Supercapacitors and the Future of Electric Vehicles

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***Abstract*—** Supercapacitors, Wind turbine and Electric vehicle were defined and detailed explanation of the three has also been addressed with examples, diagrams, and quotations where necessary. Parts and sections of a typical electric vehicle were analyzed, giving examples, and discussions made on how electric vehicles can be powered and driven using supercapacitors. The correlation between supercapacitors and wind turbine in an all-electric vehicle in terms of charging and discharging of the supercapacitor was clearly explained. Mathematical analysis of energy storage and conversion in electric vehicles and the necessary calculations were done. For a 50hp electric vehicle, it was found out that 3300wh of energy can sustain the motion of the vehicle for 1.6km for an hour. This amount of energy can be supplied by 40 supercapacitors or 20 of them for 30 minutes. Also, whenever the wind turbine is in idle mode or generates limited power, it was found out from calculation that there will always be a 12 minutes' redundancy.

***Keywords*—** Supercapacitors, Wind turbine, Electric vehicle, Mathematical Analysis of Energy Storage, Comparisons of energy sources.

1. INTRODUCTION

Supercapacitors, also known as ultra-capacitors, are electronic components with high energy storage capacity. It has capacitance value which is much higher than other regular or conventional capacitors, but lower voltage rating. Supercapacitors typically store ten (10) to one hundred (100) times more energy per unit volume or mass than electrolytic capacitors, and it can charge and release enormous amount of energy more rapidly or quickly than other rechargeable energy sources (Dricus, 2020). Since electric vehicles run on batteries, they can also be designed to be powered by supercapacitors.

1.1 How Supercapacitors Work

Capacitors generally store energy by means of static charge deposit and not through the process of electrochemical reaction. By applying a voltage differential across the positive and negative terminals of a capacitor, it becomes charged ((Dricus, 2020). The positive and negative electrical charges build up on the plates, and the separation between them known as the dielectric material prevents the two terminals from coming in contact with each other. The dielectric material determines the amount of charge a capacitor of a certain size can store at a particular voltage (Chris, 2020).

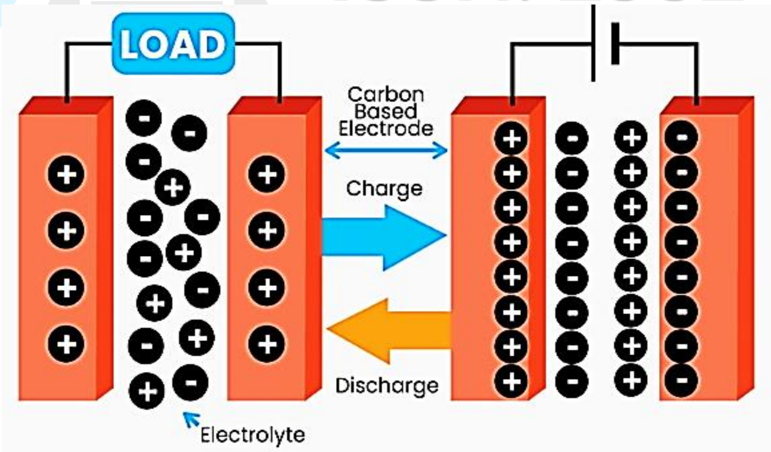

Figure 1: *Charging and discharge diagram of a supercapacitor*

2. SUPERCAPACITORS AND BATTERIES

Both supercapacitors and batteries are energy storage devices. The two can be compared in terms of the following (Battery, 2020):

i. Energy storage capability
ii. Considerable weight
iii. Cost of production
iv. Charging speed
v. Lifespan
vi. Availability of materials
vii. Charge to weight ratio
viii. Operational temperature

3. HOW ELECTRIC VEHICLES WORK

Electric vehicles can either be hybrid or fully electric. For fully electric vehicles, they simply convert electrical energy from collection of batteries to mechanical energy through some series of steps. The main parts in an electric vehicle are rechargeable batteries, electronic speed/power controller and electric motor. First, the battery is powered, then the controller converts the current from Direct Current, DC to Alternating Current so it can be used by the motor. The motor converts electrical energy to mechanical energy (The greenage, 2020). Figure (3.0) is the image of a typical electric vehicle.

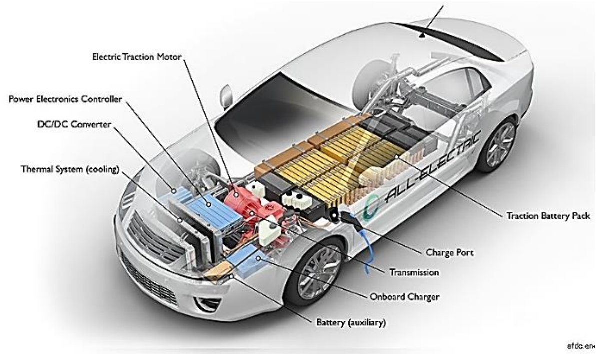

Figure 2: *Features of an all-electric car*

4. ORGANIZATION OF WORK

The remaining part of the paper is organized as follows: section 5.0 explicitly describes work relating to this one, identifying the gaps this research paper attempts to fill. Section 6.0 gives details of the materials and methods applied to clearly prove that supercapacitors are capable of being used to power electric vehicles substantially. Sections 7.0 is explained using basic mathematical approach to indicate in details what units or quantities of energy is enough to power electric vehicles. The benefits and contributions of this proposed techniques to knowledge, conclusion as well as suggested work for researchers in the future are stated in section also.

5. RELATED WORK

(Sekhar RR, Ka-Wai EC, Xiang-DX, Yat-Chi F and Simon C, 2021) wrote a paper on hybrid electric vehicles. A paper titled: *Hybrid Energy Storage System with Vehicle Body Integrated Super-Capacitor and Li-Ion Battery: Model, Design and Implementation, for Distributed Energy Storage.* In this, they try to blend supercapacitors installed in car body with battery for them to work harmoniously. The shaping of these capacitors in panel form to fit in car doors solves the design issues and prepares for configurable electric vehicles. Body integration of super-capacitors enhances the acceleration, and regenerative braking performances of the electric vehicle increases the operating life of the Li-ion battery and improves space utilization by giving more area for the main energy source, the Li-ion battery. Integrating super-capacitor into the car body involves special packaging technology to minimize space and promotes distributed energy storage within a vehicle.

(Hemant S, Imroz K, Anjali K, Prem P, 2021) also wrote a paper on hybrid power for vehicles. A paper titled: *Super-Capacitor based Electric Vehicle charging*. This also consist of the integration of supercapacitors and batteries. Their research paper describes briefly the benefits, features, advantages, and disadvantages of hybrid energy systems based on batteries and supercapacitors.

6. METHODOLOGY

From the related work in 5.0 and 5.1, it is evident that supercapacitors play a vital role in hybrid electric vehicles. From the same sources, they are used in regenerative braking system while the other highlights the merits and demerits of hybrid electric vehicles using supercapacitors and batteries.

In this section, a partial hybrid system of energy storage is proposed. Instead of using supercapacitors as energy backup, they are proposed to be the primary energy storage unit within an electric vehicle but backed up by a generator powered by the wind.

6.1 Mathematical Analysis of Energy Storage and Conversion in Electric Vehicles

Supercapacitors: these energy storage devices can maintain energy within and suddenly release all when discharged. Due to their larger energy storage capability, supercapacitors are rated in Farads (F).

$$1\ F = 1{,}000{,}000\mu F \quad \ldots (6.0)$$

The amount of charge stored in a capacitor is:

$$Q = CV = Capacitance \times Voltage \quad \ldots (6.1)$$

Energy stored in a supercapacitor is given by:

$$Energy_{stored} = \frac{1}{2}CV^2 \quad \ldots (6.2)$$

The amount of energy stored in a supercapacitor required for backup applications is given by:

$$Energy_{required} = \frac{1}{Efficiency} \times power \times charging\ time \quad \ldots (6.3)$$

On demand for energy stored in a supercapacitor, not all of it can be drained, losses occur. The lost voltage is referred to as dropout voltage. This is an important factor to consider when using a supercapacitor. Considering voltage dropout, available energy becomes:

$Energy_{Available} = \frac{1}{2}C(V^2{}_{Capacitor} - V^2{}_{Dropout})$..(6.4)

Lithium ion batteries: these are also energy storage devices used in electric vehicles.

For a battery, the power to be dissipated is given by:

$Battery\ voltage \times battery\ current$ ..(6.5)

6. COMPUTATIONAL ANALYSIS OF SUSTAINABLE POWER USING SUPERCAPACITORS

In this section, the use of supercapacitors as sole power source in electric vehicles is proposed. Supercapacitors are passive components because they neither produce energy of their own nor regenerate energy but only give out what has been stored in them. The more supercapacitors are laid up together either in series or parallel, the more power is stored. For increased current, they must be connected in parallel while for voltage addition, they must be connected in series.

To use a supercapacitor as an independent power supply in all-electric vehicle, to continuously drive it, the following must be in place:

a. The capacitor bank must store enough current to drive the load.
b. They must have good internal resistance to withstand the power drain by the load.
c. The supercapacitor has to be in a continuous charging mode.
d. The discharge time of the supercapacitor has to be far more than the charging time. That is:

$$\boldsymbol{Charging\ time \ll Discharge\ time}$$

To achieve making a vehicle purely electric, a constant charging system has to be introduced into the vehicle. This charging system can be a mini wind turbine electricity generator.

These turbines can be installed or embedded in the body of such vehicles along air channels. As the vehicle moves, the oncoming air drives them, providing power to charge the capacitors.

Supercapacitors are used to help smooth out the intermittent power supplied by wind turbines. In electric and hybrid vehicles, supercapacitors are increasingly being used as temporary energy storage device for regenerative braking.

The motor drives in electric vehicle gives-off hundreds of volts of energy in form of heat (Chris, 2020).

7.1. Wind Turbines as Charging Generators

For a wind turbine to generate electricity, the following parameters must be in place and good enough:

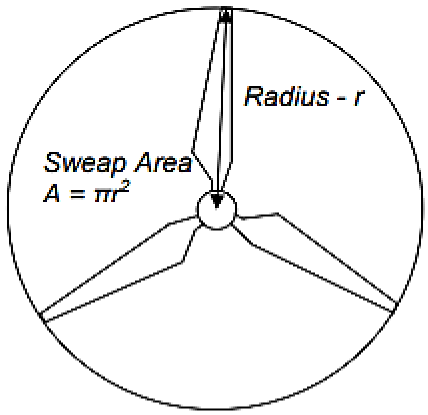

Figure 3: *Wind turbine schematic*

i. Length of blade
ii. Air density
iii. Power coefficient
iv. Wind speed

$P_{generated} = \frac{1}{2}\rho A v^3 C_p$ …(7.0)

Where:

$P_{generated}$ = Power generated $= W$
ρ = Density of air $= kgm^{-3}$
A = Blade swept area $= \pi r^2$
v = Wind speed $= ms^{-2}$
C_p = Coefficient of power = 0.4

7.2 Supercapacitors-Wind Turbine Power Correlation

7.2.1 Supercapacitors: here, the amount of charge in supercapacitors is calculated and converted to current.

Power, P $= Voltage, V \times Curent, I$ …(7.1)

From equation (6.0),

$1\ F = 1{,}000{,}000\mu F \ldots$ (7.2)

Considering a single supercapacitor rated $500F/3.7V$:

$500F = 500{,}000{,}000\mu F$

But, $Amount\ of\ charge, Q = Capacitance \times Voltage, V$ ...(7.3)
$1A = 3600C$ … (7.4)
Substituting the capacitance and voltage into equation (7.3), we have:

$$Q = 500{,}000{,}000 \times 3.7 = 1{,}850{,}000{,}000C$$

The capacitor current becomes:

$$I = \frac{1{,}850{,}000{,}000}{3600} = 513{,}888A \quad \ldots(7.5)$$

7.2.2 Electric Vehicle and Energy Requirement: here, the required amount of power needed to drive the vehicle is determined.

Considering a $50hp$ vehicle for example, the following amount of energy, is required:

An average electric car consumes at least $\mathbf{3.3kwh}$ of power to travel $\mathbf{1.6km}$ (Alex, 2020).

To obtain the number of capacitors capable of providing $\mathbf{3.3kwh}$ of energy per $\mathbf{1.6km}$**,** and duration of discharge, we have:

$$3.3kwh = 3300wh = Energy$$

$$3300wh = (50hp \times 749)W \times t$$

$$t = \frac{3300}{37{,}450} = 0.088s = 0.000024hr$$

This means, a $50hp$ can drain $3300wh$ of energy in 0.000024.

The number of supercapacitors that can provide $3300wh$ of energy is:

Work done, $W = \frac{1}{2}CV^2$ (7.6)

Energy required to run the system is given by:

$E = P \times t$ (7.7)

Work done required to travel through $\mathbf{1.6km}$ in an hour is:

$W = 37{,}450W \times (60 \times 60) = 134{,}820{,}000J$

(7.8)

From equation (7.6), the energy in each capacitor is:

$W = \frac{1}{2} \times 500 \times (3.7)^2 = 3{,}422.5J \ldots$ (7.9)

Hence, the total number of capacitors required is:

$$\frac{134{,}820{,}000J}{3{,}422.5J} = 39{,}392.2 \ldots.. \quad (7.10)$$

From equation (8.0), there will be a need to use a total of $\mathbf{40,000}$ by $\mathbf{500F}$ **s**upercapacitor to travel $\mathbf{1.6km}$ at a stretch on a single charge.

Since the capacitor will be in constant charge mode, the number of supercapacitors can be dropped by half, still maintaining redundancy.

7.2.3 Wind Turbine Power

From equation (7.0),

$$P_{generated} = \frac{1}{2}\rho A v^3 C_p \quad \ldots. (7.11)$$

From the above equation, as the turbine spins to generate sufficient voltage and current, the charging time of the supercapacitor can be deduced by the expression:

$$\frac{Capacitance,\ C \times Voltage,\ V}{Charging\ current,\ I} \quad \ldots (7.12)$$

At $70A$ charging current, the charging time becomes:

$$\frac{20{,}000(total\ capacitors\ required\ to\ supply\ power\ for\ 30m) \times 3.7V(capacitor\ voltage)}{70}$$

$$\frac{74{,}000}{70} = 1{,}057s$$

The charging time, $1{,}057s$ is far less than the redundancy time of the capacitors. The total time it takes the capacitors to deliver power (redundancy time) is: $1{,}800s$.

The difference is:

$$1{,}800s - 1{,}057s = 743s = 12mins$$

Therefore, the vehicle can have an un-charging roll time of $\mathbf{12mins}$.

8. COMPARISONS OF ENERGY SOURCES USED TO POWER VEHICLES

Table 8: *Comparisons of vehicle energy sources*

S/N	ENERGY SOURCE	READILY AVAILABLE	LIFESPAN	SAFETY	COST
1.	Supercapacitor	Scarce	Last long	Quite safe is properly handled	Relatively cheap
2.	Gasoline	Readily available	Easily exhaustible	Volatile	Cheap
3.	Battery	Relatively available	Lifespan depletes fast	Hazardous	Quite expensive

9. BENEFITS AND CONTRIBUTIONS OF PROPOSED TECHNIQUES

Some benefits of the proposed techniques are:

i. Maintaining a clean, safe and carbon pollution free environment.
ii. Providing affordable means of transportation.
iii. Proposing long lasting vehicular energy sources.
iv. Suggesting and opening up a new area of research.

9. CONCLUSION/FUTURE WORK

From the discussions made and calculations written, it has been clearly deduced that supercapacitors can be used to power an electric vehicle if only they are constantly being charged. Values used can be adjusted to suit specific calculations.

As recommendation for future work, supercapacitors can be designed specifically for a presentation such as this and not just from an off-the-shelf one. This would enhance the production of supercapacitors with larger values capable of providing more power.

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