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Application of a Single Supercapacitor for Driving an Electric Vehicle

***Abstract**. The current paper focuses on standalone supercapacitors (SCs) for round-trip electric vehicle (EV) propulsion for reasonable distances and can be used around the clock without hours of charging. Supercapacitors instead of batteries are a form of the fast-charging energy storage system. And can be charged during braking or slowing down. The capacity design of the supercapacitor can drive a four-seater electric vehicle. The advantage of a supercapacitor is its high-power density, high efficiency, fast charging and discharging, long service life, wide operating temperature range, and being environmentally friendly. The benefits are that it can drive an electric vehicle that uses supercapacitors, with a total weight of 405 kg, a driving distance of 1,150 meters in 6 minutes and 21 seconds, an average speed of 10.86 km/h, and a maximum efficiency of 97.06%. In addition, this system offers efficient use of renewable energy resources of the future.*

Streszczenie.** Obecny artykuł koncentruje się na samodzielnych superkondensatorach (SC) do napędu pojazdów elektrycznych (EV) w obie strony na rozsądnych odległościach i mogą być używane przez całą dobę bez godzin ładowania. Superkondensatory zamiast akumulatorów są formą systemu szybkiego ładowania energii. I może być ładowany podczas hamowania lub zwalniania. Konstrukcja pojemności superkondensatora może napędzać czteromiejscowy pojazd elektryczny. Zaletą superkondensatora jest duża gęstość mocy, wysoka sprawność, szybkie ładowanie i rozładowywanie, długa żywotność, szeroki zakres temperatur pracy oraz przyjazność dla środowiska. Zaletą jest to, że może prowadzić pojazd elektryczny, który wykorzystuje superkondensatory, o całkowitej masie 405 kg, przebyciu 1150 metrów w 6 minut i 21 sekund, średniej prędkości 10,86 km/h i maksymalnej wydajności 97,06 %. Ponadto system ten oferuje efektywne wykorzystanie odnawialnych zasobów energii przyszłości.* (Zastosowanie pojedynczego superkondensatora do napędzania pojazdu elektrycznego***)

Keywords: Electric Vehicle, Supercapacitors,
Słowa kluczowe: pojazd elektryczny, superkonensator

Introduction

Generally, batteries are important energy storage devices, which are applied in multiple tasks, such as portable flashlights, remote control, mobile phone, laptop, electric vehicle, and photovoltaics. However, the battery has limitations of chemical energy storage and can't generate by itself, which is its disadvantages. Note that the charging battery is an important part of the experimental process because it can create risk of drying out of the electrolyte. It requires several hours It takes a several hours for charging the batteries to complete the chemical charge process. It is will not be charged effectively of 100% but only charged by 80%. There are two important part of charging methods; fast and slow charge. Firstly, the fast-charging method will be resulted of 80% of effectiveness and reduce battery life due to the thermal and chemical loss while charging and discharging, which results from long charging and discharging time. Note that after the setting is done, the battery must rest for 5 - 10 hours to cool down [1, 2]. Energy storage systems are critical process that are used in various electric vehicles, including pure, hybrid, and plug-in hybrid electric vehicles. In addition, a continuous yet primary energy supply is needed to meet the desired traveling range. On the other hand, peak power with high current demand is a significant necessary to handle vehicle acceleration and regenerative braking for vehicle performance and energy recovery. A hybrid energy storage system with battery and supercapacitor have been proposed drawbacks by using either battery or supercapacitor alone to overcome drawbacks [3]

In this research, the development of energy storage and emission of supercapacitors during braking and decelerating were particularly studied. As the running round-trips, the supercacitors was experimentally used as the power sources for driving electric motors, which can be driven by electric vehicles. The Supercapacitors was token by the time of 1 to 5 minutes for each charge by installing a high-efficiency charging station at each building. As the running of electric vehicles, the supercapacitor was charged by every time using braking or decelerating. After that, the supercapacitor will be recharged. Thus, this research is led to the development of a prototype energy storage system. As the benefits of these results, it can be positively affected to electric vehicles, for example, increasing efficiency of electric vehicles which is a direct result to the golf and resort-type establishments that can be used for their desired. [4-6].

Research methodology

General (using batteries)

The original circuit consists of ac power source, charger, batteries, and electric vehicle. General includes:

Lead-acid battery TROJAN size 12V.
120Ahr.
Service live is two years or 500 cycles.
High energy density properties.

However, there is a limitaion on the current charge and the high cost of battery replacement, as shown in Fig. 1.

This research was conducted at the location of Dhonburi Rajabhat University, Samutprakarn, in Thailand. According to a landmark, 102 acres of land have been conveerted. And there are 14 building of school.

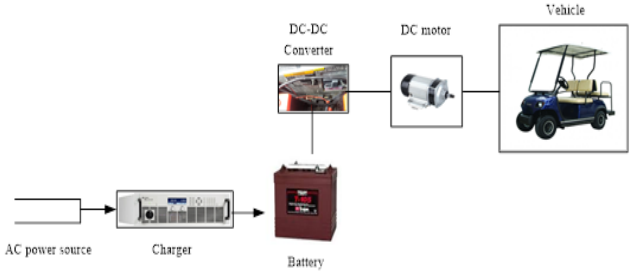

Fig.1.The Structure of the Original Electric Vehicle Drive System

Synthesis (add to SCs)

Synthesis systems have been considered for the following :

1) Maxwell supercapacitors 165F, 48V
2) The generator for electric vehicle regenerative

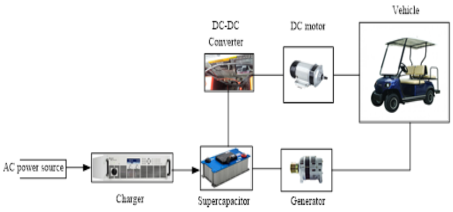

Fig.2. New Electric Vehicle Propulsion System Structure

Based on the study of charging and electric vehicle propulsion with SC, the research has been conducted as follows:

1. Electric Vehicle Drive System Design

The design of this electric vehicle propulsion system shows the working model of the supercapacitor power supply and distribution system to the dc motor through the power transmission of the electric vehicle wheels. The system was connected by the dc generator braking or decelerating brakes [7-9]. The generator will be charged by electric energy for the supercapacitor, as shown by Fig. 3.

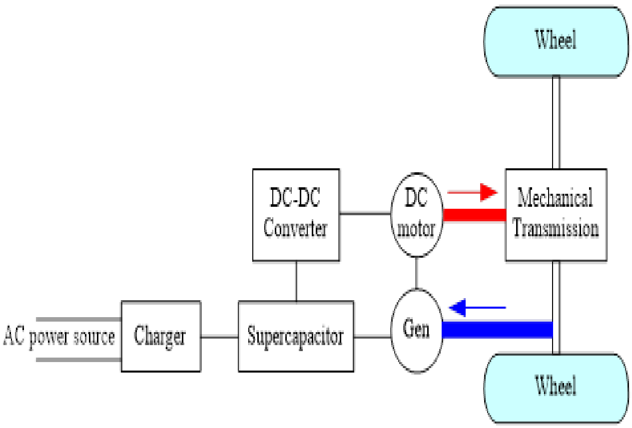

Fig.3. Diagram of Electric Vehicle Propulsion

2. The Design of the Capacity of Supercapacitor

According to the Designing of the supercapacitor capacity, it can be used through 4-seats. 290-kg of the total of vehicle weight, and 400 kilograms of the total are experimentally used to run the process between the school building to the library building of Dhonburi Rajabhat University, Samutprakarn together with a distance of 505 meters per trip. Moreover, 1010 meters of distance can be used to calculate the size of supercapacitors and was used to drive electric vehicles [10,11]. In order to obtain optimum result, 505 meters of distance was used to calculate, as follows.

A supercapacitor in the size of 165-F and 48-Vdc, two banks, total capacity is 330-F 48-Vdc, 1 Module were used.

3. The amount of time that can be running

The energy formula (E) of the supercapacitor can be used to find the time (t) used to drive electric vehicles as following by equation (1)

(1) $$E = \frac{\frac{1}{2}\times c\times v^2}{3600} = \frac{\frac{1}{2}\times 330\times 48^2}{3600} = 380{,}160 \quad Joules$$

From the formula for electricity consumption

(2) $$P = \frac{E}{t}$$

When the rate of the DC motor, P = 2000 kW, How long the electric vehicle can run.

$$t = \frac{380160}{2000}$$ = 190.08 sec or 3 minutes and 10 second

4. The Distance that Electric Vehicles can be Running

As the circumference or wheel of the electric vehicle, A3.7 meters/cycle of distance was determined. The speed of electric vehicles is 12 km/hour along with 54 cycles/minute. Therefore, the distance to run per minute to get 200 meters/minute were found. Thus, by using 1 set of supercapacitors 330F and 48V, the electric vehicles can run a distance of 633.6 meters.

5. Charging Time

Because the supercapacitors can be charged at higher currents and set at rated voltages with protection system [12,13]. Which can find the time and current used to charge the supercapacitor as following,

(3) $$t = \frac{C}{I}$$

Table 1. Current and charging time of supercapacitors [14-15]

Current (A)	Percentage (%)	Charging time(s)
1900	100	1
950	50	2
100	5.26	19
90	4.74	21
80	4.21	23.75
70	3.68	27.14
60	3.16	32
50	2.63	38
40	2.10	47.50
30	1.57	63.33
20	1.05	95
10	0.53	190

Data analysis

As the analyzation of current murement, voltage, and energy in the charging and discharging process of the SCs were investigated [14-16].

(4) $$W_t = \int_o^t pdf = \int_o^t Iv_c dt = \int_o^t \left(c\frac{dv}{dt} \right) v_c dt = c\int_o^t vdv$$

$$W_c = \frac{1}{2} CV_c^2$$

W_c is the amount of energy stored in the SC (Joules; J); C is the capacitance (Farads; F) ; V_c is the voltage level of the Capacitor (Volts; V)

Energy stored in the SC can be calculated as following equation (5).

(5) $$\Delta W\left(W_t\right)=\frac{1}{2}C\left(V_1^2-V_2^2\right)$$

when: V_1 is the charging voltage (V); V_2 is the dischargingvoltage (V)

Analyze the Efficiency of the SC

As the equation (8), the collected voltage and current data from the data logger was found to plot a graph and analyses to the characteristics of change in voltage and current by this time. Using the data to calculate the stored energy, the SC of the energy from the equivalent series resistance (ESR) were considered and can be calculated the power loss from

(6) $$W_R=I^2R_t$$

The equivalent series resistance (ESR)

(7) $$\left(ESR\right)=\frac{V_f-V_{\min}}{I_d}$$

From equation (3) and (4), we can calculate the efficiency of SC.

(8) $$\eta=\frac{W_c}{W_t}=\frac{W_c}{W_c+W_R}$$

Analyze the Data using the SC

In the first stage,the secondary power supply with the designing circuit was designed. And then, the using of the data from the data logger to plot a graph was analyzed by using the characteristics of changing in voltage and current. And the charging/discharging process was the process that was proceduced by time using the data to calculate the stored energy in the SC and then the efficiency was found [17-20].

Analyze the Data using Batteries as to Driving Electric Vehiclest

In this part, the data from the data logger was analyzed by the characteristation of changing in voltage and current of the charging/discharging process by the time [21-22].
The efficiency of the battery can be calculated by following.

(9) $$\eta=\frac{P_{out}}{P_{in}}$$

Analyze the Data using the SC

The battery was set as the secondary power supply. Then, the data was used from the data logger to analyze the characteristics of changing in the two important of variables, including, voltage and current of the charging/discharging process by time [23-24].

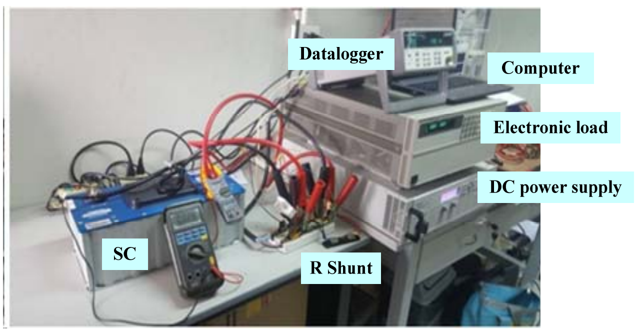

Fig.4. The experiment of charging and discharging of super capacitors

Experimental result and summary

In this study, the development of electric vehicles was investigated through the supercapacitors to supply energy and deceleration during braking. Furthurmore, the supercapacitors' energy storage and discharges behavior were used to drive electric motors by installed on electric vehicles. Two charging stations was installed at the school building, including building four and the library building, to charge power to a supercapacitor, and find the efficiency of a supercapacitor [25-27]. The researchers were carried out to test the efficiency of two parts: a supercapacitor to charge and discharge in the laboratory Fig. 4. Then, the further experiment with supercapacitors and electric vehicles, as shown in Fig. 5, to run a round-trip test between the school building four and the library building. Dhonburi Rajabhat University, Samut Prakan. The experimental procedure is as follows.

Fig.5. Install a supercapacitor with electric vehicles

Experiment with charging and discharging of super capacitors

The research processes are as follows;

1) The efficiency of a supercapacitor was studied by charging and discharging. The experimental charging and discharging of the supercapacitors are presented as following, By constant voltage as 48V and changing the current level of 10 A, 20A, 30A, 40A, 50A, 60A, 70A, 80A, 90A and 100A, respectively, the result was obtained.

2) The charge by operating with the switch S1 to position 2 was illustrated by Fig. 6. There have been found that the charging will be stop when the voltage drop across the supercapacitor is constant. Then, record the voltage and current while charging together with a data logger.

3) When the charge reaches a constant voltage that discharges the electronic load. By Operating with the switch S1 to position 3. Record the voltage and current while releasing the charge by stopping the charge when the voltage across the supercapacitor starts to be stable [28].

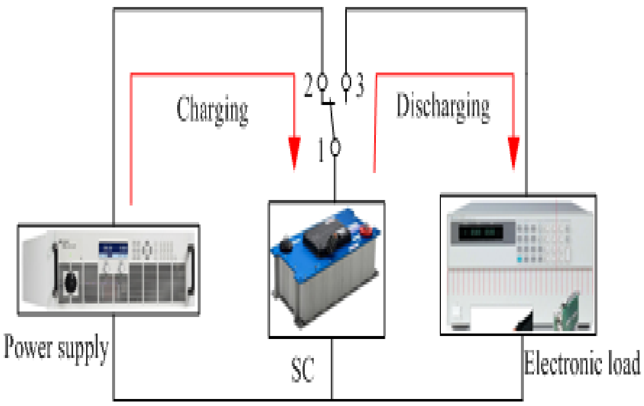

Fig. 6. Details of the experiment

4) The Determines Efficiency of Supercapacitor
The efficiency of supercapacitor
(10)

$$\eta_{SC} = \frac{\sum(V_{out} \times I_{out})}{\sum(V_{in} \times I_{in})} \times 100\% \quad = \frac{210,140}{278,425} \times 100\% \quad = 98.88\%$$

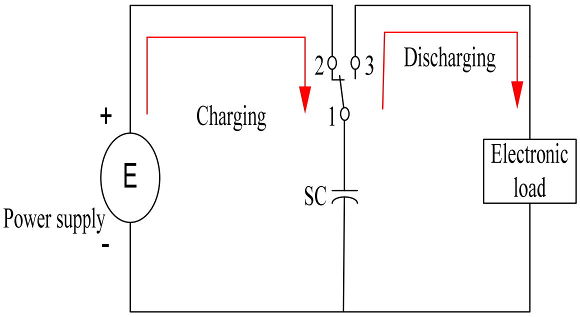

Fig.7. Details of the Experimental Equivalent Circuit

Table 2.The data charging and discharging at constant voltage 48 V, current 10 A, 20A, 30A, 40A, 50A, 60A, 70A, 80A, 90A and 100A, respectively.

I_d (A)	V_f (V)	V_{min} (V)	ESR (Ω)	t_{charge} (s)	t_d (s)	W_s (J)	W_d (J)	η (%)
10	0.97	0.67	0.03	1075	790	278,425	210,140	98.88
20	35.47	34.16	0.065	501	137	231,036	29,185	96.28
30	34.18	32.77	0.047	482	149	203,034	93,344	93.67
40	38.18	37.18	0.025	290	113	225,480	59,035	92.88
50	41.04	40.31	0.015	201	82	181,169	27,989	90.34
60	35.90	35.34	0.010	197	135	223,519	81354	94.01
70	40.86	40.46	0.0057	164	81	209,326	48,216	95.52
80	42.34	41.90	0.005	141	67	210,884	38,654	94.74
90	35.87	35.37	0.005	146	134	230,804	75,879	93.32
100	35.87	35.37	0.005	127	53	226,465	29,417	91.74

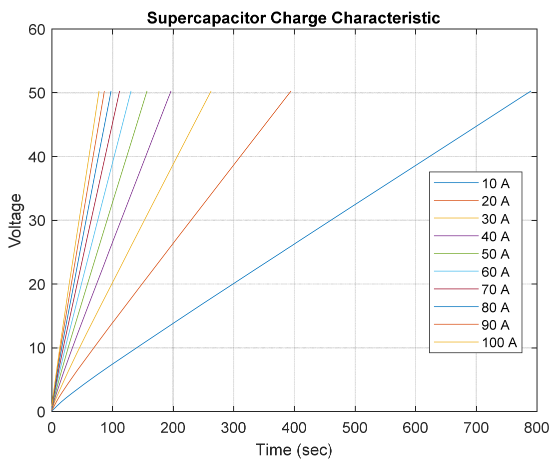

Fig. 8.The SC Energy Contribution Charging Characteristic

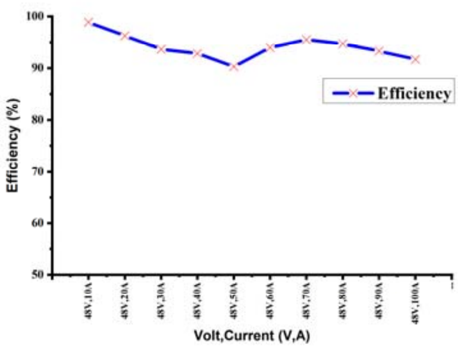

Fig.9. Efficiency of the Supercapacitor

5) The analysis uses a Supercapacitor to drive Electric Vehicles

The results of the analysis use supercapacitors as energy sources instead of batteries to drive electric vehicles, by running the test back and forth between station I and station II, of Dhonburi Rajabhat University, Samutprakan, which has a distance of 505 meters per trip and a total distance of 1010 meters, as shown in Fig. 10.

Fig.10. Diagram of the Experimental Run of Electric Vehicles

Analysis Results using Supercapacitors to Drive Electric Vehicle

The analysis results by using supercapacitor power to drive motor of electric vehicles are as follows:

1) Analysis of Charging at a Constant Voltage 50.52V and Current 20.33A

The charging time is 447 seconds (7 minutes 27 seconds), charging average power consumption as 822.47W. Looking the information in more detail, there have been found that the maximum power is presrnted by 1384.03 W together with 502.65W of minimum power, respectively. After that, the actual running test was conducted on the specified path with three persons with the total weight of (290kg+60kg+65kg+65kg) equals 480 kilograms. It takes 315 seconds (5 minutes, 15 second) to measure the distance of running of 1010 meters. Moreover, the average energy consumption was shown by 798.29W, with the maximum energy of 4914.15W, and minimum power of 12.91W, respectively. The voltage and current response can be seen in Fig. 11, and the energy charge and discharge were showed by Fig.12. The initial circuit in a supercapacitor will be cut off the power supply when the minimum voltage is 30.10V.

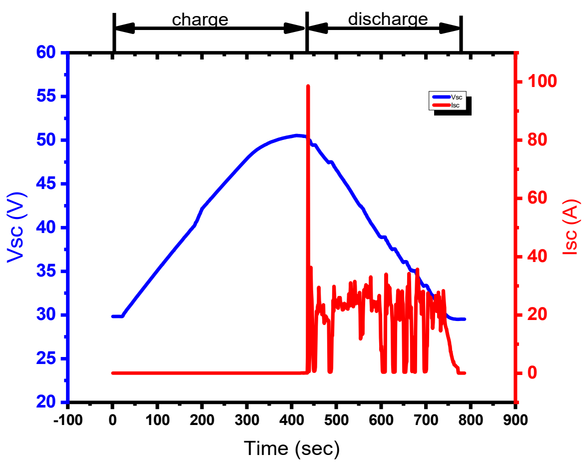

Fig.11. Charging Voltage at 50.52V, Current is 20.33A, Running at a total Weight of 480 kg

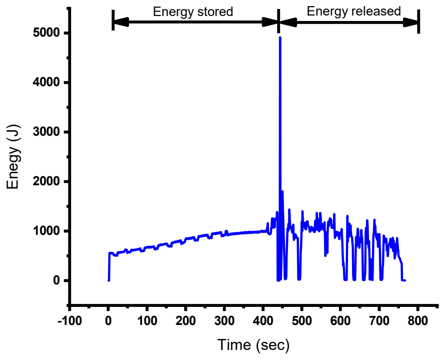

Fig.12. Power Charging Ratedat 50.52V,Current is 20.33A,trial Running at a total Weight of480 kg.

2) The Analysis Results of Charging at Constant Voltage at 50.53V, Current is 39.53A

At the voltage rating of 50.53V, 39.53 Av of current was displayed, which takes 310 seconds to charge (5 minutes 10 seconds). The charging of the average power consumption is 1459.30 W with the maximum power of 1777.04 W. The minimum power is 874.95W. After that, the actual running test is carried out according to the determined path, with the weight of 2 persons including the total weight (290kg + 60kg + 65kg) equals 415 kg.

At 388 seconds of time, in order to drive/travel/run distance of 1100 meters, the average power consumption is presented by 896.92W with the highest power of1174.06 W, and the lowest power of 64.02 W. The voltage response is shown in Fig. 13. The power range of charge and discharge showed in Fig. 14. This is because of the internal circuit of the supercapacitor will cut off the power supply when the minimum voltage is 31.14V.

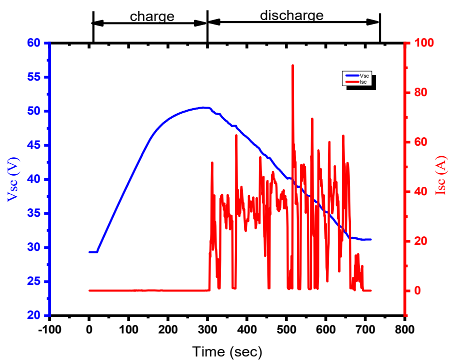

Fig. 13.The charging at a voltage of 50.53V, current is 39.53A, running with a total weight of 415 kg.

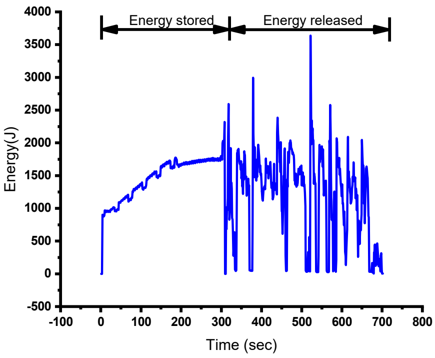

Fig. 14.Shows the change of energy

3) The Analysis Results of Charging at Constant Voltage 50.50V, Current 57.41A

At the voltage rating of 50.50V, 57.41A of current is presented, which takes 238 seconds to charge (3 minutes 58 seconds). The average power consumption is illustrated by 2484.53 W with the maximum power of 2956.45W, and minimum power of 1531.77W. In addition to ths point, the actual running test is carried out by according to the determined path, with the weight of 2 persons, including the total weight. (290kg+60kg+65kg+65kg) equals 480 kg, takes time is 313 seconds (5 minutes 12 minutes). Remarkly, the distance running 990 meters, the average power consumption of 743.39W, the maximum power is 1667.78W, the lowest power is 10.99W. The voltage and current response are shown in Fig. 15, and the energy, charge, and discharge as shown in Fig. 16. The internal circuit of the supercapacitor will cut off the power supply when the minimum voltage is 30.15V.

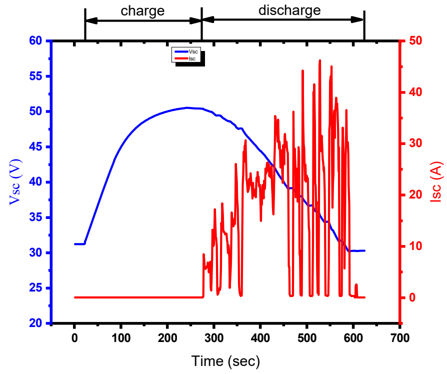

Fig.15. Charging at Voltage 50.50V, Current is 57.41A and Run at a total Weight of 480 kg

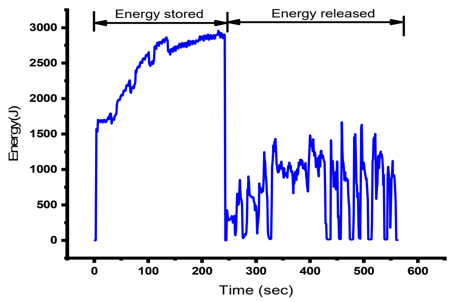

Fig.16. Energy Storage and Release Range

4) Analyzing Results of Charging at Constant Voltage of 50.49V, Current of 79.15A

When fully charged, the voltage rating is 50.49V, and the current 79.15A takes 222 seconds to charge (3 minutes 42 seconds). The average power consumption is 3428.44W, and maximum power is 4100.26W, minimum power is 2052.51W. After that, the actual running test is carried out according to the determined path, with the weight of 2 persons including the total weight (290kg+60kg+55kg) equals 405 kg, takes time is 381 seconds (6 minutes 21 seconds) measuring the distance running of 1150 meters, the average power consumption is 591.78W, the maximum power is 1216.17W, the lowest power is 3.69W. The response of the voltage and current is shown in Fig. 17, and the energy during charge and discharge is shown in Fig. 18. The circuit in the supercapacitor will cut off the power supply when the minimum voltage is 30.82V.

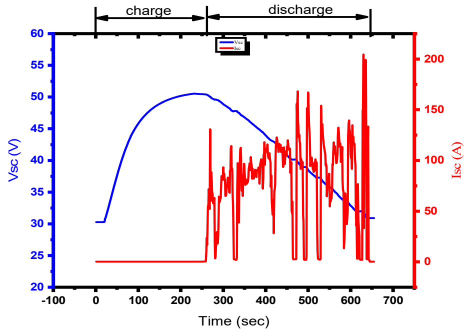

Fig.17. The Charging at a Voltage of 50.49V, Current is 79.15A, Running with a total Weight of 405 kg

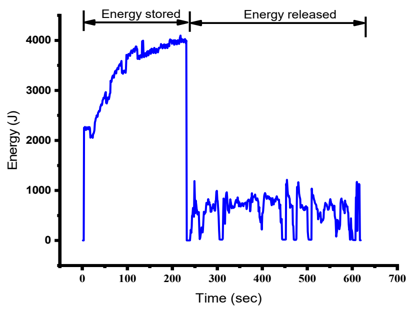

Fig.18. Energy Storage and Release Range

The experimental results were used to study the energy storage of supercapacitors during braking and decelerating. The supercapacitors will receive the voltage from the alternator, which will make the supercapacitors get charged during the brakes and slow down the brakes again. The voltage and current during braking and decelerating are shown in Fig. 19.

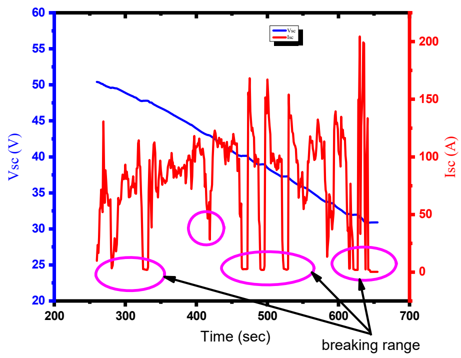

Fig. 19.Shown that the Current and Voltage During Braking and Decelerating Brakes

5) The Results of the Analysis of the Efficiency of Electric Vehicles

The installation of supercapacitors to driven electric vehicles by testing the charging current at various values is shown in Table 3.

Table3. Shows that the energy used to charge and drive electric vehicles

Charged current (A)	Time (s)		Energy stored (W)	Energy released (W)	Efficiency (%)
	charge	discharge			
20.33A	447	315	798.29	822.47	97.06
39.53A	310	388	896.92	1459.30	61.46
57.41A	238	313	743.39	2484.53	29.92
79.15A	222	381	591.78	3428.44	17.26

Then, running along the actual route resulted in the highest efficiency of 97.06%, at the charging current of 20.33A, and when the charging current increased at 79.15A, the efficiency would be reduced to 17.26 %. As shown in Table 3 and results are summarized in Fig.20.

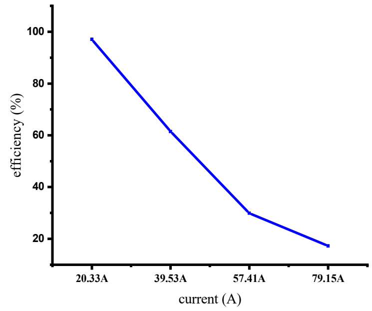

Fig.20. Efficiency in Driving Electric Vehicles

Conclusion

As a results of this research, the renewable energy was displayed that can be recycled in more than one million cycles and do not pollution to the environment. When considering the parameters from the experiment, results and calculations show the performance of the supercapacitor as a power source for driving electric vehicles. The analysis result uses supercapacitors as power sources to drive electric vehicles with a total load of 480 kg. Supercapacitors can drive an electric vehicle for 5 minutes 15 minutes. The distance of the test was 1010 meters. During the test, run with braking or slowing down, found that the supercapacitor router is recharged at a voltage of 31.06V. From the installation of the charger.

Acknowledgments and Legal Responsibility

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