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Charging Station for Two-wheelers Electric Vehicle Powered by Photovoltaic System

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Abstract **– Indonesia has significant solar energy potential, ranging from 4.88-5.78 kWh/m2 /day with a production of 444 GWh by 2022, which is supported by various government initiatives and research projects focused on renewable energy-based two-wheeled electric vehicles. The increasing prevalence of electric vehicles in Indonesia necessitates the adaptation of photovoltaic (PV)-based renewable energy infrastructure to provide power sources for battery-operated two-wheeled electric vehicle charging stations. This paper presents proposals for the implementation of two-wheeled electric vehicles, utilizing various battery technologies combined with PV-based renewable energy systems, incorporated into various plans and schemes. The research methodology was developed by evaluating the electric vehicle battery requirements and system component capacities, while the charging cycle describes the relationship between the battery capacity and the capacity of 200 Wp, 400 Wp, and 500 Wp photovoltaic panels. The calculation results show that the charging system uses various PV panel capacities. The 200 Wp PV panel requires the longest charging duration. The 400 Wp photovoltaic panel serves as an intermediate charging station. The 500 Wp photovoltaic panel shows the fastest charging duration among the three types of panels, ranging from 1 to 3.7 hours, depending on the battery load rating of the electric wheeled vehicle. In addition, the proposed PV charging system provides various battery capacity options with consideration of autonomous time (1-4 days) where the charging time of 4 days for electric vehicle battery capacity >2000 Wh will be in line with the battery demand in the charging station.**

Keywords: Battery Technology, Charging Cycle, Charging Station, Photovoltaic, Two-Wheeled Electric Vehicles.

I. Introduction

The growth of electric motorcycle companies in Indonesia is accelerating, thanks to the issuance of Presidential Regulation Number 55 of 2019[1] concerning the Acceleration of the Battery Electric Vehicle Program for Road Transportation, followed by Minister of Transportation Regulation Number 65 of 2020 concerning the Conversion of Motorcycles with Fuel Motor Drivers into Battery-Based Electric Motorcycles[2], [3]. There are already at least 20 electric motorbike manufacturers, both domestic and international, with the expansion of multiple battery swap facilities in major cities like as Jakarta and Bali[4]. The present administration is providing a lot of room and support for the growth of the electric car ecosystem. Electric motorcycles are regarded as the most acceptable answer at this time in terms of rising fossil fuel use, as well as the total of emissions, as they are said to emit no emissions at all when in operation[5]. Electric vehicles are thought to be easier to operate and maintain, as well as more energy-efficient. This is a challenge for existing conventional motorcycle manufacturers to produce more ecologically friendly and low-emission vehicles.

In 2022, as the number of electric vehicles and swap stations increases, the average distance between switch stations may decrease to less than 3 km. Organizing exchange stations in a single area with more docks makes sense[6]. According to MEMR of the Republic of Indonesia in 2023, the charging station must meet the provisions of electricity safety, certificate of operation of the charging station by the engineering inspection agency, and product standard conformity of the charging station by the product certification agency.

The power cost for battery charging is IDR 1,644.5/kWh + service charge, or IDR 714/kWh in bulk for medium voltage. Meanwhile, the battery swap system simply charges battery rental fees for charging and investing[7]. Based on MEMR press release No: 66. Pers/04/SJI/2024 on January 19, 2024 then stated that the development of Public Electric Vehicle Battery Exchange Stations (PEVBES) in Indonesia has taken several significant steps, including the realization and target by the end of 2023 of the construction of Battery-Based Electric Motor Vehicle (BBEMV) infrastructure, which reached 2,704 units with a target of 1,035 units. This indicates that the realization outperformed the objective by 261%[8]. Java Island continues to have the most PEVBES units deployed, with 294 in Banten, 555 in DKI Jakarta, 367 in West Java, 72 in Central Java and DI Yogyakarta, and 217 in East Java, Bali, and Nusa Tenggara. The government and PT. PLN (Persero) continue to fund the construction of PEVBES infrastructure in order to

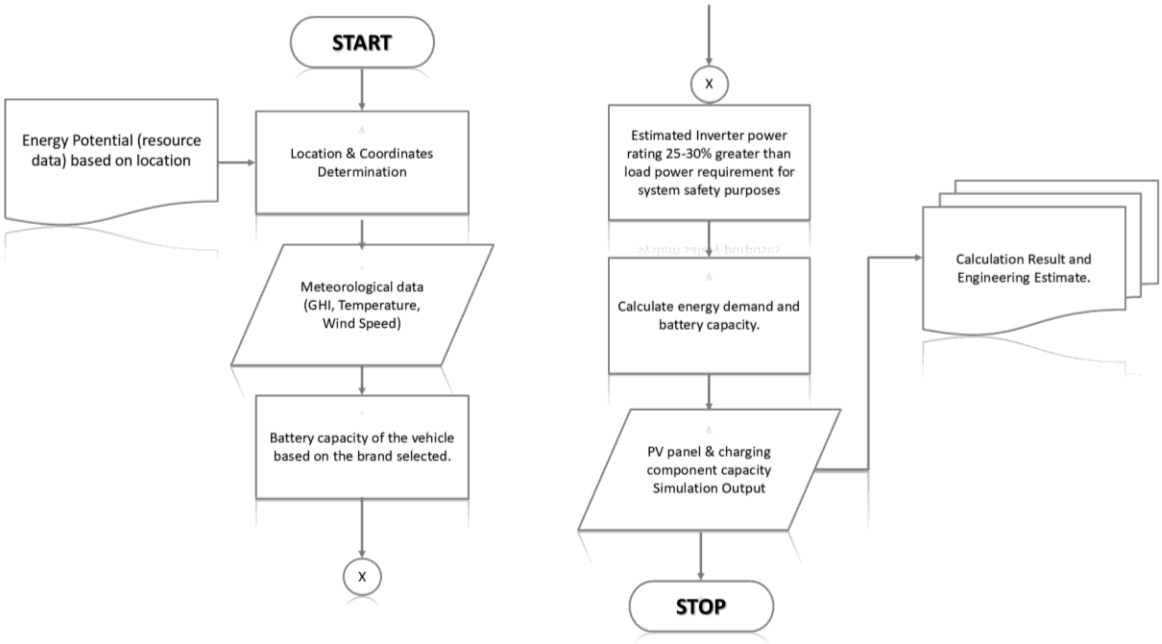

Figure 1. Assessing system design methods

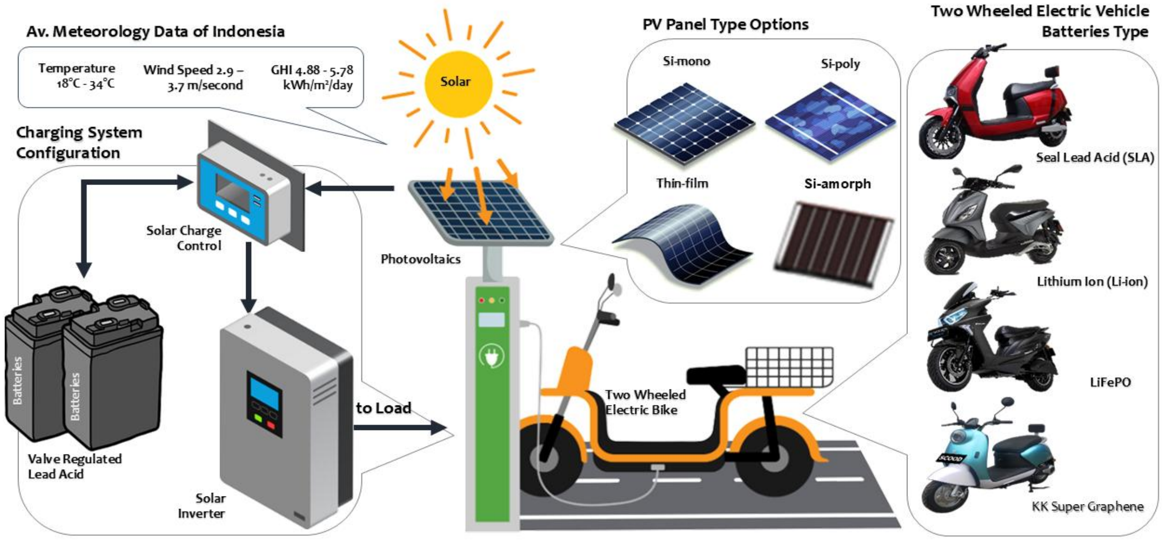

Figure 2. Proposed configuration and design concept of charging station design

expedite the adoption of electric cars in additional cities and make them accessible to everybody[9]. With numerous efforts made by the government and state agencies[10], it is envisaged that the development of PEVBES in Indonesia will continue to accelerate and promote the transition to more environmentally friendly electric vehicles[11], [12]. However, significant challenges occur when considering the user market, which employs electric bicycles as short-distance transportation or simply public utilities in residential areas and tourist destinations[13], [14]. Against this background, the government has paid little attention to the electric bicycle industry, which is typically affordable to the lower middle class, whether for personal or commercial usage. To support this, a proposal for the use of electric bicycles is made utilizing a system derived from solar PV-based renewable energy (RE), which is included in various types of plans and schemes. Furthermore, the benefit and attractiveness of electric two-wheelers is that they provide an ecologically clean and effective mode of transportation. They employ an electric motor attached to a battery, which reduces reliance on fossil fuels and carbon emissions[15], [16]. More efficient batteries enable electric bicycles to travel further on a single charge, making them a viable option for daily commuting. As technology becomes more competitive and installation costs decline, PV systems can be erected on the roofs of charging stations or adjacent structures, while the integration of innovative technologies and effective algorithms continues to advance[17], [18], [19]. The Vehicle-to-Grid (V2G) idea is a revolutionary step forward in the evolution of charging stations. With this method, EVs can help stabilize the grid and earn money for themselves by feeding excess power back into the system when they're not using it. There is a lot of promise for implementing V2G technology in Indonesia, and it has already been deployed in a number of nations, including Denmark[20], [21], [22].

This paper examines a suggested charging system that diverges from the current model in several aspects, mostly regarding the energy source. This method utilizes electric power from solar panels installed at the station as its primary source for charging electric vehicles, whereas the conventional system relies solely on the grid. Secondly, about energy sustainability It is more ecologically sustainable, diminishes reliance on fossil fuels, and has the capacity to lower carbon emissions relative to current systems utilizing fossil energy. The dimension of energy security necessitates consideration of reliance on solar availability. When weather conditions are optimal, the system operates with high efficiency; but, during overcast days or nighttime, efficiency diminishes unless energy storage (battery) is available to utilize accumulated solar energy. This study discusses the selection of PV cell types and the capacity of system components, evaluating several possibilities that remain within the limits of the charging load capacity.

The systematic discussion in this paper begins with an introduction that provides background information and study objectives. The second section is the research method, which includes the basic theory for performing calculations, as well as a description of the proposed solar-PV-based power generation scheme based on the needs of the electric bicycle battery and the capacity of the solar-PV system's components. The third chapter covers the outcomes of the calculations, testing, and modelling performed. Chapter 4 summarizes the test findings and analysis based on the solar-PV generating scenario.

II. Method of Research

Figure 1 illustrates the fundamental phases in the design of a PV-based electric vehicle (EV) charging system. The design process commences with the assessment of the site and the viability of solar energy. Geographical coordinates are crucial for assessing the solar energy potential of a region. Energy potential data, specifically derived from Global Horizontal Irradiance (GHI)[23], assumes the utilization of the GHI standard measured in kWh/m²/day in Indonesia. Determining the battery energy for two-wheeled electric vehicles, assessing the PV panel rating, and evaluating the inverter capacity, ensuring that the inverter capacity exceeds the load power needs to ensure system integrity. Assessment of energy requirements and battery capacity of the charging station according to the chosen electric vehicle; the necessary energy for complete battery recharging will be determined.

This research's construction and the examination of battery-based electric vehicle charging stations utilizing PV technology demonstrate substantial advancement in bolstering the electric vehicle ecosystem, particularly in Indonesia[24], [25]. The rising prevalence of electric vehicles in Indonesia, encompassing both four-wheeled and two-wheeled models, necessitates modifications to renewable-based infrastructure to accommodate traditional electricity sources. The environmental effects and advantages of utilizing PV systems at electric bike charging stations are anticipated to lead to diminished greenhouse gas emissions, enhanced air quality, decreased reliance on fossil fuels, and the promotion of sustainability objectives. Consequently, a proposition in support of this is elaborated upon in the following approach.

A. Potential Energy of Indonesia

Indonesia possesses significant potential for solar energy growth, bolstered by numerous projects and research efforts. Indonesia has a huge total renewable energy capacity 637 MW, and will increase production to 444 GWh by 2022[26]. Indonesia has a huge total renewable energy capacity 637 MW, and will increase production to 444 GWh by 2022[26]. This shows that Indonesia, located on the equator, has high solar radiation, with a Global Horizontal Irradiation (GHI) of around 4.88 until 5.78 kWh/m²/day to higher values depending on specific locations[27]. This figure reflects the country's advantageous conditions for solar energy production, exceeding those of numerous nations recognized for their solar prowess, including Germany and Japan[28],[29]. Indonesia, characterized by elevated GHI values and considerable untapped potential, is at a critical juncture in advancing its solar energy sector. Ongoing investment in solar technology and infrastructure will be crucial for efficiently utilizing this rich resource[30], [31].

B. Design System and Calculation

Figure 2 shows the design of the renewable energy-based electric two-wheeler charger configuration is determined based on several considerations that are explained further in this paper, namely the first is charging station capability. The establishment of EV Charging Stations capable of charging two-wheeled electric bikes with diverse power requirements based on each vehicle's power consumption. The daily power demand in watt-hours (Wh) is determined based on the maximum output of the charger. The EV Charging Station is anticipated to function for 12 hours. Consequently, the power demand may be determined by Equation (1)[32],

$$Daily\ E_{Total}(Wh) = P_{hour}(Wh) \times Op._{hour} \quad (1)$$

The subsequent stage involves calculating the power requirements of the PV panel. The PV panel's capacity can be computed. The equation for determining the necessary PV panel capacity is shown

Table 1. Market Value Customized PV Panel Capacity Options[35]

PV Cell Technology	PV Capacity Option											
	200 Wp				400 Wp				500 Wp			
	I_{mp}	V_{mp}	I_{sc}	V_{oc}	I_{mp}	V_{mp}	I_{sc}	V_{oc}	I_{mp}	V_{mp}	I_{sc}	V_{oc}
Si-mono	10,96	18,24	11,62	21,80	9,82	40,78	10,59	49,55	11,69	42,80	9,90	48,06
Si-poly	5,66	35,40	6,050	44,20	10,81	41,20	11,54	49,00	13,00	40,80	13,8	49,00
Thin Film*	5,50	37,00	6,06	42,00	12,31	42,30	13,50	49,50	13,17	41,01	13,85	49,53
Si-amorph	5,30	42,06	6,00	40,01	12,90	31,01	13,79	37,07	12,98	42,33	13,93	45,12

Notes: *) Capacity determination predicated on availability and online marketplace inquiries; **) Thin film varieties, with the most comparable capacity available, including but not limited to monocrystalline and polycrystalline silicone technology.

Table 2. Various Alternative based on Available VRLA Battery Capacity[36]

Rated Capacity			Batteries Characteristics Parameter			
Voltage (V)	Ampere Hour (Ah)	Power per Hour (Wh)	Max. Charge Current (A)	Max. Discharge Current (A/5 sec)	Cap. At temp. 25°C (77°F)	Internal Resistance (mΩ±10%)
12	7	84	2.1	70	7 Ah*	29.0
12	9	108	2.7	90	9 Ah*	16.5
12	18	216	5.4	180	18 Ah*	15.0
12	40	480	12.0	400	40 Ah**	8.85
12	60	720	18.0	600	60 Ah**	65.0
12	80	960	24.0	24	80 Ah**	6.0
12	100	1200	30.0	30	100 Ah**	5.35
12	120	1440	36.0	36	120 Ah**	4.90
12	150	1800	40.0	40	150 Ah**	3.95

Notes: *) Capacity temperature at 20 hr to 1.75 V/cel; **)10 hr to 1.80V/cel.

in Equation (2). PV panel efficiency refers to the effectiveness with which a panel transforms sunlight into electrical energy. Modern PV panels usually have an efficiency between 15% and 20%.

$$N_{PV} = \frac{Cap_{PV}\ (Wp)}{Cap_{PV_{perPanel}}(Wp)} \tag{2}$$

Determining the number of PV panels is considered after the capacity of the PV panel is known. Each PV panel has a certain capacity, which is usually stated on the panel label (a survey was conducted with the availability in the market), so simply to determine the number of PV panels required. However, what needs to be taken into account in determining the capacity of PV panels is the power demand of the load in (Ed), the oversupply coefficient (fo) between 1.3 and 2 for PV systems, then the average solar radiation ≈ 4.88 kWh/m^2/day, and the product of the battery load coefficient, Solar Charge Control (SCC), and inverter, assuming an ideal value of 80%. follow the following Eq. (3)[33], [34]

$$Cap_{PV}(Wp) = \frac{E_d \times fo}{G \times \eta_{PVSS}} \tag{3}$$

Assessing the appropriate PV panel capacity mostly relies on comprehending your energy requirements, the solar irradiance of the specific site, the efficiency of the PV panel, and additional considerations such as system losses. Through meticulous calculations, one may ascertain that the installed PV panel system adequately meets energy requirements efficiently and sustainably. Following the aforementioned steps and critical factors, the requirement for the Solar Charge Controller (SCC) must be determined inside a solar power generation system (PV system)[37], [38]. The current necessary for the SCC can be determined by utilizing the Isc value of the PV panels and the quantity of panels employed. To determine the total Isc value for many PV panels, multiply the Isc value by the quantity of panels utilized. The existing SCC rating satisfies Eq. (4) by using a system safety coefficient of 1.25.

Table 1 displays different types of solar cell technologies together with various PV panel capacity options. This conveys details regarding the quantity of panels and the applicable rating.

$$Cap_{SCC}(A) = I_{Sc\_PV} \times N_{paralel} \times 1.25 \tag{4}$$

Calculating the SCC requirement involves the specifications of the PV panels and the current required for the system. Adhering to the aforementioned processes will ascertain the appropriate SCC, so guaranteeing the optimal and safe operation of the PV system. Assessing the inverter capacity is a crucial phase in the design of a solar power generating system (PV system), since the inverter functions to convert the direct current (DC) produced by the PV panels into alternating current (AC), suitable for fulfilling the requirements of the charging station. The correct inverter capacity ensures that the solar system can perform optimally and prevent damage to electrical equipment. The derating factor is a significant concern as it leads to diminished efficiency caused by elevated operating temperatures or other operational situations. An inverter does not consistently operate at its maximum capacity. Consequently, to guarantee the inverter operates effectively even under suboptimal situations, the inverter capacity may be modified. The inverter power rating must exceed the load's power need by 25 to 30% for the safety of the PV system, necessitating changes as indicated in Eq. (5).

$$P_{Max}(W) = P_{Tot}(W) + 30\% \tag{5}$$

Table 3. Review of Two-wheeled Electric Vehicle Indonesian's Market Available

Type of Two-wheel EV Sample Market in Indonesia	Battery Two-wheel EV Technology				Capacity (V/Ah)	Charging Cycle	Power (Watt)
	Li-ion	$LiFePO_4$	KK Super Graphene	Seal Lead Acid (SLA)			
RAYA	√	-	-	-	72V/20Ah	1000	1500
EXOTIC BIKE	√	-	-	-	48V/12Ah	1000*	500
FOX - R	-	-	-	-	72V/52Ah	2000	3000
TX-1800	√	-	-	-	60V/28Ah	1000*	2000
Q1L	√	-	-	-	48V/12.8Ah	700	2000
ONE	√	-	-	-	48V/24Ah	800	1800
EX3000	√	-	-	-	72V/24Ah	1000	3000
T1800	√	-	-	-	60V/28Ah	1000*	2000
VITO	-	√	-	-	48V/20Ah	2000	1000
GT- SCOOD	-	-	√	-	48V/20Ah	2000	1500
N9 PRO	-	-	-	√	72V/32Ah	800	2000
VIRGO	√	-	-	-	48V/20Ah	1000	2000
ONE	√	-	-	-	48V/20Ah	1000	4000
G1	√	-	-	-	60V/26Ah	1000	2000
SELIS	-	-	-	√	48V/12Ah	800	1200

Notes: *) Assumes a maximum of 1000 cycles for a Li-ion battery

Table 4. Calculation of Yield of Various PV Capacities

Type of Two-wheeled EV sample Market in Indonesia*	EV Charging Cycle	EV Batt. Capacity (Wh)	Energy Total Daily (kWh) In Hour				PV Capacity (Wp) In Hour				Inverter Capacity (W)
			2 H	4 H	8 H	12 H	2 H	4 H	8 H	12 H	
Q1L	700	614,4	1,2	2,5	4,9	7,4	222	443	886	1330	1728
ONE	800	1152	2,3	4,6	9,2	13,8	415	831	1662	2493	3241
N9 PRO	800	2304	4,6	9,2	18,4	27,6	831	1662	3324	4986	6481
SELIS	800	576	1,2	2,3	4,6	6,9	208	415	831	1246	1620
RAYA	1000	1440	2,9	5,8	11,5	17,3	519	1039	2077	3116	4051
EXOTIC BIKE	1000	576	1,2	2,3	4,6	6,9	208	415	831	1246	1620
TX-1800	1000	1680	3,4	6,7	13,4	20,2	606	1212	2424	3635	4726
EX3000	1000	1728	3,5	6,9	13,8	20,7	623	1246	2493	3739	4861
T1800	1000	1680	3,4	6,7	13,4	20,2	606	1212	2424	3635	4726
VIRGO	1000	960	1,9	3,8	7,7	11,5	346	692	1385	2077	2701
ONE	1000	1152	2,3	4,6	9,2	13,8	415	831	1662	2493	3241
G1	1000	1560	3,1	6,2	12,5	18,7	563	1125	2250	3376	4388
FOX - R	2000	2304	4,6	9,2	18,4	27,6	831	1662	3324	4986	6481
VITO	2000	960	1,9	3,8	7,7	11,5	346	692	1385	2077	2701
GT SCOOD	2000	1392	2,8	5,6	11,1	16,7	502	1004	2008	3012	3916

Notes: *) Vehicles are categorized by charging cycle, starting with the smallest.

Determining the right battery capacity for a PV system is crucial to ensuring that the system can operate efficiently and fulfil energy needs. Assessing the appropriate battery capacity for a PV system is essential for optimizing operational efficiency and meeting energy requirements. The duration (in hours) that the system can function without recharging must be assessed; this period is referred to as autonomy time.

$$C_{Ah}(Ah) = \frac{E_{Tot}(W) + D_{aotonom}}{V_{DC} \times DoD} \qquad (6)$$

According to Eq. (6), the battery cannot be fully utilized; therefore, the charging efficiency must be modified. Furthermore, the battery possesses a Depth of Discharge (DoD) limitation to guarantee its durability[39]. In this instance, lead-acid batteries typically possess a DoD of approximately 50%. Autonomous daytime operation is designated for a 24-hour period to ensure the battery readiness of the charging station system components. This study presents a system design by presenting multiple alternatives for solar cell technologies, system components, battery types in electric two-wheelers, and numerous external battery capacity possibilities. The selection of 24 Volt Valve-Regulated Lead-Acid (VRLA) batteries for PV systems has several strong reasons including minimal maintenance, higher safety (minimal risk of acid and hydrogen gas leakage), relatively affordable prices and a service life of up to 10 years depending on the type of maintenance carried out on the system[40],[41].

See Table 2 for the capacity available of this battery technology. Use Equation (7) to determine how long it will take to charge the battery. In order to arrive at a charging time that is more accurate, we need to take into account the efficiency of the system. The efficiency assumption for the system is 80%, which takes into account both the efficiency of the charge controller and the energy loss[42].

$$Charg\_time(h) = \frac{Batt._{Cap}\,(Wh)}{PV_{Cap} \times GHI \times 0.8} \qquad (7)$$

In this case, it takes time (hours) to fully charge the battery of a two-wheeled electric vehicle of various capacities (Wh) using different types and numbers of Wp panels with a minimum average of 4.88 kwh/m^2/day in peak sunshine hours per day and a system efficiency of 80%. Consider that the time may vary depending on weather conditions, and other factors that may affect charging efficiency.

III. Results and Discussion

In Indonesia, two-wheeled electric are becoming increasingly varied, providing a multitude of possibilities to meet user requirements (refer to Table 4). Due to government subsidies making them more affordable and the convenience of home charging, electric bicycles present an appealing option for environmentally conscious individuals seeking efficient transportation solutions, particularly in residential areas or for short distances.

Table 3 presents details regarding the diverse electric two-wheeler alternatives in the Indonesian market, together with the fundamental characteristics of the batteries. Various technologies for two-wheeled electric vehicle batteries are determined by the selected sample type. While predominantly utilizing Li-ion technology, some additionally employ SLA and Lithium Iron Phosphate ($LiFePO_4$). Li-ion exhibits a high energy storage capacity and superior energy density compared to SLA. According to manufacturer claims, $LiFePO_4$ offers a lifespan of up to 2000 charge cycles, and both technologies provide rapid charging. KK Super Graphene lacks a widely accepted formal acronym. The designation 'KK' pertains to the battery manufacturer, whilst 'Super Graphene' denotes a battery technology that employs graphene material to enhance battery efficiency and performance. The charging cycle of a two-wheeled electric vehicle battery has numerous critical steps that must be adhered to in order to guarantee the battery's longevity and optimal performance. Utilizing the appropriate charging technique and routinely assessing the battery's state helps optimize the efficiency and longevity of their energy storage system.

Table 4 illustrates the battery charging cycle, wherein certain Li-ion batteries are presumed to have a lifespan of 1000 cycles, as this information is not indicated on the nameplate. The description of each column in Table 4 includes the type of two-wheeled electric vehicle that is being sampled for analysis. The charging cycle, which indicates how many times a day the vehicle needs to be charged. Battery capacity, which is calculated as the capacity of energy that can be stored in the battery of the two-wheeled electric vehicle. Total daily energy is the amount of energy the vehicle needs in one day to operate. PV Capacity (Wp) in hours shows the capacity of the PV panels needed to produce enough energy in 2, 4, 8, and 12 hours and the inverter capacity needed to be used by the vehicle when charging. This table displays the yield calculation data for different PV panel capacities used to charge several models of two-wheeled electric vehicles in the Indonesian market. The observed comparison is between battery capacity and the energy needed; a larger bike battery capacity necessitates more energy for a complete charge. The charging cycle demonstrates a comparable correlation: the more frequently the EV is charged daily, the bigger the solar panel capacity needed. The variation in PV panel requirements for each two-wheeled electric vehicle indicates that each vehicle type possesses distinct energy demands, necessitating varied solar panel capacities. Extended charge durations enable the utilization of PV panels with reduced capacities, while the inverter's capacity is engineered to sufficiently handle the output power of the PV panels inside the charging station system.

Table 5 presents findings on the association among electric vehicle battery capacity, the requisite number of solar panels, and the necessary charging duration. This data is essential for the development of electric two-wheeled charging infrastructure, particularly that which is PV-based. This table enumerates the various categories of electric bikes prevalent in the Indonesian market, together with the energy storage capacity of each vehicle's battery, quantified in Watt-hours (Wh). The calculation results for the number of solar panels needed to charge the two-wheeled, considering three panel capacities (200 Wp, 400 Wp, and 500 Wp), where this figure represents the maximum power that the solar panels can create under specific conditions. The analysis yielded many inverter capacity alternatives and the duration necessary to completely charge the EV battery using different configurations of solar panels and inverters. The analysis of the table's findings indicates a robust positive link between the vehicle's battery capacity and the requisite number of solar panels. A greater battery capacity necessitates an increased number of PV panels to achieve charging within the same duration. The capacity of solar panels directly influences charging time, as panels with greater capacity substantially decrease the duration required for charging. The use of 500 Wp PV panels would diminish the charging duration by fifty percent or greater in comparison to 400 Wp and 200 Wp PV panels. The capacity of the inverter also influences the charging duration. A higher-capacity inverter helps expedite energy transfer from the solar panels to the batteries. Charging duration differs markedly among EV kinds, even when utilising identical solar panel and inverter setups. This indicates that charging efficiency is influenced by other elements, including battery type, battery management system, and ambient conditions, which must be considered. The implications and recommendations derived from the calculation results indicate that this data can facilitate the planning of an effective electric bike charging infrastructure. The quantity of solar panels needed and the requisite charging duration enable the determination of the solar power generating capacity necessary at the charging station.

Table 5. Quantity of PV Panel and Charging of Time Calculation Result

Type of Two-wheeled EV sample Market in Indonesia	EV Battery Capacity (Wh)	PV Panel Quantity (Wp per Unit)			Inverter Cap. (W)	Charging Time (Wp in Hour)		
		200	400	500		200	400	500
Q1L	614,4	7	3	3	1728	0,8	0,4	0,3
One	1152	12	6	5	3241	1,5	0,7	0,6
N9 Pro	2304	25	12	10	6481	3,0	1,5	1,2
Selis	576	6	3	2	1620	0,7	0,4	0,3
Raya	1440	16	8	6	4051	1,8	0,9	0,7
Exotic Bike	576	6	3	2	1620	0,7	0,4	0,3
TX-1800	1680	18	9	7	4726	2,2	1,1	0,9
EX3000	1728	19	9	7	4861	2,2	1,1	0,9
T1800	1680	18	9	7	4726	2,2	1,1	0,9
Virgo	960	10	5	4	2701	1,2	0,6	0,5
One	1152	12	6	5	3241	1,5	0,7	0,6
G1	1560	17	8	7	4388	2,0	1,0	0,8
Fox - R	2304	25	12	10	6481	3,0	1,5	1,2
Vito	960	10	5	4	2701	1,2	0,6	0,5
GT Scood	1392	15	8	6	3916	1,8	0,9	0,7

Choosing the appropriate solar panel and inverter is essential for optimising charging efficiency. High-efficiency solar panels and inverters with superior conversion power will decrease charging duration. The advancement of batteries with increased capacity and more efficiency will allow electric vehicles to cover greater distances with reduced charge durations.

Table 6 presents the results of the computation and comparison of battery capacity for different autonomy durations. This chart displays statistics on the battery capacity necessary for various types of two-wheeled electric vehicles in Indonesia, categorized by different autonomy durations (1 to 4 days). This data offers critical insights into battery capacity needs to guarantee the vehicle operates without recharging for the specified duration. The capacity of batteries for electric vehicles (WH) ranges from 576 WH to 2304 WH, contingent upon the vehicle type and specifications. The column regarding battery capacity for photovoltaic charging systems indicates that this information is derived from the vehicle's battery capacity and the required autonomy days. The longer the desired autonomy days, the bigger the battery capacity needed for the photovoltaic charging system. The data indicates a notable enhancement in capability corresponding to the rise in days of autonomy. The comparison of battery capacities indicates that electric vehicle models with the highest battery capacity (N9 PRO and FOX-R) need correspondingly larger photovoltaic charging system battery capacities. This is logical, as automobiles with substantial battery capacity need increased energy for recharging. The impact of autonomous days significantly affects the battery capacity needed for the photovoltaic charging system. Increased autonomy days necessitate a higher battery capacity. The energy requirements for electric vehicles are contingent not only upon the vehicle's battery capacity but also on its operational demands. This table offers valuable insights for designers and manufacturers of electric car charging infrastructure, particularly those employing solar energy. This data serves as a reference for establishing the suitable battery capacity for photovoltaic charging systems to satisfy the operating requirements of electric cars based on the required autonomy duration.

Table 7 illustrates the correlation between I_{SC} and SCC capacity, as computed in equation (4). A higher short-circuit current (I_{SC}) of a PV panel necessitates a greater capacity charge controller to regulate the current effectively. The impact of PV cell type varies, as each variety exhibits distinct short-circuit current characteristics. Monocrystalline silicon PV cell technology often exhibits a greater short-circuit current than thin PV cells. The investigation indicates that various capacities of SCC are readily available in the market. 10A and 20A SCCs may be employed based on the calculations presented in Table VII. This SCC system operates at 12V/24V and has features such as off-grid capability, an LCD monitor, and a USB connector for mobile device charging. Price fluctuations are contingent upon the brand and other features offered. In actuality, while larger SCCs can effectively manage current, improper organization may result in the wastage of energy provided by solar panels if the SCC is not engineered for optimal energy utilization. Utilizing an SCC with a capacity exceeding the short circuit current of the solar panel often enhances safety and charging efficiency. It is crucial to ensure that the system is comprehensively designed for optimal and harmonious functionality of all components. Examine the duration of a vehicle battery's use by evaluating key indications of battery performance. This duration is affected by several factors, including internal ones such as the vehicle's battery capacity (Wh). The battery's energy storage capacity indicates that a higher capacity results in extended usage time or distance travelled, which is directly related to the charging duration. An additional deciding element is the capacity of the planned photovoltaic panel (Wp) to meet the vehicles battery's energy requirements (kWh). Another internal element is battery efficiency, which denotes the effectiveness of the battery in storing and discharging energy throughout the EV charging process. An efficient battery will exhibit a longer discharge duration compared to a less efficient battery; nevertheless, this metric is not specified on the battery nameplate of each

Table 6. Calculation of Battery System Capacities in Various Autonomy Days

Type of Two-wheeled EV sample Market in Indonesia*	EV Batt. Capacity (Wh)	Autonomy Day using VRLA Battery*							
		Battery for PV Charging System Capacity (Ah)				Battery for PV Charging System Capacity (Wh)			
		1 Day	2 Day	3 Day	4 Day	1 Day	2 Day	3 Day	4 Day
Q1L	614,4	32,1	32,1	32,2	32,2	769,25	770,5	771,75	773
ONE	1152	60,1	60,1	60,2	60,2	1441,25	1442,5	1443,75	1445
N9 PRO	2304	120,1	120,1	120,2	120,2	2881,25	2882,5	2883,75	2885
SELIS	576	30,1	30,1	30,2	30,2	721,25	722,5	723,75	725
RAYA	1440	75,1	75,1	75,2	75,2	1801,25	1802,5	1803,75	1805
EXOTIC BIKE	576	30,1	30,1	30,2	30,2	721,25	722,5	723,75	725
TX-1800	1680	87,6	87,6	87,7	87,7	2101,25	2102,5	2103,75	2105
EX3000	1728	90,1	90,1	90,2	90,2	2161,25	2162,5	2163,75	2165
T1800	1680	87,6	87,6	87,7	87,7	2101,25	2102,5	2103,75	2105
VIRGO	960	50,1	50,1	50,2	50,2	1201,25	1202,5	1203,75	1205
ONE	1152	60,1	60,1	60,2	60,2	1441,25	1442,5	1443,75	1445
G1	1560	81,3	81,4	81,4	81,5	1951,25	1952,5	1953,75	1955
FOX - R	2304	120,1	120,1	120,2	120,2	2881,25	2882,5	2883,75	2885
VITO	960	50,1	50,1	50,2	50,2	1201,25	1202,5	1203,75	1205
GT SCOOD	1392	72,6	72,6	72,7	72,7	1741,25	1742,5	1743,75	1745

Notes: *) See proposed in Fig. 2 to ascertain the column (Wh) by multiplying (Ah) by the stated VRLA Batt. (24 V) in this study.

Table 7. Calculation of Yield of Various PV Capacities

PV Cell Technology	**Short Circuit Current (I_{SC}) (A/Wp)**			**SCC Capacity (I) (A/Wp)**		
	200	**400**	**200**	**400**	**200**	**400**
Si-mono	11,62	10,59	9,90	15	13	12
Si-poly*	6,050	11,54	13,8	8	14	17
Thin Film	6,06	13,50	13,85	8	17	17
Si-amorph	6,00	13,79	13,93	8	17	17

brand and type, nor by the manufacturer of the electric vehicle.

IV. CONCLUSION

In general, there is a positive relationship between battery capacity and the number of PV panels. That is, the larger the battery capacity, the more solar panels can be used. The type of PV panel (200 Wp, 400 Wp, 500 Wp) also affects the number of PV panels required for a given battery capacity. Panels with greater power generally require fewer panel units to achieve the same battery capacity. The number of PV panels required does not always increase linearly as the battery capacity increases. There are fluctuations that may be caused by other factors such as panel efficiency, environmental conditions, and system design.

System planning in this paper helps in designing a solar power system by selecting a suitable combination of PV panels and batteries according to the energy requirement as well as comparing the performance of different types of solar panels under the same conditions. It helps to estimate the cost by selecting the most cost-efficient combination to achieve the desired energy storage capacity.

The comparison among these three types of PV panels indicates that the 200 Wp panel necessitates the longest charging duration. It necessitates minimal power consumption and does not demand extended charge durations. The 400 Wp panel charges more rapidly than the 200 Wp panel, although it remains slower than the 500 Wp panel. It is categorized as a moderately powered charging station. A 500 Wp PV panel (or a panel with more capacity) exhibits the most rapid charging time among the three types of panels. It is appropriate for applications with substantial power demands and necessitates rapid charging times.

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