165	13,30	18,34	222,0
Hour	Tilt Angle	Battery	Solar Panel	Output Inverter
14.00	0	12,97	16,97	222,0
	15	12,94	15,94	222,0
	30	13,05	15,05	221,7
	45	13,21	14,21	222,1
	60	13,13	14,33	222,4
	75	13,33	15,00	222,5
	90	13,41	16,31	222,8
	105	13,39	15,39	222,4
	120	13,28	15,28	222,1
	135	13,24	14,34	222,0
	150	13,16	14,16	222,0
	165	13,13	13,13	221,8

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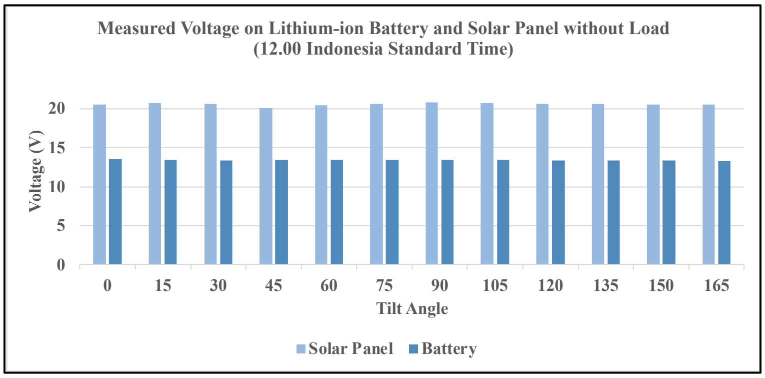
Hour	Tilt Angle	Measured Voltage on (V)		
		Battery	Solar Panel	Output Inverter
12.00	0	13,42	15,99	223,5
	15	13,37	16,13	223,9
	30	13,36	16,28	224,2
	45	13,55	16,36	224,9
	60	13,61	16,68	225,0
	75	13,58	16,01	225,0
	90	13,63	16,68	225,5
	105	13,55	15,52	225,4
	120	13,43	15,26	224,6
	135	13,36	14,49	223,0
	150	13,16	13,31	222,7
	165	13,00	13,05	222,0
Hour	Tilt Angle	Battery	Solar Panel	Output Inverter
13.00	0	13,32	15,85	223,4
	15	13,27	15,42	223,2
	30	13,16	15,98	223,5
	45	13,00	16,03	223,9
	60	13,41	16,92	224,6
	75	13,52	17,32	225,0
	90	13,63	17,68	225,4
	105	13,41	16,13	224,5
	120	13,36	15,86	224,2
	135	13,24	15,68	224,0
	150	13,16	15,37	223,8
	165	12,89	14,44	223,2
Hour	Tilt Angle	Battery	Solar Panel	Output Inverter
14.00	0	12,86	12,86	222,6
	15	12,74	12,74	222,6
	30	12,68	12,68	222,9
	45	13,05	13,05	223,0
	60	13,27	13,27	223,4
	75	13,32	13,32	223,7
	90	13,33	13,43	224,0
	105	13,31	13,31	223,6
	120	13,31	13,29	223,1
	135	13,25	13,25	222,9
	150	12,88	12,88	222,9
	165	12,74	12,74	222,7

Table 3 below provides a summary of the measurements made of the solar irradiance that strikes the solar panel cells. Measured on Thursday, 25 July 2024 with a temperature of 34˚C.

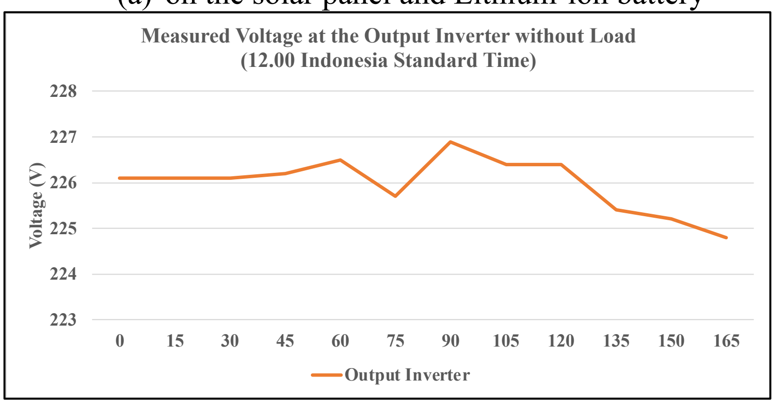
The findings of this study showed that the simple solar power plant with certain specifications of its components yields spectacular measured DC voltage for solar panel modules and both types of batteries. As for the output inverter, since its function is to convert DC voltage to AC voltage before it supplies the AC loads, the measured voltage showed above 220V AC.

Table 3 Solar Irradiance Measurement

Tilt Angle	Irradiance (Watt/m2)		
	Hours		
	12.00	**13.00**	**14.00**
0	363,6	292,3	105,3
15	471,3	360,1	111,2
30	645,7	414,5	231,2
45	804,3	621,1	423,2
60	814,2	727,0	570,2
75	861,8	796,6	697,2
90	930,5	806,3	736,4
105	864,6	800,7	765,5
120	691,2	720,2	713,2
135	531,5	701,5	670,5
150	454,5	545,2	582,2
165	342,7	348,2	355,3



(a) on the solar panel and Lithium-ion battery



(b) at the inverter output

Figure 4. Measured Voltage, type of used battery: Lithium-ion

Conclusion

The findings of observations and experiments indicate that selecting the appropriate battery technology for a solar power plant system is critical. VRLA batteries are appropriate for applications with low storage needs and minimal budgets. Lithium-ion batteries are better suited for solar power plant systems with high usage and storage requirements. However, the comparison shows Lithium-ion to have higher efficiency and 5-10 times the lifecycle of lead-acid. On charging and discharging, Lithium-ion outperforms VRLA with wide margins. Lithium-ion battery has higher efficiency, longer lifetimes, and faster charging capabilities, for energy supplied throughout their lifetime. For these reasons, Lithium-ion is deemed preferable for off-grid stationary storage applications except in low-temperature locations where VRLA proves safer.

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References

Andrea, D. (2010). Battery management systems for large lithium-ion battery packs. Artech house.

Fedorova, A., Hrynyszyn, B. D., & Jelle, B. P. (2020, December). Building-integrated photovoltaics from products to system integration–a critical review. In *IOP Conference Series: Materials Science and Engineering* (Vol. 960, No. 4, p. 042054). IOP Publishing. https://doi.org/10.1088/1757-899X/960/4/042054

Keshan, H., Thornburg, J., Ustun, T.S. (2016). Comparison of Lead-Acid and Lithium-Ion Batteries for Stationary Storage on Off-Grid Energy Systems. In 4th IET Clean Energy and Technology Conference, Kuala Lumpur 2016. https://ieeexplore.ieee.org/xpl/conhome/7958834/proceeding

Legrand (2022). Li-Ion vs VRLA batteries in UPS Applications. THE GLOBAL SPECIALIST IN ELECTRICAL AND DIGITAL BUILDING INFRASTRUCTURES. Legrand. https://ups.legrand.com/media/document/WP_Li-Ion%20vs%20VRLA%20batteries_print.pdf

Marhatang, Yunus, M.Y., Sonong, Lewi, Tandioga, R., Djalal, M.R. (2024). Design and Build a Solar Home System Prototype Using Lithium Batteries as Energy Storage. Journal of Electrical Engineering and Technology. Vol. 5, No.1 pp. 60-69. https://doi.org/10.32492/jeetech.v5i1.5106

Medco Power Indonesia (2021). Indonesia's Solar Energy Overview and Prospects. PT Medco Power Indonesia. https://www.reinvest.id/assets/source/materials/china/Eka%20Satria%20-%20Session%20III.pdf

Rosen, M.A., Farsi, A. (2023) Battery Technology: Chapter 6 - Battery system design. Academic Press. https://doi.org/10.1016/B978-0-443-18862-6.00006-9

S. P. Ayeng'o, T. Schirmer, K.-P. Kairies, H. Axelsen, and D. U. J. S. E. Sauer. (2018). Comparison of off-grid power supply systems using lead-acid and lithium-ion batteries. Vol. 162, pp. 140-152. https://doi.org/10.1016/j.solener.2017.12.049

Suyanto, H. S., Diantari, R. A., & Pramono, T. J. (2022). Study Of Optimization Of VRLA And Lithium Batteries For Load Consumption Of Linear And Nonlinear: Study Of Optimization Of VRLA And Lithium Batteries For Load Consumption Of Linear And Nonlinear. In INTERNATIONAL CONFERENCE ON GREEN TECHNOLOGY AND DESIGN (ICGTD) (Vol. 2022). https://eproceeding.itenas.ac.id/index.php/icgtd/article/view/1314

Tan, X., Vezzini, A., Fan, Y., Khare, N., Xu, Y., & Wei, L. (2022). Battery Management System and Its Applications. John Wiley & Sons. http://dx.doi.org/10.1002/9781119154013

Utomo, M.S., Nugrahanto, I, Sungkono (2023). Energy Storage Systems Using Secondary Cell Batteries in Photovoltaics. Jurnal Elkolind Volume 10, Nomor 1, pp. 85-93. http://dx.doi.org/10.33795/elkolind.v10i1.2753