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Analyzing and designing energy storage system and charging station from solar energy-lithium ion

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ABSTRACT

This paper presents the design of a battery charging center that will be used optimally by students in the Department of Electrical Engineering, Ambon State Polytechnic (POLNAM, *Politeknik Negeri Ambon*). This study would like to design a charger station with a load requirement of 145.98 Wh that can be used as a blueprint for future relevant programs. The design of the charger station is based on the results of research that has been conducted in the study. The results of this study have shown that the number of solar panels 100 WP as much as 1 piece, BMS capacity (ICh = 11.6 A and IDch = 31.7 A), SCC capacity 6.125 A 10 A, Inverter 261 Watt 0.5 KW, and battery pack 21.75 Ah.

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INTRODUCTION

Technological developments in line with the increase in world population have caused an increase in energy demand, especially the demand for electrical energy (Ahmad & Zhang, 2020; Paramati et al., 2022). Lifestyle changes also increasingly emphasize the importance of electrical energy for human life because all human activities ranging from household activities to industrial activities are very dependent on electrical energy (Hasselqvist et al., 2022; Imasiku & Ntagwirumugara, 2020; Kusumastuti et al., 2022). One activity that requires electrical energy on an ongoing basis is charging batteries on electronic devices such as cell phones (cellphones), android tablets and laptops. Continuous use of the devices requires a charging process so that this device can be used again.

Public facilities are all facilities and infrastructure provided by the government to support public services or community services (Dong et al., 2020; Mustafa et al., 2020). What is meant by public facilities in this study is educational facilities. Ambon State Polytechnic (POLNAM, *Politeknik Negeri Ambon*) is one of the public facilities or vocational education institutions located in Maluku province, Ambon City. POLNAM itself consists of 5 majors including the Department of Electrical Engineering where the number of students in this department is approximately 700 people. The use of electronic devices as mentioned above cannot be separated from supporting student activities in doing their daily assignments. The use of intense devices must be supported by the completeness of existing facilities or provided by the Educational Institution such as the use of cellular telephones. The more often it is used, the energy stored in the battery will decrease so that this energy must be replenished.

Energy charging on these mobile devices must be supported by existing facilities, such as battery charging points/centers. However, the supporting facilities for battery charging available in the Department of Electrical Engineering are not adequate or can be said to be non-existent at all so students have to try themselves to find other supporting facilities.

Seeing the problems above, this study would like to design a battery charging center that will later be used optimally by students in the Department of Electrical Engineering, POLNAM. Hopefully, this design can be used as a blueprint for future relevant programs.

METHOD

Solar Panel

Solar panels are made flat and rectangular from several interconnected solar modules. These photovoltaic cells are made from silicon materials. When sunlight hits a solar cell, photons carried by sunlight knock electrons on the silicon wafer. A solar cell consists of two layers – positive and negative that already exist allowing the flow of electricity. When many photovoltaic cells are connected together, solar panels are formed. Each photovoltaic cell generates electricity and hence many modules in the panel are combined to make electricity output current and voltage (Hargroves, 1983; Rout et al., 2015; Tirmare & Khandare, 2015).

The type of solar panel used in this study was monocrystalline. This type of solar cell uses pure silicon crystal rods. These pieces of solar cells are identical to each other so that they have a high level of efficiency (equivalent to 15-25%). Physically, this solar cell has a solid black color and there will be a cavity or empty part between one solar cell and another solar cell if arranged into a solar panel. This happens because the solar cells used are cut slightly at each corner and are round or rectangular in shape which can cause losses because of it. This can reduce the energy produced in this breed. The high price is also one of the considerations in choosing this type of solar cell (Dobrzański et al., 2013; Sofijan, 2020). The following are the specifications of the solar panels used:



Figure 1. Solar Panel Specifications

To calculate the number of solar panels used the equation:

$$Solar\ Panel\ Total = \frac{Watt.Hour}{WP\ Panel \times Sun\ Efficiency} \quad (1)$$

Battery

Battery is an energy storage device that is able to convert chemical energy into electrical energy so that it can be used as an energy source in electronic devices (Diantari & Pujotomo, 2017). The use of batteries as energy storage devices is almost used in all electronic devices. With the battery, the use of electronic devices can be more efficient because they do not have to connect the device to a power source to activate it so that electronic devices can be used everywhere. The battery must have a large energydensity and power density (Rout et al., 2015). Lithium ion batteries are the most widely used energy storage technology today, especially for devices that use batteries as their main source. Lithium ion batteries can produce large energy and power densities, another advantage is high efficiency, without memory effects and relatively long life cycles (Otong, 2019).

LIB rechargeable batteries are a practical and easy solution that has been accessible for a long time, especially in electronic products such as mobile phones, laptops, and smart watches. Inside LIBs, lithium ions migrate in and out of the two interior electrodes (Wu et al., 2015). When discharging, the reaction mechanism at the anode is described in the following equation: xLi+ + 6C + xe− = LixC6 (Li et al., 2014). Although the main mechanism is clear, this is inevitable and troublesome side effects occur on electrodes and electrolytes. Such side effects cause problems in the following areas: chemical and physical stability, oxidation-reduction quality, decreased capacity, coulomb efficiency, expansion-shrinkage volume and cost. The classic rocking chair battery, in which lithium ions move continuously, is clearly presented Figures 1(a) and (b) (Otong, 2019).

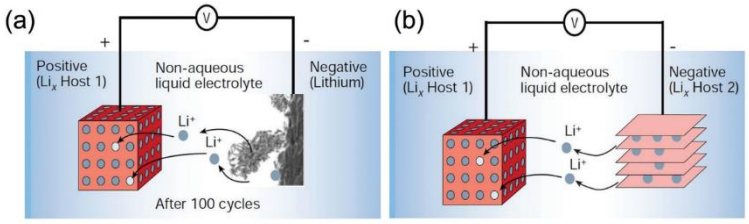


Figure 2. (a) Schematic design of secondary Li-metal battery (picture of dendrite growth at Li surface was obtained directly from in situ scanning electron microscopy measurements). (b) Rechargeable Li-ion battery (Tarascon & Armand, 2001)

Description and model of lithium ion batteries used in this study:

Table 1. Description and Model of Lithium Ion 18650 Battery

Description	Lithium Ion Rechargeable Cell
Model Name	EVE-INR1865025P
Item	**Specification**
Nominal Discharge Capacity	2500mAh Charge: 1.25A (0.5C), 4.20V, CCCV 100mA cut-off Discharge: 0.5A (0.2C), 2.50V DC cut-off
Nominal Voltage	3.60V
Standard Charge	CCCV, 1.25A, 4.20±0.05V, 100mA cut-off
Rapid Charge	CCCV, 4A, 4.20±0.05V, 100mA cut-off
Standard Discharge	DC, 0.5A, 2.50V cut-off
Max. Continuous Discharge	DC, 30A, 2.50V cut-off
Charge/Discharge Voltage Range	4.20~2.50V
Cell Weight	48.0g Max
Cell Dimension	Height: 65.00±0.15mm Diameter: 18.35±0.10mm
Operation Temperature	Ambient Temperature : Charge: 0 to 45°C Discharge: -20 to 60°C Cell Surface Cut-off Temperature : Charge: 0 to 50°C (recommended recharge release < 45°C) Discharge: -20 to 80°C (recommended re-discharge release < 60°C)

BMS (Battery Management System)

Battery Management System (BMS) or battery management system is an electronic system that manages batteries. BMS systems are essential for monitoring parameters such as charge status, thermal condition monitoring, ampere hour calculation, terminal voltage and current flowing. BMS also helps in controlling or balancing the battery environment. BMS is used to keep every cell in the battery pack in a safe condition. BMS has an important role in improving battery performance and optimizing vehicle operation in a safe and reliable manner. BMS can be used to monitor the condition of the battery by the rider. So that the driver can find out the estimated mileage on the vehicle (Wahyudi et al., 2021).

The capacity of the BMS can be determined using the equation

$$I_{DCh} = \frac{100\,WP \times H\,Sun\,Effectivity}{V \times n_{cell}} \quad (2)$$

$$I_{Ch} = \frac{P_{Load}}{V \times n_{cell}} \quad (3)$$

Inverter

Inverter is a power electronics circuit that has a function to convert or convert direct voltage (DC) into alternating voltage (AC) (Diantari & Pujotomo, 2017). That is why this power circuit is also called an inverter because it is in accordance with its function. Another function of this inverter is to regulate and make a stable voltage at the electrical output it produces. The type of inverter used is the type of Pure sine wave (PSW), has the characteristics of this wave works optimally on all electronic equipment because the waves produced are pure as waves generated from PLN. The advantage of this type of inverter is higher power efficiency because of less power consumption.

The equation for calculating the capacity of the inverter is

$$P_{Tot} = \{Watt.Hour + (5\% \times Watt.Hour) + (18\% \times Watt.Hour) + (20\% \times Watt.Hour)\} \times 1{,}25 \quad (4)$$

Solar Charger Controller (SCC)

SCC is a charge controller used in solar powered applications and is also called a solar battery charger. Its function is to regulate the voltage and current from the solar array to the battery to prevent overcharging and also overuse. There are many technologies that have been incorporated into the design of solar charge controllers. For example, the MPPT payload controller includes a maximum power point tracking algorithm to optimize PV production of cells or modules. The solar charge controller ± regulate the voltage and current coming from the PV panel towards the battery and prevent overcharging of the battery and extend battery life battery life (Diantari & Pujotomo, 2017).



Figure 3. Solar Charger Controller (SCC)

The amount of SCC used, can be calculated by the equation
SCC = 1 solar panel x 4.90 A x 1.25 (5)

RESULTS AND DISCUSSION

Electrical Power Consumption Requirement (Watt-Hour)

The need for electrical power at the charging station is determined based on the amount of electrical power in the electronic device being used and the length of time in its use (charging process). The devices used in this study are mobile phones with several types and laptops whose specifications can be seen in Table 2. below.

Table 2. Research Tools and Their Capacities

Research Tools	Trademark	Electric Power Capacity (Watts)
Handphone	Iphone 7 S+	5
Laptop	Toshiba	65,98
Handphone	Samsung Galaxy A11	5
Oppo	A57	30

The amount of electrical power required, in this study, is shown in Table 3 below

Table 3. Total Electrical Power Requirement used in Hours

Research Tools	Trademark	Electric Power (Watt)	Usage Time (Hour)	Power Requirements (Waat.Hour)
Handphone	Iphone 7 S+	5	2	10
Laptop	Toshiba	65,98	1	65,98
Handphone	Samsung Galaxy A11	5	2	10
Oppo	A57	30	2	60
Total Power Consumption (Watt-Hours)				145,98

Calculating Solar Panel Needs

Solar panels to be used must be able to supply power continuously in accordance with the desired power needs. In this study, solar panels used had a capacity of 100 WP. If the power requirement to be used is 145.89 Watt-Hours, then the number of solar panels used is

$$Solar\ Panel\ Total = \frac{145{,}98}{100\ \times 4}$$

$$Solar\ Panel\ Total = 0{,}36\ panel \approx 1\ Solar\ Panel$$

Calculating BMS needs

Calculating Battery Management System (BMS) capacity requirements

$$I_{DCh} = \frac{100\ WP \times 4}{4{,}2 \times 3}$$

$I_{DCh} = 31{,}7\ A$

$I_{Ch} = \frac{145{,}98}{12{,}6}$

$I_{Ch} = 11{,}6\ A$

For BMS type Daly, the BMS capacity is 0.5: 1, which means the charging current must be 50% of the discharging current, where based on the calculation of the BMS capacity above the discharging current is 31.7 A 60 A, while the charging current is 11.6 A 30 A.≈≈

Calculating Solar Charger Controller (SCC) Capacity

In calculating the needs of scc, you must first know the datasheet and specifications of the solar panel, on this 100wp solar panel there is the following data information:

Pm = 100 W Vm = 21.45 V Voc = 24.66
Imp = 4.67 A Isc = 4.90 A

What must be considered is the ISC (short circuit current) number, the value multiplied by the number of solar panels and the safety factor (safety Factor) which is 1.25, the result is what is the minimum value of SCC (solar charge controller) needed:

SCC = 1 surya panel x 4.90 A x 1.25 = 6.125 A

So the scc (solar charge controller) must have a minimum capacity of 6.125 A. In the market, SCC with a capacity of 6.125 A is very unlikely to be obtained, for that SCC with a capacity of 10A was chosen. But to anticipate the overcurrent in solar panels when the intensity of light from the sun is very high (at 12.00 to 13.00), it was decided to have an SCC with a capacity of 20A.

Calculating Inverter Capacity

The capacity of the inverter must be greater than the total power requirement (Watt.Hours) used added with the power losses on solar panels, SCC, safety factors and the inverter itself.

$$P_{Tot} = \{145{,}98 + 7{,}3 + 26{,}3 + 29{,}2\} \times 1{,}25$$
$$P_{Tot} = 208{,}8 \times 1{,}25$$
$$P_{Tot} = 261\ Watt.Hour$$

This means that the capacity of the inverter used must be greater than the total power needed, in this case the inverter used is 1.6 KW.

Calculating Battery Pack Needs

Based on the power requirements above, the battery capacity is determined based on power requirements divided by the battery voltage needed in this case DC 12 Volts.

$I = \frac{P_{Tot}}{V}$

$I = \frac{261\ Watt.Hour}{12}$

$I = 21{,}75\ A.Hour$

Battery Pack Assembly Process

Battery/Cell Measurement

To build a battery pack, measuring the capacity of the battery itself is very important. The purpose of the measurement is to see the voltage (V), the magnitude of ampere hours in the battery (Ah), internal resistance (mR) and also the condition of the SoC and DoD of the battery.

Table 4. Battery/Cell capacity testing (EVE-25P 18650 3.7V 2500 mAh 30 A 12 C system 3S 13P

No. Cell	Tegangan charging (V-char)	Tegangan Dicharging (V-Dchar)	Arus Char dan DChar (I) mA	Waktu (t)	Kapasitas (mAh)	Internal Resistensi (mR)
1	2,8	4,2	500	4,48	2465	41
2	2,8	4,2	500	5,06	2452	14
3	2,8	4,2	500	5,01	2519	14
4	2,8	4,2	500	5,00	2466	13
5	2,8	4,2	500	5,20	2531	13
6	2,8	4,2	500	4.54	2523	10
7	2,8	4,19	500	4,57	2500	12
8	2,8	4,19	500	5,01	2540	15
9	2,8	4,19	500	4,44	2528	14
10	2,8	4,2	500	4,58	2516	12
11	2,8	4,2	500	5,03	2504	14
12	2,8	4,2	500	4,56	2463	11
13	2,8	4,2	500	5,05	2525	10
14	2,8	4,2	500	5,04	2519	11
15	2,8	4,19	500	3,36	2489	12
16	2,8	4,19	500	3,38	2491	17
17	2,8	4,19	500	3,34	2477	12
18	2,8	4,19	500	3,33	2488	12
19	2,8	4,19	500	5,02	2507	10
20	2,8	4,2	500	5,00	2472	15
21	2,8	4,19	500	4,58	2476	10
22	2,8	4,2	1000	2,40	2505	10
23	2,8	4,19	1000	2,29	2494	10
24	2,8	4,19	1000	2,30	2512	15
25	2,8	4,19	1000	2,27	2476	10
26	2,8	4,19	1000	2,28	2475	12
27	2,8	4,2	1000	2,27	2453	19
28	2,8	4,19	1000	2,31	2531	15
29	2,8	4,19	1000	2,35	2510	15
30	2,8	4,2	1000	2,30	2498	17
31	2,8	4,19	1000	2,28	2481	14
32	2,8	4,19	1000	2,31	2525	11
33	2,8	4,2	1000	2,3	2490	12
34	2,8	4,2	1000	2,27	2442	14
35	2,8	4,19	1000	2,31	2485	14
36	2,8	4,2	1000	2,38	2483	15
37	2,8	4,2	500	5,01	2487	19
38	2,8	4,19	500	5,03	2501	14
39	2,8	4,19	500	5,03	2512	14

Battery Group/Cell for Series and Parallel Systems

Based on the results of the calculation of the needs of the pack battery, the composition of the battery pack assembly is 3 series and 19 parallel to get a voltage of 12 V 32 Ah. The arrangement of battery groups in series and parallel can be seen in Tables 5 and 6 below.

Table 5. Group Cell for Series System (3S)

Group Cell	No. Cell	Tegangan charging (V-char)	Tegangan Dicharging (V-Dchar)	Arus Char dan DChar (I) mA	Waktu (t)	Kapasitas (mAh)	Internal Resistensi (mR)
	3	2,8	4,2	500	5,01	2519	14
1	5	2,8	4,2	500	5,20	2531	13
	6	2,8	4,2	500	4.54	2523	10
	7	2,8	4,19	500	4,57	2500	12
2	8	2,8	4,19	500	5,01	2540	15
	9	2,8	4,19	500	4,44	2528	14
	10	2,8	4,2	500	4,58	2516	12
3	11	2,8	4,2	500	5,03	2504	14
	13	2,8	4,2	500	5,05	2525	10
	14	2,8	4,2	500	5,04	2519	11
4	22	2,8	4,2	1000	2,40	2505	10
	23	2,8	4,19	1000	2,29	2494	10
	24	2,8	4,19	1000	2,30	2512	15
5	28	2,8	4,19	1000	2,31	2531	15
	29	2,8	4,19	1000	2,35	2510	15
	30	2,8	4,2	1000	2,30	2498	17
6	32	2,8	4,19	1000	2,31	2525	11
	38	2,8	4,19	500	5,03	2501	14
	39	2,8	4,19	500	5,03	2512	14
7	19	2,8	4,19	500	5,02	2507	10
	16	2,8	4,19	500	3,38	2491	17
	33	2,8	4,2	1000	2,3	2490	12
8	15	2,8	4,19	500	3,36	2489	12
	18	2,8	4,19	500	3,33	2488	12
	31	2,8	4,19	1000	2,28	2481	14
9	35	2,8	4,19	1000	2,31	2485	14
	36	2,8	4,2	1000	2,38	2483	15
	37	2,8	4,2	500	5,01	2487	19
10	17	2,8	4,19	500	3,34	2477	12
	20	2,8	4,2	500	5,00	2472	15
	21	2,8	4,19	500	4,58	2476	10
11	25	2,8	4,19	1000	2,27	2476	10
	26	2,8	4,19	1000	2,28	2475	12
	1	2,8	4,2	500	4,48	2465	41
12	4	2,8	4,2	500	5,00	2466	13
	12	2,8	4,2	500	4,56	2463	11
	2	2,8	4,2	500	5,06	2452	14
13	27	2,8	4,2	1000	2,27	2453	19
	34	2,8	4,2	1000	2,27	2442	14

Table 6. Group Cell for Parallel Systems (13 P)

Group I							Group II						
No. Cell	(V-char)	(V-Dchar)	mA	(t)	(mAh)	(mR)	No. Cell	(V-char)	(V-Dchar)	mA	(t)	(mAh)	(mR)
3	2,8	4,2	500	5,01	2515	14	5	2,8	4,2	500	5,2	2513	13
7	2,8	4,19	500	4,57	2500	12	8	2,8	4,19	500	5,01	2540	15
10	2,8	4,2	500	4,58	2516	12	11	2,8	4,2	500	5,03	2504	14
14	2,8	4,2	500	5,04	2519	11	22	2,8	4,2	1000	2,4	2505	10
24	2,8	4,19	1000	2,3	2512	15	28	2,8	4,19	1000	2,31	2531	15
30	2,8	4,2	1000	2,3	2498	17	32	2,8	4,19	1000	2,31	2525	11
39	2,8	4,19	500	5,03	2512	14	19	2,8	4,19	500	5,02	2507	10
33	2,8	4,2	1000	2,3	2490	12	15	2,8	4,19	500	3,36	2489	12
31	2,8	4,19	1000	2,28	2481	14	35	2,8	4,19	1000	2,31	2485	14
37	2,8	4,2	500	5,01	2487	19	17	2,8	4,19	500	3,34	2477	12
21	2,8	4,19	500	4,58	2476	10	25	2,8	4,19	1000	2,27	2476	10
1	2,8	4,2	500	4,48	2465	41	4	2,8	4,2	500	5	2466	13
2	2,8	4,2	500	5,06	2452	14	27	2,8	4,2	1000	2,27	2453	19

Group III						
No. Cell	(V-char)	(V-Dchar)	mA	(t)	(mAh)	(mR)
6	2,8	4,2	500	4.54	2523	10
9	2,8	4,19	500	4,44	2528	14
13	2,8	4,2	500	5,05	2525	10
23	2,8	4,19	1000	2,29	2494	10
29	2,8	4,19	1000	2,35	2510	15
38	2,8	4,19	500	5,03	2501	14
16	2,8	4,19	500	3,38	2491	17
18	2,8	4,19	500	3,33	2488	12
36	2,8	4,2	1000	2,38	2483	15
20	2,8	4,2	500	5	2472	15
26	2,8	4,19	1000	2,28	2475	12
12	2,8	4,2	500	4,56	2463	11
34	2,8	4,2	1000	2,27	2442	14

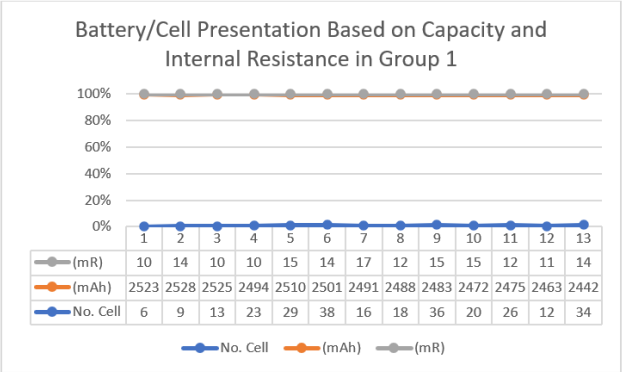


Figure 4. Battery Presentation Based on Specificity and Internal Resistance in Group 1

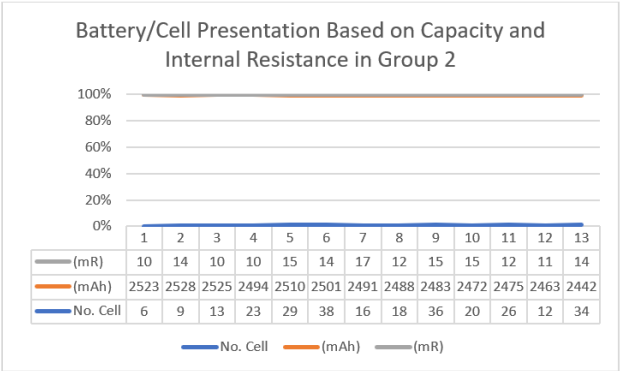


Figure 5. Battery Presentation Based on Specificity and Internal Resistance in Group 2

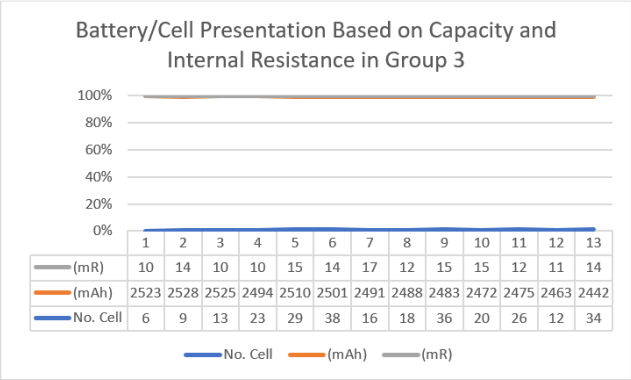


Figure 6. Battery Presentation Based on Specificity and Internal Resistance in Group 3

Battery/Cell SoC and DoD Composition

SoC and DoD are parameters that indicate the condition of the battery at a given time. SoC describes how much charge is available in a battery compared to its capacity, while DoD describes how much discharge or how much the battery has used. The results of SoC and DoD calculations can be seen in table 7 below.

Table 7. State of Charge (SoC) and Depth of Discharge (DoD) Conditions

No.	No. Cell	(V-char)	(V-Dchar)	mA	(t)	(mAh)	(mR)	SoC (%)	DoD (%)
1	3	2,8	4,2	500	5,01	2515	14	100,6	0
2	5	2,8	4,2	500	5,2	2513	13	100,52	0
3	6	2,8	4,2	500	4.54	2523	10	100,92	0
4	7	2,8	4,19	500	4,57	2500	12	100	0
5	8	2,8	4,19	500	5,01	2540	15	101,6	0
6	9	2,8	4,19	500	4,44	2528	14	101,12	0
7	10	2,8	4,2	500	4,58	2516	12	100,64	0
8	11	2,8	4,2	500	5,03	2504	14	100,16	0
9	13	2,8	4,2	500	5,05	2525	10	101	0
10	14	2,8	4,2	500	5,04	2519	11	100,76	0
11	22	2,8	4,2	1000	2,4	2505	10	100,2	0
12	23	2,8	4,19	1000	2,29	2494	10	99,76	0,24
13	24	2,8	4,19	1000	2,3	2512	15	100,48	0
14	28	2,8	4,19	1000	2,31	2531	15	101,24	0
15	29	2,8	4,19	1000	2,35	2510	15	100,4	0
16	30	2,8	4,2	1000	2,3	2498	17	99,92	0,08
17	32	2,8	4,19	1000	2,31	2525	11	101	0
18	38	2,8	4,19	500	5,03	2501	14	100,04	0
19	19	2,8	4,19	500	4,54	2436	20	97,44	2,56
20	40	2,8	4,19	500	5,02	2507	10	100,28	0
21	16	2,8	4,19	500	3,38	2491	17	99,64	0,36
22	33	2,8	4,2	1000	2,3	2490	12	99,6	0,4
23	15	2,8	4,19	500	3,36	2489	12	99,56	0,44
24	18	2,8	4,19	500	3,33	2488	12	99,52	0,48
25	31	2,8	4,19	1000	2,28	2481	14	99,24	0,76
26	35	2,8	4,19	1000	2,31	2485	14	99,4	0,6
27	36	2,8	4,2	1000	2,38	2483	15	99,32	0,68
28	37	2,8	4,2	500	5,01	2487	19	99,48	0,52
29	17	2,8	4,19	500	3,34	2477	12	99,08	0,92
30	20	2,8	4,2	500	5	2472	15	98,88	1,12
31	21	2,8	4,19	500	4,58	2476	10	99,04	0,96
32	25	2,8	4,19	1000	2,27	2476	10	99,04	0,96
33	26	2,8	4,19	1000	2,28	2475	12	99	1
34	1	2,8	4,2	500	4,48	2465	41	98,6	1,4
35	4	2,8	4,2	500	5	2466	13	98,64	1,36
36	12	2,8	4,2	500	4,56	2463	11	98,52	1,48
37	2	2,8	4,2	500	5,06	2452	14	98,08	1,92
38	27	2,8	4,2	1000	2,27	2453	19	98,12	1,88
39	34	2,8	4,2	1000	2,27	2442	14	97,68	2,32

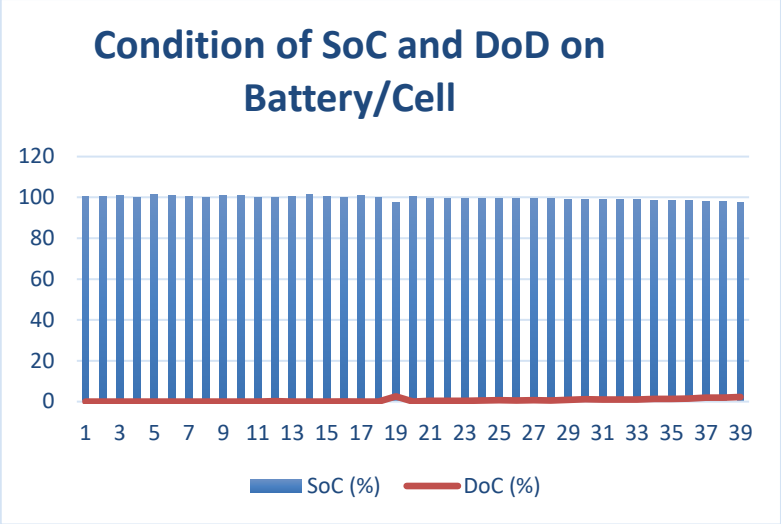


Figure 7. SoC and DoD Conditions in EVE-INP18650 25P Lithium Battery

CONCLUSION

Based on the results of research that has been conducted in the design of the charger station, it can be concluded that to build a charger station with a load requirement of 145.98 Wh requires the number of solar panels 100 WP as much as 1 piece, BMS capacity (ICh = 11.6 A and IDch = 31.7 A), SCC capacity 6.125 A 10 A, Inverter 261 Watt 0.5 KW, and battery pack with a capacity of 21.75 Ah. If assembled in 3 Series and 7 Parallel, it requires 31.85 Ah≈≈.

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