Analysis of supercapacitor as a battery substitute in motorcycle

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Abstract. Lead acid battery is the main resource of motorcycle. It has some disadvantages, look like long charging time, short cycle life and also is not environment friendly. Supercapacitor is an electronic tool which can conserve electric current. It has higher power density compared to lead acid battery, but lower energy density. It is also faster in terms of charging, environment friendly, and has longer life cycle than lead acid battery. In this article, supercapacitor is used to substitute battery. The model is able to charge, discharge, and support engine starter in motorcycle. The result of this research shows that supercapacitor is able to substitute battery in motorcycle.

Keywords: battery, motorcycle, supercapacitor.

1. Introduction
Motorcycle uses lead acid battery as it main resource [1]. Battery conserves energy when the engine is idle, and becomes the main resource when it is activated. When the engine is inactive, battery is the main source of motorcycle’s electricity [2]. When the engine is active, battery is charged by the vehicle charging system. Battery uses electrochemistry reaction to produce electricity [3,4]. Battery’s main component is sulphuric acid ($\text{H}_2\text{SO}_4$) as electrolyte and lead (Pb) as electrode [5]. There are 2 kinds of lead acid battery, they are Vented Lead Acid (VLA) and Valve Regulated Lead Acid (VRLA) [6].

However, lead acid battery has some disadvantages. Some of the disadvantages of lead acid batteries include long charging times, short cycle life and are hazardous to the environment. Its charging process takes a long time [7]. The ideal current of battery charging is 10% of battery capacity. Lead acid battery charging time is up to 10 hours. Temperature and the age of battery might contribute to longer charging time [8]. Charging voltage has to be 110% - 115% higher than battery voltage. Vehicle’s load, which is vary, makes outflow and inflow unbalance. Charging process causes electrolyte to evaporate. Inadequate gas handling might cause fire as gas is flammable. Lead acid battery only has less than 1000 cycle life [9]. Surely, it is also affected by condition and usage. Aforementioned life cycle is based on the best usage possibility, so it may vary in different usage and conditions [10].

As many people use battery, they contribute toward great amount of battery waste. Battery waste has to go through special care as it is harmful for environment [11]. Battery is made of lead
and acid solutions, and the lead is taken from earth’s crust. Around 80% of lead around the world is used to make batteries [12]. It contains lead as much as 60%, which is dangerous and poisonous. Battery waste contains lead that can accumulate in human body. If lead-acid battery water splashed the skin, it has to be rinsed in flowing water. This shows that battery usage might cause danger toward environment and human.

Supercapacitor is an electronic tool which can conserve electric current [13]. Supercapacitor is one of electrochemical storage device. It is also called as ultracapacitor. Supercapacitor can work better than lead acid battery [14]. It can save and transfer energy quickly. It also works better in extreme temperature. Supercapacitor charge faster with VRLA and VLA battery [15]. Moreover, it has superior cycle efficiency, which is almost 100% [16]. Some of its advantages are: bigger energy density, environment friendly, recycle-able, safe, and longer life cycle up to 1,000,000 cycle [17]. Surely it exceeds battery life cycle which is only up to 1000 cycle. It is environment friendly because it does not contain corrosive element and less chemical solution [18]. This research observes supercapacitor as the substitute of battery in motorcycle.

2. Supercapacitor model

Supercapacitor used in this research is ELDCs 2.7 V 500 F. The circuit is a series circuit which has 6 supercapacitors connected. This arrangement is meant to be able to provide motorcycle’s voltage needs. This series circuit is a circuit which laid six devices in a row with only one way current. This arrangement can add the voltage. Every cell of the battery produces 2.2 V at the maximum. Series circuit has the ability to raise voltage of the arrangements, as shown in equation 1.

\[ \Delta V_{total} = \Delta V_1 + \Delta V_2 + \Delta V_3 + \Delta V_4 + \Delta V_5 + \Delta V_6 \]  

Where \( V \) is voltage (V). This arrangement enables batteries have higher voltage up to 14.2 V.

This arrangement is equipped with charge control which control this circuit’s charging (Figure 1). Charging system in motorcycle is not stable, depends on engine’s speed. Too high voltage can make fatal damage to supercapacitor. Not only for safety purpose, circuit charge control also sustains it and avoids short circuit current.

![Figure 1. Supercapacitor Model](image)

2.1 Voltage

A single device of supercapacitor ELDCs is able to sustain 2.7 V voltages. Motorcycle charging produces voltage up to 13-14.8 V. In this arrangement, we use series circuit [19] to add the voltage from 2.7 V. The addition of voltage is following equation 2.

\[ \Delta V_{total} = \Delta V_1 + \Delta V_2 + \Delta V_3 + \Delta V_4 + \Delta V_5 + \Delta V_6 \]
\[ \Delta V_{total} = 2,7_1 + 2,7_2 + 2,7_3 + 2,7_4 + 2,7_5 + 2,7_6 \]
\[ \Delta V_{total} = 16.2 \text{ V} \]  

This arrangement of supercapacitor is able to bear up to 16.2 V, which is bigger than battery capacity. This arrangement voltage is capable to receive charging from motorcycle.
2.2 Capacitance

A single device used in this research has capacitance up to 500 F. This research uses 6 supercapacitor devices which have the same capacitance, 500 F. The capacitance of this supercapacitor arrangement is described in equation 3.

\[ C = C_1 + C_2 + C_3 + C_4 + C_5 + C_6 \]
\[ C = 500 + 500 + 500 + 500 + 500 + 500 \]
\[ C = 3000 \text{ F} \] (3)

C is capacitance (F). Electrical charge produced by this supercapacitor arrangement is calculated follows equation 4.

\[ Q = \Delta V \cdot C \] (4)

Q is electrical charge (C), V is voltage (V), and C is capacitance (F). Thus, from equation 3 and 4 we get the value of electrical charge (equation 5).

\[ Q = 48600 \text{ C} \] (5)

This formula is used to convert electrical charge to ampere hour (equation 6).

\[ Ah = \frac{Q}{3600} \] (6)

Thus,

\[ Ah = \frac{48600}{3600} \]
\[ Ah = 13.5 \text{ Ah} \]

Where Q is electrical charge (C), I is electric current (A), and t is time (s). To put it simply, the result of electrical charge calculation is 13.5 Ah. The calculation of initial capacity of supercapacitor can be done by charging and discharging constantly. The formula to determine supercapacitor capacity follows equation 7.

\[ C = \frac{I(t_1 - t_2)}{V_1 - V_2} \] (7)

Where C is capacitance (F), I is electric current (A), and t is time (s), s is initial time (s), t is end time (s), V is initial voltage (V) and V is end voltage (V).

2.3 Charging

Supercapacitor arrangement is superior in terms of charging process. It can charge faster than battery. The formula for charging follows equation 8.

\[ I = 10\% \times Ah \] (8)

Where I is electric current (A) and Ah is battery capacity (Ah). Battery with 4 Ah capacity can only be charged with 0.4 A current. Normally, battery will need 10 hours to charge, which is way longer compared to supercapacitor charging. Salami [20] also did a research about supercapacitor charging time. The research used 2.7 V supercapacitor with capacitance between 2000 F - 3000 F. Several tests considering different factors show that charging time only takes up to 30 seconds.

2.4 Discharge

Discharging in battery lasts longer than in supercapacitor. Battery can supply longer electric current compared to supercapacitor. Research by Ghufron [21] shows that 12 V battery can supply 20 A current for more than 3500 minutes. Supercapacitor circuit has a characteristic of self-discharge. Supercapacitor circuit discharge takes shorter time compared to battery. This statement
is supported by the research which observed discharge time of some brands of 2.7 V 1600 F supercapacitors. 6 A discharging only takes 1000 s [22].

2.5 Self discharge
Self discharge in supercapacitor circuit is defined as reduction of electrical charge in supercapacitor arrangement which is marked by voltage decreasing in supercapacitor circuit. As supercapacitor is let inactive, the electrical charge in it will decrease. Meanwhile, motorcycle is usually inactive for the whole night. This makes supercapacitor circuit cannot charge. Supercapacitor self-discharge is calculated follows equation 9.

\[
U = U_0 \exp \left( -\frac{t}{\tau} \right)
\]

(9)

Where \( U \) is voltage (V), \( U_0 \) is initial voltage (V), \( t \) is discharge time (s) and \( \tau \) is time constant from the test. Research done by Pantazica [23] demonstrated that self-discharge is quite high in the first hour and decreasing as the time goes. Supercapacitor has to reserve electrical charge as the motorcycle is inactive to support engine starter.

2.6 Controller
In motorcycle, charging system is done by alternator. Voltage produced depends on engine speed. The higher engine speed is, the higher voltage produced in charging process. Usually, motorcycle’s charging system has a regulator to keep it producing 14.8 V at the maximum when charging battery. The mechanism is already adjusted to battery’s characteristics to avoid exploding. Meanwhile, the battery itself does not need additional devices to ensure safety. This arrangement, which reserves energy better than lead acid battery, however needs careful charging management. Mistakes in charging control might cause fatal damages to it. Inflow voltage is limited to avoid leaking. This controller construction ensures no short circuit current happens. Supercapacitor circuit without controller makes it hot and overheated thus decreasing in capacity [24].

3. Method
This research is conducted by testing supercapacitor circuits on motorcycles. Two motorcycles used is described in Table 1. Supercapacitor is installed to substitute battery in motorcycles and its installation process is shown Figure 2.

| Table 1. Motorcycle types |
|----------------------------|
| **Media**                  | **Honda New Megapro** | **Yamaha Mio Z** |
| Cylinder Volume            | 150 cm$^3$            | 125 cm$^3$       |
| Fuel System                | carburettor           |EFI               |
| Ignition                   | CDI, battery          | Full Transisterized, Battery |
| Battery                    | MF 12V-4 Ah           | MF 12V-4 Ah       |
4. Result and discussion

4.1 Charging

Supercapacitor has charging characteristics. The supercapacitor voltage will increase when the supercapacitor is charged. In the first experiment, the supercapacitor was charged with a charger. The charger has an output voltage of 13.95 V and an output current of 0.3 A (Table 2). Charging the supercapacitor with a charger is done by charging the supercapacitor which has a voltage of 1 V until the supercapacitor voltage reaches 13 V then see how long it takes to charge. Test result is as follows.

| Media       | Charger output voltage (V) | Charger output current (I) | Charging time (minutes) |
|-------------|---------------------------|---------------------------|-------------------------|
| charger     | 13.95                     | 0.3                       | 16.3                    |

In the second experiment, the supercapacitor is installed in the vehicle as shown in Figure 2. The charging of the supercapacitor on the vehicle is done by starting the motorbike and allowing the supercapacitor to be charged by charging the motorbike. The initial voltage of the supercapacitor is set to 7.5 V and will be charged until the supercapacitor has a voltage of 13 V. The supercapacitor charge time on this vehicle will be calculated. There is a difference in initial voltage on the supercapacitor between the first and second experiments because motor cycle cannot be start under 7.5 V voltage. Electricity current under 7.5 V cannot sustain engine ignition. Test result is shown in Table 3.

| Media          | RPM  | Charging voltage (V) | Charging time (minutes) |
|----------------|------|----------------------|-------------------------|
| charger        | -    | 13.95                | 6.43                    |
| Honda Megapro  | Low  | 13.86                | 1.25                    |
|                | High | 14.05                | 0.53                    |
| Yamaha Mio Z   | Low  | 13.8                 | 1.55                    |
|                | High | 14.15                | 0.45                    |

The result shows that charging time for supercapacitor is very short compared to lead acid battery, which takes 10 hours charging. Charging by charger is longer indeed compared to direct charging in the motorcycle. It is because the charger has output voltage 13.95 V and 0.3 V current. However, this is still faster than battery charging, which normally takes 10 hours. Supercapacitor direct charging in the motorcycle is faster than using charger. Charging time is apparently affected
by engine rotation. If the rotation is higher, charging time will be faster, too. In short, supercapacitor circuit is able to charge in motorcycle.

4.2 Discharge
Discharge test is conducted in motorcycle. The supercapacitor is discharged by emptying the supercapacitor with an initial voltage of 13 V. The supercapacitor is discharged until it has a voltage of 2 V. Test result is shown in Table 4.

| Motorcycle       | Load                              | Electricity current (I) | Time (minutes) |
|------------------|-----------------------------------|-------------------------|----------------|
| Honda Megapro    | Ignition key on                   | 0.36                    | 44.35          |
|                  | Ignition key on + low beam headlight | 1.17                    | 14.2           |
|                  | Ignition key on + high beam headlight | 3.17                    | 4.32           |
| Yamaha Mio Z     | Ignition key on                   | 2.00                    | 5.54           |
|                  | Ignition key on + fuel pump       | 1.24                    | -              |
|                  | Ignition key on + turn signal     | 2.65                    | 4.06           |

The result shows that supercapacitor discharge is quite short. It is equal to supercapacitor charging. It can last up to 44.35 minutes in Megapro model and 5.54 minutes in Mio Z model when the ignition key is on. The large difference is because Mio Z model has more load than Megapro model when the ignition key is on. On the other hand, lead-acid battery last longer than supercapacitor circuit. It is because battery has higher energy density than supercapacitor circuit. The result demonstrates that supercapacitor is able of discharge, thus it can be motorcycle’s energy resource although in shorter time compared to battery.

4.3 Starter engine

| Voltage (V) | Honda New Megapro | Yamaha Mio Z |
|-------------|-------------------|--------------|
| 13          | Double starter    | Double starter |
| 12.5        | Double starter    | Double starter |
| 12          | Double starter    | Double starter |
| 11.5        | Double starter    | Double starter |
| 11          | Double starter    | Double starter |
| 10.5        | Double starter    | Double starter |
| 10          | Kick starter      | Double starter |
| 9.5         | Kick starter      | Double starter |
| 9           | Kick starter      | Kick starter   |
| 8.5         | Kick starter      | Kick starter   |
| 8           | Kick starter      | Kick starter   |
| 7.5         | Kick starter      | Kick starter   |
| 7           | No starter        | No starter     |

Starter test is conducted by starting engine in supercapacitor’s initial voltage, 13 V, and then the voltage will be reduced until the engine cannot start. Test result is shown Table 5. The result shows that supercapacitor circuit can provide energy to sustain engine starter. However, there are different minimum voltage limit to do double starter. In the Megapro model, it needs a quite high voltage, which is 10.5 V to start engine. It is because Megapro model has bigger cylinder volume compared to the other model, Mio Z. Different cylinder volume causes different minimum voltage
limit to start the engine. Mio Z model needs has minimum voltage limit, which is 9.5 V. Both motorcycles have the same minimum voltage limit to do ignition, which is 7.5 V. Supercapacitor voltage less than 7.5 V cannot start engine at all.

4.4 Self discharge and starter engine
Self discharge is assessed by installing supercapacitor circuit in motorcycle. Test result is shown in Table 6. Supercapacitor circuit experienced immense voltage reducing. After 12 hours inactive, its voltage reduced up to 2.5-3 V. However, after 12 hours being idle, it still can support engine starter. In Megapro motorcycle after 10 hours, it can only support kick starter. It is because the voltage is less than 10.5 V. In the different model of motorcycle, Mio Z, it is able to support double starter after 12 hours. Voltage dropping when doing double starter apparently also affects engine starter. Voltage dropping when doing double starter makes supercapacitor energy decrease drastically. Low voltage of supercapacitor allows only two times starting attempts after supercapacitor is idle for 12 hours. If those two attempts fail to start the engine, it needs kick starter right away.

| Time (hours) | Megapro Voltage (V) | Mio Voltage (V) | Megapro Starter | Mio Starter |
|--------------|---------------------|----------------|----------------|-------------|
| 1            | 13.41               | 13.56          | Double starter | Double starter |
| 2            | 12.18               | 12.67          | Double starter | Double starter |
| 3            | 11.75               | 12.20          | Double starter | Double starter |
| 4            | 11.47               | 11.87          | Double starter | Double starter |
| 5            | 11.24               | 11.64          | Double starter | Double starter |
| 6            | 11.04               | 11.45          | Double starter | Double starter |
| 7            | 10.87               | 11.30          | Double starter | Double starter |
| 8            | 10.72               | 11.15          | Double starter | Double starter |
| 9            | 10.52               | 11.01          | Double starter | Double starter |
| 10           | 10.45               | 10.89          | Kick starter | Double starter |
| 11           | 10.34               | 10.78          | Kick starter | Double starter |
| 12           | 10.21               | 10.68          | Kick starter | Double starter |

4.5 Safety
For the safety test, supercapacitor circuit is installed in motorcycle. It is set to maintain engine rotation up to 8000 rpm. Test result shows that supercapacitor voltage can last in the maximum voltage of 14.15 V. In this level of voltage, supercapacitor will not be broken. However this level is still under the maximum voltage which is 16.2 V. Controller construction in supercapacitor circuit is able to limit its voltage to avoid leaking and explosion as mentioned in part 2. Moreover, controller also keeps it from overheating. To sum up, supercapacitor circuit is safe to be installed in motorcycle.

5. Conclusions
This article suggests using supercapacitor as an alternative to substitute battery in motorcycle. Part 1 shows battery capacity and negative impact of battery waste toward environment. Also, supercapacitor has more advantages than lead-acid battery, which was the fundamental idea for this research. Part 2 explains supercapacitor model, mathematical calculation, and its capacity. Part 3 explains result and discussion of this research. Considering that, the conclusion is as follow:
- Supercapacitor circuit is able to supply motorcycle electricity needs.
- Discharging a supercapacitor circuit is faster than a battery. Battery can last longer supplying motorcycle energy without charging.
- Supercapacitor circuit can charge.
- Charging time for supercapacitor circuit in motorcycle is only 2 minutes, which is faster than battery.
- Supercapacitor circuit is able to start motorcycle engine.
- Supercapacitor circuit can only do double starter 2 times. If it fails, it needs kick starter right away.
- Supercapacitor circuit can maintain its energy for 12 hours also start the engine.
- Ignition key cannot be in stand by position for long time as it will spend supercapacitor energy and cannot start the engine.
- Supercapacitor circuit is safe for motorcycle.

These conclusions fulfill the expectation of supercapacitor as battery substitute in motorcycle.

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