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Power Requirement and Cost Analysis of Electric Bus using Simulation Method with RCAVe-EV1 Software and GPS Data; A Case Study of Greater Jakarta

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Abstract. Electric vehicles' power requirement and cost analysis require consideration in terms of their usage load and mileage. It is due to the unique character of the charging energy compared to internal combustion vehicles. The motor capacity and mileage will affect the vehicle's weight, especially the battery. If the battery is excessively big, it will affect passenger space. In comparison, buses with diesel engines are generally designed for long distances and rough roads. If used in the city, with relatively gentle road types, the engine will tend to be over-specification. This research aims to design the bus power requirements according to road conditions. The method is theoretical and simulated with specific GPS data. In this case, the bus power is designed for the city's needs, with a case study of battery electric buses (BEBs) for the route of the city of Jakarta and its surroundings, namely Bogor, Depok, Tangerang, and Bekasi. In addition, an economic study will also be a part of this research. Bus companies need this study to decide on the procurement and use of an electric bus fleet. The simulation results show that the power and battery capacity of inner-city buses need not be as large as inter-city buses. A bus with a motor power rating of 100 kW and batteries with a total of 200 kWh is very appropriate to carry 85 passengers over a distance of 200 km on one charge. Moreover, with proper incentives from the government, the price of electric inner-city buses is very competitive. It has the advantage of having a service life of more than ten years.

Keywords: BEBs; Cost analysis; Electric bus fleet; EV; Power requirement

1. Introduction

Because decision-makers depend on the findings, bus fleet design is fascinating for researchers. Inner buses have become one of the targets to be used as electric buses because the population in the city is expected to replace many private vehicles. Inner buses can achieve the target of clean air in the city and town to become comfortable to live in or become a place for healthy activities (Adheesh et al., 2016). However, the transition from the diesel bus era to the electric bus was not free from problems. It has been discussed and

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described in research conducted in Italy (Pelletier et al., 2019). The discussion of this bus design is generally to overcome the time required for charging the battery. The fast-charging strategy is one option, but a short stop time is not enough for the fast charger to charge the battery adequately. Other strategies, such as swapping, are also possible alternatives, although later infrastructure will be needed, especially for buses' battery withdrawal mechanism and installation. In the end of it is the costs of charging station infrastructure. The results suggest:

- The service frequency, circulation length, and operating speed of a transit system;
- Charging lanes enabled by currently available inductive wireless charging technology;
- Swapping stations;
- Charging stations are cost-competitive only for transit systems with shallow service frequency and short circulation; and
- Reduce their unit-length construction cost or enhance their charging power (Chen et al., 2018).

Fast charging is a good solution, but it requires charging station infrastructure and good battery life (Ding et al., 2015). The wireless charging method has also been developed to reduce the plug-in and plug-out time of the charger cable. This induction charging requires environmental conditions and the precision of the bus position when at the bus stop or charging station (Bi et al., 2015). Uncertainty in demand and bus utility must be addressed. It is much more complex than handling buses with diesel engines, where these buses do not have much problem with the distance and the presence of a gas station. However, bus lanes must be appropriately designed on electric buses, and drivers must be disciplined to pass through predetermined routes. Otherwise, the risk of running out of energy and not finding a charging station and a long queue of charging stations will be a big problem (Teoh et al., 2018). Again, the battery must be considered in the design of the charging station infrastructure. The deployment of charging infrastructures and the number of standby buses available significantly affect the operational efficiency of electric bus systems. This work has developed a stochastic integer program to jointly optimize charging station locations and bus fleet size under random bus charging demand, considering time-of-use electricity tariffs (An, 2020).

The mileage concern was also overcome by the design of the hybrid bus. Thus, there are two types of propulsion on the bus. It is not much different from creating a small hybrid vehicle or sedan. With this design, the mileage becomes more flexible. However, the targets for obtaining energy and a cleaner environment have not been achieved. Thus, the hybrid bus is not the best solution in this case. This research was carried out at the beginning of the era of electric vehicles being touted (Xiong et al., 2009). For particular needs, hybrid buses may be needed. Therefore, research on this matter also remains strategic. Optimizing energy use on hybrid buses is done by creating a dynamic power management program (Peng et al., 2017).

Research with a case study in Penghu seeks to reduce the construction costs of plug-in electric buses. In this study, extensive analysis has been done on every facet of expenses deemed significant. Vehicle scheduling and vehicle route planning are options for solving cost problems. The optimized parameters involved the hourly residual battery capacity and battery charging times during the daytime operating hours. The results showed that although daytime charging involved electricity uses during peak hours and thus incurred additional costs, it contributed to the use of e-buses and an overall reduction in construction costs.

In summary, the proposed optimization method would successfully reduce the construction cost of the Penghu e-bus transportation system (Ke et al., 2016). The studies mentioned above were conducted when buses were already available. The results of these studies are needed to complete the bus design to be made.

In this study, a bus will be planned according to the route taken, namely the inner city of Jakarta. The data or conclusions from this research are expected to be the basis for making an appropriate electric bus. In general, on electric buses, the powers for power steering and compressed air are generated from a separate electric motor. These powers are obtained from the crankshaft rotation on buses with diesel engines. Research to electrify bus brakes is also carried out to simplify control and reduce losses (Budiono et al., 2020; Nugraha et al., 2021; Nazaruddin et al., 2020). The type and number of transmission acceleration levels are also necessary because, without a gearbox, the power and torque losses will be very significant (Rahman et al., 2022). Meanwhile, small electric car planning with the help of GPS and software is carried out to minimize trial and error in determining the main motor and the number of batteries (Sumarsono et al., 2021).

The challenge of this research are:

- The low population of electric buses in Jakarta or Indonesia. So, data collection requires a unique strategy;
- the absence of regulations regarding electric buses makes the problem boundaries must be processed so that they are not too broad;
- the procurement of buses must be based on planning according to the needs and conditions in the field.

With this fact, this research offers a solution for designing motor and battery power needs with a combination strategy of theoretical examination and simulation with GPS data and mechanical properties. The target is to develop a bus that fits the needs of the route with a little trial and error. It also proves the usefulness and importance of the RCAVe-EV1 software designed by the University of Indonesia.

2. Methods

The method used in designing the bus power requirements is theoretical calculations and, combined with specific empirical data, the vehicle route using GPS. Meanwhile, the bus operational costs were obtained from interviews with related parties, one of Jakarta's largest bus operators.

A calculation involving several resistance parameters is required to determine the power of the primary motor. These parameters are inertial forces (R_i), aerodynamic drag (R_a), gradient or incline angle (R_g), and rolling resistances (R_{rl}).

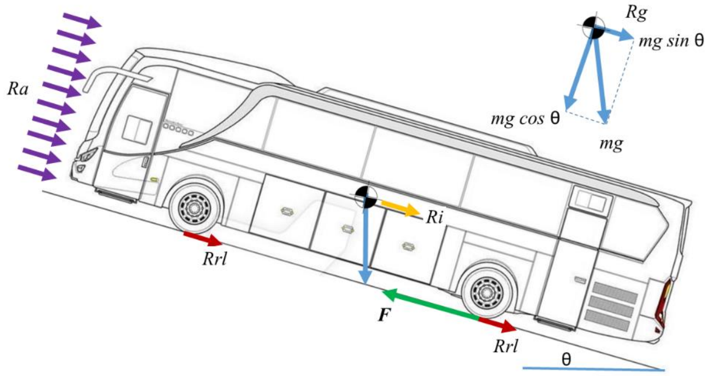

Figure 1 Force and resistance in a bus

After the resistance forces are known, the calculation of the power required by the vehicle can be determined by the following formula:

$$Po = \left(m\,a + \frac{1}{2}\rho\, C_d\, A_f\, v^2 + f_{rl}\, m\, g \cos\theta + m\, g \sin\theta\right).v \quad (1)$$

Where:

Po	= *Required motor power (Watt)*	*Af*	= *Frontal area (m^2)*
m	= *Mass of vehicle and its load (kg)*	*v*	= *Velocity (m/s)*
a	= *Acceleration (m/s^2)*	f_{rl}	= *Rolling coefficient*
ρ	= *Density of air (kg/m^3)*	*g*	= *Gravity (m/s^2)*
C_d	= *Drag coefficient*	*θ*	= *Gradient of slope (^{o})*

Formula (1) is one of the foundations of running the RCAVe-EV1. It shows that acceleration is a crucial parameter in determining the ability of an electric motor or engine.

If the power already exists or is set, the maximum acceleration (a_{max}) to reach a certain speed can be calculated by the formula (2).

$$a_{max}(ms^{-2}) = \left(\frac{\frac{P_o}{v} - \frac{1}{2}\rho C_d A_f v^2}{m}\right) - g(f_r \cos\theta - \sin\theta) \quad (2)$$

In general, if an electric motor is to be used in an electric vehicle, it is necessary to consider the plans and functions of the car. For example, buses for passengers or transport require ample torque and do not require high speed or acceleration.

Data recording with GPS is crucial to complete vehicle performance scrutiny. The primary data are vehicle speed and gradient. One of the software that can acquire GPS data is Geo Tracker .

Another GPS software, STRAVA, was also used to compare the validity of GPS data. Athletes often use this software for running, cycling, and others. Apart from software for GPS data acquisition, other software is used to validate and correct elevation data. The software is available online, namely GPS Visualizer. When the Geo Tracker and Strava data were compared with the GPS visualizer, there was the fact that the deviation of the Strava elevation was the smallest and most logical. Thus, a decision is to use data from Strava.

Data from the power analyzer or other GPS software can be processed with confident handling. Data processing with spreadsheet software is ideal. GPS data must be converted into distance, speed, time, and derivatives. One of them is the ***Haversine*** method (formula 3). The distance between two points (d) is expressed as:

$$d = 2r \sin^{-1}\left(\sqrt{sin^2\left(\frac{\theta_2 - \theta_1}{2}\right) + \cos\theta_1 \cos\theta_2\, sin^2\left(\frac{\lambda_2 - \lambda_1}{2}\right)}\right) \quad (3)$$

Another way is the ***Euclidean*** method (formula 4). This method is to measure the distance between two points on a plane.

$$n = k.\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad (4)$$

Where:

d or n	= *Distance (m)*	*r or k*	= *Radius of earth (m)*
θ_2 *or* x_2	= *Latitude*$_2$	θ_1 *or* x_1	= *Latitude*$_1$
λ_2 *or* y_2	= *Longitude*$_2$	λ_1 *or* y_1	= *Longitude*$_1$

3. Results and Discussion

3.1. Conventional Bus Cost Calculation, Travel Route Profile Measurement, and Electric Bus Cost Calculation

The shift from conventional to electric buses is undoubtedly inseparable from economic studies. Therefore, this research will generally explain how much the operational costs of the ICE bus within the city will be.

According to data from Transjakarta, the average bus cruising target per day is 237 km/day. It operates for 19 hours. Under DKI Regional Regulation no. 5 of 2014, the maximum age of bus use is ten years. The purchase price for a new bus is between 1.8M to 2.2M for a 12m bus class (Table 1).

High operational costs include maintenance costs, fuel costs, and driver wages. The local government subsidizes the fare charged to passengers. With around 3500 fleets owned by Transjakarta, studying operational cost savings, especially fuel costs, is very strategic. Therefore, the use of electric buses is the right and strategic solution.

Table 1 Transjakarta Conventional Bus Costs Planning

No.	Item	Diesel Bus AAA	Diesel Bus BBB	
1	Type	12	12	meter
2	Bus price	1,800,000,000.00	2,200,000,000.00	Rupiah (appx.)
3	Gross weight	7,000.00	7,000.00	kg
4	Passenger capacity	85.00	85.00	person
5	Mileage per day	237.00	237.00	km
6	Maintenance Cost	2,100.00	3,500.00	Rupiah/km
7	Fuel Efficiency	2.50	2.50	km/litre
8	Fuel price	5,150.00	5,150.00	Biodiesel/litre
9	Fuel cost	2,060.00	2,060.00	Rupiah/km
10	Bus lifetime (Regulation)	10.00	10.00	year
11	Utility	95%	95%	total
12	Operation time	19.00	19.00	Hour/day

In addition to economic studies, the author also tested the profile of Transjakarta buses on the Blok M to Raden Inten route and vice versa. The one-way distance of the course is about 30 km, taken in about 2 hours. Data were acquired using two GPS software, i.e., Geo Tracker and STRAVA (Figure 2).

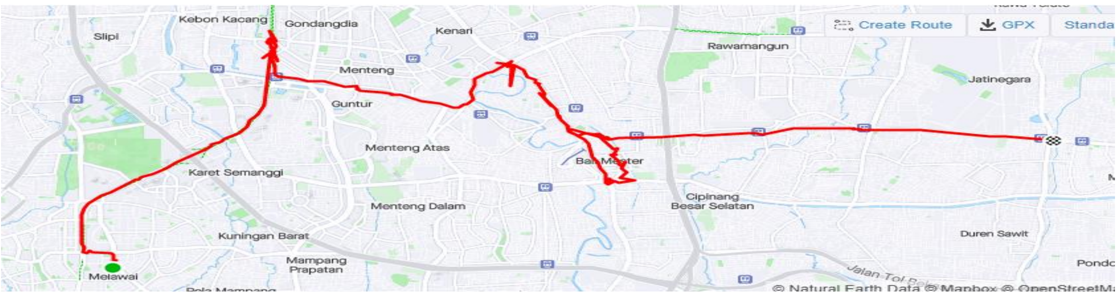

Figure 2 Transjakarta Bus Route Blok M to Raden Inten

The test results show that the travel route is classified as sloping. The average speed of the bus in the city was plodding. A distance of 30 km is covered in about 2 hours, or an average rate of 15 km/hour.

This data is beneficial as a basis for determining the power capacity of electric bus motors and batteries. From the two GPS software data, it can be seen that there is a difference or deviation in the road elevation readings. Therefore, other software is used as a validator to get the most accurate data. In this case, the GPS Visualizer is used (Figure 3).

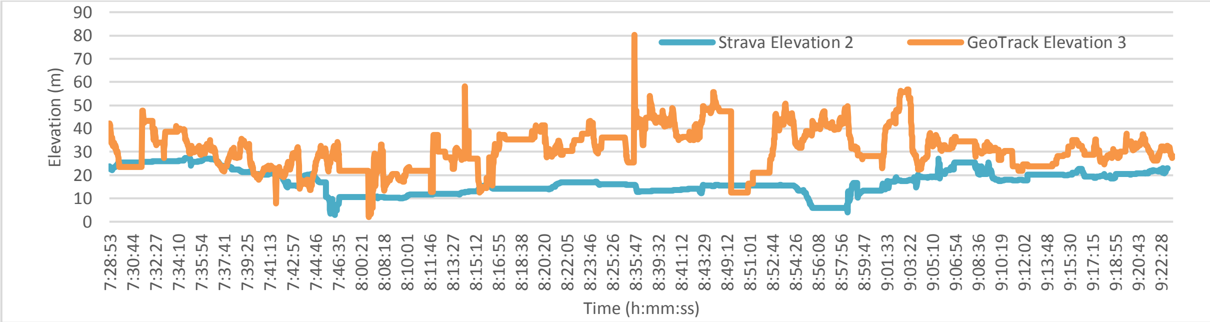

Figure 3 Elevation of Transjakarta Bus line Blok M – Raden Inten

From the evaluation of operational cost data for Transjakarta conventional buses, we can see that the energy costs incurred in one year are between 539 million and 700 million rupiahs. The fuel cost is Rp.2,000/km. Meanwhile, maintenance costs are between Rp 2,100/km to Rp 3,500/km. Those costs will change if you use the electric bus (Table 2).

Table 2 Conventional Bus Operating Cost

No.	Item	Bus AAA	Bus BBB	Remark
1	Depreciation cost	180,000,000.00	220,000,000.00	Rp/year
		93,150.68	602,739.73	Rp/day
2	Energy cost	178,200,300.00	178,200,300.00	Rp/year
		88,220.00	488,220.00	Rp/day
3	Maintenance cost	181,660,500.00	302,767,500.00	Rp/year
		97,700.00	29,500.00	Rp/day
	Total cost	1,479,070.68	1,920,459.73	Rp/day
		539,860,800.00	700,967,800.00	Rp/year

From several references, by simulation, the energy requirement of a 12 m electric bus is around 0.9 kWh/km to 1.6 kWh/km. Moreover, the 18 m bus is 1.7 kWh/km to 2.4 kWh/km (Al-Ogaili et al., 2020). As for the real-world test, in the minimum load scenario, the 12-m bus achieves 138 kWh/100 km to 175 kWh/100 km or 1.38 kWh/km to 1.75 kWh/km. However, when the air conditioning and load are at their maximum values, the energy consumption increases by 21% to 27% (Zhou et al., 2016).

If the electricity price/kWh in Indonesia is Rp. 1,114, the energy cost of electric buses is around Rp. 1,300/km. This cost is cheaper than the energy costs of conventional buses (Table 3). However, the still high investment cost of electric buses makes the operational costs of electric buses less than traditional buses.

Table 3 Estimated Operational Cost of Electric Buses in Transjakarta

No.	Item	Value	Remark
1	Type	12.00	meter
2	Bus price (appx.)	3,500,000,000.00	Rupiah
3	Gross weight	7,000.00	kg
4	Passenger capacity	85	person
5	Mileage per day	237.00	km
6	Maintenance Cost	2,100.00	Rupiah/km
7	Electric energy consumption	1.15	kWh/km
8	Electric energy price	1,114.74	Rp/kWh (P3/TM)
9	Electric energy cost	1,281.95	Rupiah/km
10	Bus lifetime (DKI Regional Regulation no. 5 of 2014)	10.00	year
11	Utility	95%	total
12	Operation time	19.00	Hour/day

With the increasing population and electric bus manufacturers, it is expected that the selling price of buses will be more competitive. One of the highest costs of an electric vehicle/electric bus is the battery (Table 4). Therefore, determining the correct number of batteries, the suitable motor, and devices on the bus will make the vehicle's weight and electricity consumption more efficient.

The passion for cleaner air goes hand in hand with the development of electric buses. The regulation of ten years of service life for conventional buses can be added to 15 years for electric buses.

Table 4 Estimated Annual Cost of An Electric Bus in Transjakarta

No.	Item	Value	Remark
1	Depreciation cost	350,000,000.00	per year
2	Energy cost	110,895,171.26	per year
3	Maintenance cost	181,660,500.00	per year
	Total cost	1,760,426.50	per day
		642,555,671.26	per year

3.2. Electric Bus Technical Specification Calculation

The electric motor's load is affected by the speed in electric buses, while usage patterns and time influence the motor compressor, power steering, and air conditioning.

Therefore:

$$w_{(t)} = P_m.\frac{\Delta s}{\Delta v} + \left(P_c + P_{ps} + P_{AC} + P_{acc}\right).\Delta t \qquad (5)$$

Where:

$W_{(t)}$	= *Electric vehicle power (w)*	P_{ps}	= *Power steering power (watt)*
P_m	= *Main motor power (watt)*	P_{AC}	= *Air conditioner power (watt)*
P_c	= *Compressed air power (watt)*	P_{acc}	= *Accessories power (watt)*

The 12 m bus type is designed with a passenger capacity of up to 85 people for the inner-city bus. The maximum speed is set at 120 km/h with the ability to climb around 22^o (Table 5).

Aerodynamic resistance, rolling coefficient, and vehicle weight result from assumptions. The vehicle's mass is set at 15500 kg. Rolling coefficient assuming the wheels (tires) are on the asphalt road with a value of 0.012. Wind resistance from the front with a drag coefficient of 0.533 and the assumption of a cross-sectional area of 7.8 m^2 (Table 6).

Table 5 Bus Character

Properties		
Maximum Speed	120	km/hour
Gradient	40.3	Tangent (%)
Tire diameter (cm)	104	11R22.5 148/145
Tire circumference	3.27	m
Motor P max	200	kW
Motor N max	3000	rpm
Motor rpm limits	90%	
System Efficiency	95%	

Table 6 Mechanical Properties

Mechanical Properties		
m	15500	kg
f_{rl}	0.012	
g	9.81	m/s^2
Cd	0.533	
A_f	7.8	m^2
rho	1.2	kg/m^3

With the existing transmission, differential ratios, and the maximum motor rotation of 2700 rpm, the bus speed data is obtained at each gear position. The total vehicle ratio in the

1st gear is 1:35, and in the 6th gear, it is almost 1:4. In the 5th gear, the vehicle's speed can reach 108 km/h. While in the 6th gear, it is limited to 120 km/h (Table 7).

Table 7 Testing Gear Ratio

Gear Ratio		Total Ratio	Motor Speed (RPM)	Wheel Speed (km/h)	Wheel Speed (RPM)
1st	7.305	35.612	2700.0	14.86	76
2nd	4.736	23.088	2700.0	22.93	117
3rd	2.738	13.348	2700.0	39.65	202
4th	1.651	8.049	2700.0	65.76	335
5th	1.000	4.875	2700.0	108.57	554
6th	0.787	3.837	2348.5	120.00	612
Reverse	7.839				
Final Gear	4.875				

Bus speed in the city is limited to 50 km/h and 70 km/h on highways. Thus, the most widely used transmission is the first to fourth position. However, two-speed transference can be a good choice, especially in an automatic manual transmission (AMT) that fits a large vehicle like a bus (Jun-Qiang et al., 2008).

After inputing all the design parameters, the result is that the energy consumption per km for this condition is 1.02 kWh.

3.3. Motor and battery determination

The main parameters used to determine the motors are power and torque. In the simulation, by deciding on the electric motor with a peak power of 200 kW, data obtained that the torque required is between 700 to 800 Nm. The battery capacity is calculated by setting the distance traveled in one charge. For example, if it is assumed that the energy requirement of the bus is 1.15 kWh/km, and the distance traveled per day is 250 km, then the energy requirement is 287.5 kWh.

The next step is to determine the battery voltage. One of the considerations is the voltage range of the maximum electrical loads. For example, if the motors have a working voltage range of 250 to 400 volts, then a 400-volt battery circuit can be considered. Higher battery voltages, for example 600 volts, can be used with one consideration reducing cable load. With 400 volts, the total hourly battery current required is about 720 Ah.

Table 8 Energy and Torque Requirement

Gear Position	Max. Acceleration (m/s^2)	Inertia (N)	Aerodynamics (N)	Friction (N)	Gradient (N)	Total Force (N)	Power (kW)	Energy (kWh)	Torque Requirements on Wheels (Nm)	Torque on the motor (Nm)
1	2.849	44153.48	42.50	1824.66	0.00	165.702.16	200.00	0.23	25.179.97	707.07
2	1.801	29710.47	101.12	1824.66	0.00	107.790.78	200.00	0.36	16.324.76	707.07
3	0.976	15121.88	302.54	1824.66	0.00	62.112.20	200.00	0.61	9.437.75	707.07
4	0.500	7744.38	832.07	1824.66	0.00	37.531.73	200.00	1.02	5.690.91	707.07
5	0.142	2207.17	2268.05	1824.66	0.00	22.692.71	200.00	1.68	3.446.95	707.07
6	0.071	1104.78	2770.56	1824.66	0.00	20.560.22	200.00	1.85	3.188.73	812.88

Meanwhile, 600 volts takes a battery hour current of about 480 Ah. The voltage and current hour data determine the number of packs and the series or parallel battery circuit scheme. It must be noted that this capacity does not consider other electrical loads. For example, if the battery is 3.2 volts and 120 Ah per cell, than 752 cell batteries are needed. The configuration is 180S and 4P.

4. Conclusions

Strava GPS data, RCAVe-EV1 software, and additional data from the interviews were beneficial and provided data and conclusions about the required electric bus specifications. Motor and battery power capacity is adjusted to the needs and bus routes. The power and torque can be minor for the inner bus with a relatively low speed. Besides, the battery capacity does not need to be too large with the correct charging strategy. It is so that the space for passengers remains wide. The use of design software and route data taken with GPS greatly helps the accuracy of the design. Bus operating costs are relatively competitive compared to conventional buses. In addition, even though the study results have not included an incentive factor from the government. The service life of electric buses can be longer than ten years because the motor's efficiency is relatively more stable than an internal combustion engine. For Transjakarta bus with the route of Blok M – Raden Inten, it can be considered that the bus transmission in the city can be simplified. It is also advantageous in terms of vehicle weight and maintenance costs. The 100 kW rated electric motor (200 kW max.) can provide a maximum torque of about 700 Nm. Then, with a bus operating time of 19 hours per day, there is a stop time of 5 hours. This time can be used for maintenance and charging the battery. Thus, the ideal time for charging is around 4 hours or less than 5 hours.

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