Final Technical Report

CCDP 2100 Q Team Project: Improving Efficiency of Electrical Vehicles

Design of the Battery of Electrical Vehicel

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Abstract

Vehicles are the main source of carbon emission which leads to put the climate change in danger in increasing amount time to time. This report is a research on EV which is to increase its efficiency and to decrease the effect of non-EV on the climate change.

EV's consist five main components the battery design, the motor, the inverter, the regenerative braking system, and the battery management system. The report's main topic is the lithium-ion battery. The lithium-ion battery is directly connected to the vehicle's charging port, and as a result, electric energy gained flows within the battery, moving the electron, which then causes the ion to move and stores chemical energy. When the car is moving, the chemical energy is transformed into mechanical energy and sent to the vehicle's motor.

Electromotive force (emf) and power density, the two key design tenets for batteries used in electric vehicles (EVs), are the main topics of discussion in this article. Charges can travel around a circuit as a result of the emf, a form of force that can be generated by an electrochemical cell or an electromagnetic field. Electron flow, carbon emissions reduction, and climate change are all impacted positively by emf in the case of EV batteries. On the other side, power density refers to the measurement of power production per unit of volume or mass. As it affects the performance of the vehicle, it is a crucial engineering principle in the design of EV batteries. As a result, extensive research has been done to enhance EV battery performance, increase battery life, and power density.

The feasibility of the design of the battery of EV's is promising. However, challenges came from the mass production lithium battery of EV's which have high carbon emission more than its life time, the technical barriers to recycle at end of the battery life time and using the earth scarce source lithium.

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1.0 Introduction

This report is written in response of the final technical report CCDP 2100 Q project deliverable. The Engine crusaders have been working in this project to improve the efficiency of Electric Vehicles (EV's) in order to decrease their effects on the climate change. In order to improve the efficiency of the EV's Engine crusader team look the main components of EV's and do research about the working principle of each component as attached on Appendix A: Project Outline. This specific report focus on the design of the battery of EV's, one of the main components of EV's. The purpose of this report is to cover the working principle of the design of the battery of the EV's which includes electromagnetic force (EMF) and power density.

This technical report began by explaining the background on transportation means and their danger on the climate which imposes a design of EV's in order to protect the climate. This is followed by the discussion on the one the component of EV's which is the design of the battery of EV's. The discussion contains two sub-section 3.1 EMF and 3.2 power destiny which are the two working principle of the battery of EV's. After the technical discussion a conclusion is followed up. The conclusion gives a brief summary about this technical report and includes the feasibility of the design of the battery of EV's. A glossary is also included to give definitions of words, which will be italicized, used within the report to better convey the purpose of the battery of EV's.

2.0 Background on the Danger Imposed on the Climate Change by Non-EV’s

Nowadays vehicle is among the main part of human life around the world for different purposes. There are so many worldwide and local vehicle companies which produce vehicles in different models. Vehicles are not only differentiated based on their models and the brand company but also on their source of power: steam, gasoline, electric and hybrid. Steam vehicles are among the first vehicles in human history to be produced. Because of some barriers in their production, steam vehicles aren’t mass produced and used these days. Gasoline vehicles came after steam vehicles in the production line of vehicles. On January 29, 1886 Karl Benz received the first patent for a gas-fueled vehicle [1].

The importance of gasoline vehicles in making human day to day life easy outweighed any damage brought by it in the first era of the gasoline vehicle production. As time passed the dangers imposed on the climate change came to be main issues. Some of the dangers are: carbon emission, *greenhouse gases*, global warming, usage of non-renewable resources of earth from underground and etc. If we look in to carbon emission statistics tell us that a typical passenger vehicle emits about 4.6 metric tons of carbon dioxide per year [2]. This study calls for a solution in the climate change that is imposed by gasoline vehicles.

Team Engine crusaders look into EV’s as a solution for the climate change that is endanger because of the mass use of gasoline vehicles around the world. In 1996 General Motors released the EV1, the first mass-produced purpose-built modern electric car, from one of the industry's key players [3]. After this mass production they became in use slowly. But these days because of the role they play in decreasing a carbon emission, global warming and the usage of non-renewable resources from underground, they gain popularity around the world.

Team Engine crusaders proceed to do research on EV's components and their principles as solution in replacement of gasoline cars.

3.0 Discussion of the design of the battery of EV's

EV's consist of five main components: regenerative braking system, the motor, the inverter, the design of the battery and battery management system. The components of the EV's attached on Fig 1 will give more visual illustration of the EV's components mentioned.

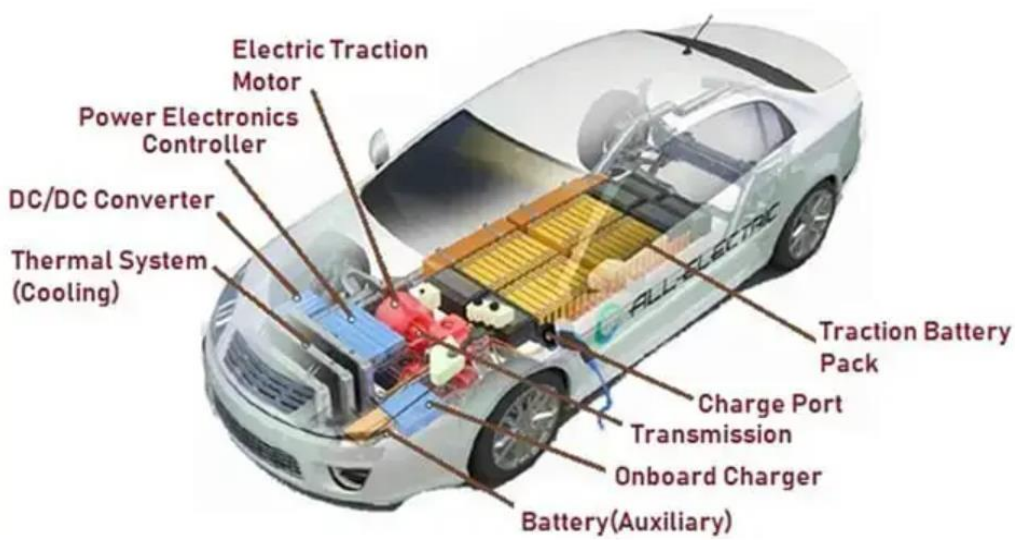

Fig 1: Components of EV [4]

Although the design of the battery of EV can be different type, the main focus of this report is a battery of EV made from lithium. The battery of EV is directly connected to charge port of the vehicle. After the vehicle is charged the electric energy gained made the electron to flow inside the lithium-*ion* battery. The electron flow caused by electric energy also cause ion movement which can be described as electron flow. This ion movement cause to have *chemical energy* inside the battery. After wards the chemical energy is changed to *mechanical energy*. This mechanical energy is transferred to the motor of the vehicle whenever the vehicle is working. On the other hand, if the vehicle is not running the battery stores the chemical energy inside it. The rest of this discussion emphasis on the two main working principles of the design of the battery of EV's: emf and power density.

3.1 Principle 1: Electromotive Force (emf)

A constant *current* can be maintained in a closed circuit through the use of a source of emf, which is a device (such as a battery or generator) that produces an *electric field* and thus may cause charges to move around a circuit. One can think of a source of emf as a "charge pump." When an electric potential difference exists between two points, the source moves charges "uphill" from the lower potential to the higher. The emf is calculated the *work* done per unit *charge* as described on equation 1 below, and hence the SI unit of emf is the volt [5]. Emf is a type of force that can be produced either in *electrochemical cell or electromagnetic field.*

emf = W/Q (Eq 1) W: Work

Q: charge

When there is *potential difference* between the two electrodes called *anode* and *cathode* an electric field will be produced inside the electrochemical cell. This electric field will produce an emf between the *electrodes* in the electrochemical cell. Now we can imagine the electromotive force inside the cell as pump. Because it causes an electric current to flow around the circuit of the electrochemical cell. The standard hydrogen electrode (SHE) acts as a primary reference in electrochemistry. The standard potentials (emf) of all other reference electrodes are linked to that of the SHE at the same temperature [6]. This standard potential is used to calculate non-standard emf of all electrochemical cell. The formula used to calculate emf in non-standard is called Nernest equation named after the scientist as attached on equation 2 and 3 respectively.

Figure 2 gives visualization on how emf is measured in electrochemical cell. For an ion–metal electrochemical *equilibrium* such as $M^{n+} + ne^{-} \rightleftharpoons M$ (Eq 3) [7]

$$E_{M^{n+}/M} = E^{\circ} + \frac{RT}{nF} \ln \frac{a_{M^{n+}}}{a_{M}}$$

Eq 2: Nernst equation [7]

a_{Mn+} activities of the *oxidized* Mn+

a_m activities *reduced* M species

E^0 stands for the electrode potential

R for the gas constant = 8.3144598 J.mol-1.K-1

T for the absolute Temperature

F for Faraday's constant

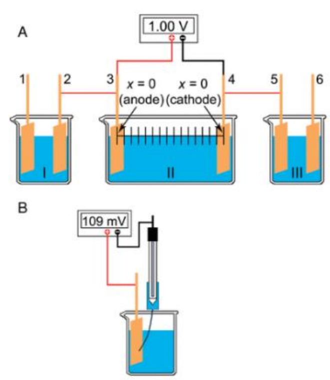

Fig 2: Measuring emf in electrochemical cell [7]

In addition to electrochemical cell, electromagnetic field can produce emf. The work done by the electromagnetic field on a unit positive point charge along the closed path considered. It presents itself as the natural definition of the emf, within the Maxwell-Lorentz theory: emf = £ [8]. This theory is described with the equation 3 below.

$$\mathcal{E} = \oint_l \left(\vec{E} + \vec{v}_c \times \vec{B}\right) \cdot \vec{dl}.$$

Eq 4: Maxwell-Lorentz formula [8]

Vc: velocity of charge

B: magnetic field

dl: derivative of length of the coil

The electromagnetic filed produce emf on *conductors* most of the time which are made of turns of coil. So that the direction of emf s described using Lenz's law [9].

Emf on the battery of EV's take the same principle that was described on electrochemical cell. Because this report focuses on a battery made of lithium ion, the lithium-ion serve as both the metal and the ion source. This satisfy the electrochemical equilibrium equation mentioned in equation 2 and equation 3 respectively. A work is done when it is charged with electrical energy through its charge port. This make a potential difference between the two electrodes and induces electric current which leads us to say emf is one of the basic engineering principle of the design of EV's. However, the battery design isn't going to be pure. If their is resistor in the design of the battery their way of connection will be in consideration either *paralle*l or *series* connection. From this part of discussion, we can see that the major role emf plays is to flow the electrons which prevents carbon emission from EV's. Reducing a carbon emission during this cycle leads us for improving the climate change.

3.2 Principle 2: Power Density

Power density is a measured in two ways. The first one is of using the power output per unit volume [10]. This will lead us to two steps to calculate and find the formula of power density. The first step is to measure how much power is applied into that enclosed surface area which is standardized international unit of *watt*. The second step is to identify what kind of surface area is the power applied. If it is among the popular surface volume: cube, hemisphere, cylinder and etc. Use their specific shorthand formula otherwise calculate the volume of surface using the triple integration method. Equation 5 provides the precise formula of power density.

Power Density = Power / Volume   Eq 5[10]

The second method is to find the amount of power in a given mass. Instead of finding over the volume measure the mass and power then formula on equation 11 will gave the power density [11].

Power Density = Power / Mass Eq 6[11]

One thing to notice while finding the power density, that it has difference from *energy density*. The design of EV battery are designed to store power inside themselves mainly. Whenever power is transferred to different part of the EV and applied to on a specific mass or volume. So the engineering principle power density is also the other vital principle in the design of the battery of EV’s. With an increasing awareness of environmental issues, interest in and research on electric vehicles (EVs) worldwide have increased. In EVs, the battery design is a core component that determines the vehicle's performance, and therefore, much research has been carried out to improve EV battery performance. In order to maximize battery performance, power conversion units (PCUs) should also be considered as part of the main technology in EVs. Power conversion systems for electric vehicles (EVs) have been researched to improve power density and efficiency at low cost [12]. Recently the researches attempts became applied which provides improved power density and the efficiency of the EV. This leads into long life of the battery. The long life of the battery could prevent the climate change not to be endangered which is imposed by mass production of the battery and the wastage of the battery at the end of its lifetime.

Conclusion

In order to reduce the impact of electric vehicles on climate change, the Engine Crusaders team has been working on the CCDP 2100 Q project to increase their efficiency. This technical research focuses on the two working principles of the design of the battery of EV's: electromagnetic force (EMF) and power density. Background information on the threat non-EV vehicles pose to climate change has also been covered, highlighting the necessity for alternatives to gasoline-powered vehicles. Because to its role in reducing carbon emissions, global warming, and the use of subterranean non-renewable resources, electric vehicles (EVs) have gained popularity as a solution.

With a focus on the lithium-ion battery, the debate on the battery design of EVs offers an overview of the key elements of EVs and how they are connected. When the vehicle is operating, the battery transfers mechanical energy from the chemical source to the motor. The battery stores its internal chemical energy when the engine is off. EMF and power density, the two fundamental design tenets for EV batteries, have also been thoroughly explained.

Overall, the paper underscores the significance of EVs as a climate change solution and stresses the significance of EV battery design in enhancing their efficiency. The Engine Crusaders team's research and design of EV batteries have been a significant contribution to the CCDP 2100 Q project. The feasibility of the design of the battery of EV’s came from the mass production lithium battery of EV’s which have high carbon emission more than its life time, the technical barriers to recycle at end of the battery life time and using the earth scarce source lithium.

Glossary

Ion: a sub group of atoms formed from lost or gained electrons [13]

Chemical Energy: an energy produced by chemical reaction [13]

Mechanical energy: an energy gained by the motion of an object [13]

Current: a flow of electrons per given time [13]

Electric Field: a region where force is exerted because of charged particles [13]

Work: is a force applied to a give distance not in perpendicular point [13]

Electrochemical cell: is a device that generates electrical energy from chemical energy [13]

Electromagnetic Field: a region formed by both electric and magnetic force [13]

Anode: an ion that is formed by gaining electrons [13]

Cathode: an ion that is formed by losing electrons [13]

Electrode: is a substance in solid state which transfer electron [13]

Equilibrium: a balanced condition or state reached between different [13]

Oxidized: is a state when an ion loses its electrons [13]

Greenhouse gases: are gases in the earth’s atmosphere that trap heat. [14]

Energy Density: Energy density is the amount of energy in a given mass (or volume) [11].

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Available: https://www.nationalgrid.com/stories/energy-explained/what-are-greenhouse-gases#:~:text=Greenhouse%20gases%20(also%20known%20as,greenhouse%20gases%20in%20the%20atmosphere. [Accessed : Mar , 28, 2023]

APPENDIX A: Project Outline Form

PROJECT TOPIC TITLE: Improving efficiency of Electric Vehicles	TEAM NAME Engine Crusaders	TEAM MEMBERS' NAMES 1. Hannah Selden 2. Andrew Haddad 3. Jana Alharbi 4. Peniel Terfa 5. Mitchell Beaven

Background:

Back in 2020, Canada produced around 672 megatons of carbon dioxide [1], One way we can reduce these numbers is switching from gas powered vehicles to electric vehicles.

PRINCIPLES / LAWS / THEORIES FROM 1ST (or possibly 2nd) YEAR ENGINEERING COURSES:

Component 1: Regenerative braking	Team member: Hannah Selden
Principle 1: Capacitance	Principle 2: Boolean algebra (relay logic)
Source course: PHYS1004 [5]	Source course: SYSC2310 [6]
Component 2: Battery management System	Team member: Andrew Haddad
Principle 1: interfaces	Principle 2: Handling errors
Source course: SYSC2004 [3]	Source course: SYSC2004 [3]
Component 3: Power Inverter	Team member: Jana Alharbi
Principle 1: DC/AC conversion	Principle 2: Amplifiers
Source course: ELEC2501 [2]	Source course: ELEC2507 [4]
Component 4: Battery Design	Team member: Peniel Terfa
Principle 1: Voltage Difference	Principle 2: Power Density
Source course: ECOR 1043 [2]	Source course: ELEC 2501 [2]
Component 5: Electric motor	Team member: Mitchell Beaven
Principle 1: Electromagnetism	Principle 2: Torque
Source course: PHYS 1004 [5]	Source course: ECOR 1045 [7]

REFERENCES (in IEEE format)

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[5] J. Walker, R. Resnick, and D. Halliday, *Fundamentals of physics*, 10th ed. Hoboken, NJ: John Wiley & Sons, Inc., 2014.

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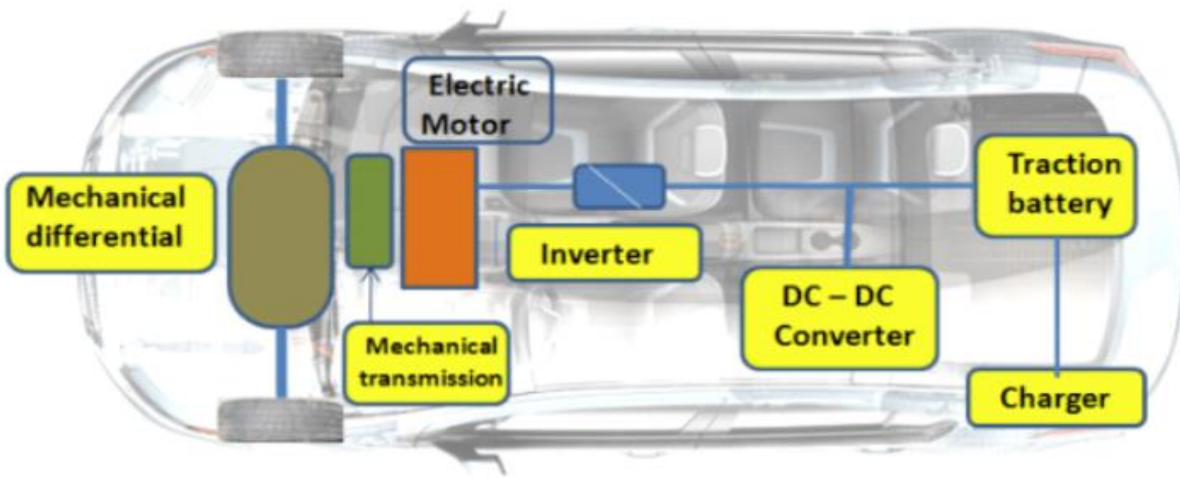
SYSTEM DESCRIPTION

Electric vehicle modifications span a range of related improvements to existing electric vehicle (EV) models. Each component considered addresses a specific area of concern in the transformation of power, starting from the battery and ending with the motors that drive the EV's motion. To avoid excessive use of the battery, regenerative braking can employ boolean algebra to decide when to use the vehicle's momentum to store energy in super-capacitors, and when to discharge the capacitor as an energy source. The battery itself can be designed to maximize power density by using materials with an appropriate voltage difference. The battery management system monitors the battery's condition using the vehicle's interface and uses the data in handling errors. The Power Inverter takes a DC signal and improves it by using the amplifiers, then converts it to an AC signal. The Electric motor uses electromagnetism to produce forces which when designed correctly will produce a torque which is used to move the EV.



[Fig. 1] W. Liu, T. Hauck, and J. Drobnik, "Effective Thermal Simulation of Power Electronics in Hybrid and Electric Vehicles" , *World Electric Vehicle Journal*, vol. 5, pp. 574–580, 06 2012.

Appendix B: Peer Mentor's Review Form

CCDP2100 - Final Design Report: draft review by peer mentor

Student's Name: Peniel Terfa

Just FYI, I have commented only on the technical aspects of the report and have not edited for style, grammar, etc…

-Have the theoretical concepts been explained accurately?

Section 3.1 appears to be copy and pasted from another resource. That being said, what is there is accurate, but needs to be explained in much more detail. The principle outlined in section 3.2 (MPPT) is mostly accurate (see in text comments about the relationship between sunlight and voltage), but also needs more detail.

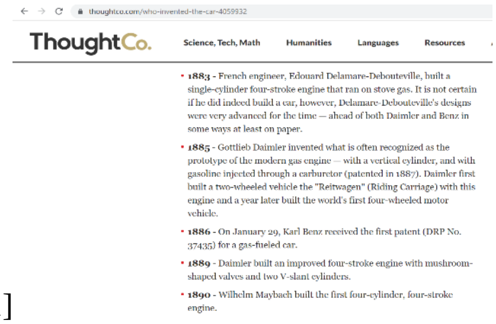
-Has the theory been applied accurately when explaining the design?

In 3.1 the application is somewhat applied accurately, but needs to be expanded. More detail is needed on how the principle is applied to your component.

For 3.2 the theory has not yet been applied to the design, although the connection is fairly clear. Add an explanation of how MPPT will be used for your component, and why it is needed in the design.

Please see the comments in your attached draft for more detailed feedback.

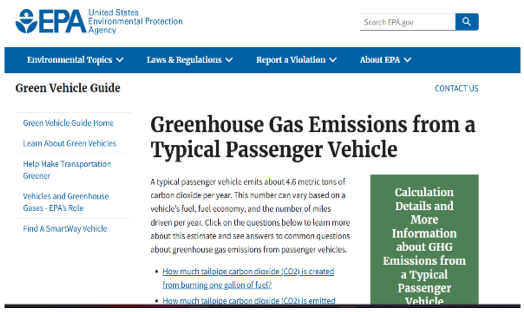
Appendix C: Screenshots of Sources


thoughtco.com/who-invented-the-car-4059932

ThoughtCo. Science, Tech, Math Humanities Languages Resources

- **1883** - French engineer, Edouard Delamare-Debouteville, built a single-cylinder four-stroke engine that ran on stove gas. It is not certain if he did indeed build a car, however, Delamare-Debouteville's designs were very advanced for the time — ahead of both Daimler and Benz in some ways at least on paper.
- **1885** - Gottlieb Daimler invented what is often recognized as the prototype of the modern gas engine — with a vertical cylinder, and with gasoline injected through a carburetor (patented in 1887). Daimler first built a two-wheeled vehicle the "Reitwagen" (Riding Carriage) with this engine and a year later built the world's first four-wheeled motor vehicle.
- **1886** - On January 29, Karl Benz received the first patent (DRP No. 37435) for a gas-fueled car.
- **1889** - Daimler built an improved four-stroke engine with mushroom-shaped valves and two V-slant cylinders.
- **1890** - Wilhelm Maybach built the first four-cylinder, four-stroke engine.

[1]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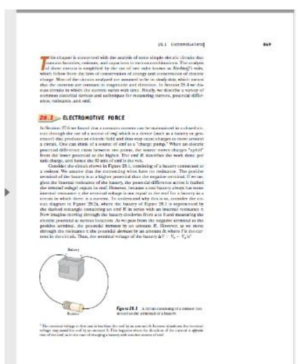
Greenhouse Gas Emissions from a Typical Passenger Vehicle

A typical passenger vehicle emits about 4.6 metric tons of carbon dioxide per year. This number can vary based on a vehicle's fuel, fuel economy, and the number of miles driven per year. Click on the questions below to learn more about this estimate and see answers to common questions about greenhouse gas emissions from passenger vehicles.

- How much tailpipe carbon dioxide (CO2) is created from burning one gallon of fuel?
- How much tailpipe carbon dioxide (CO2) is emitted

Calculation Details and More Information about GHG Emissions from a Typical Passenger Vehicle

[2]



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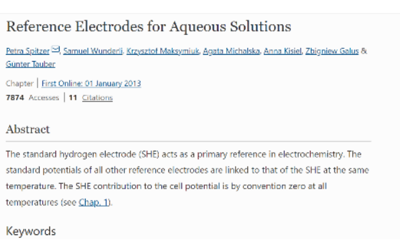

Reference Electrodes for Aqueous Solutions

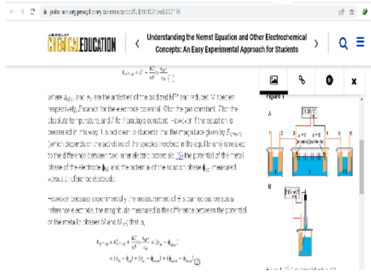
Petra Spitzer, Samuel Wunderli, Krzysztof Maksymiuk, Agata Michalska, Anna Kisiel, Zbigniew Galus & Gunter Tauber

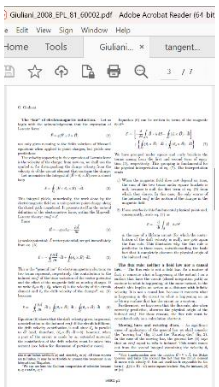
Chapter | First Online: 01 January 2013
7874 Accesses | 11 Citations

Abstract

The standard hydrogen electrode (SHE) acts as a primary reference in electrochemistry. The standard potentials of all other reference electrodes are linked to that of the SHE at the same temperature. The SHE contribution to the cell potential is by convention zero at all temperatures (see Chap. 1).

[6] Keywords

[7] 
Understanding the Nernst Equation and Other Electrochemical Concepts: An Easy Experimental Approach for Students

[8] 
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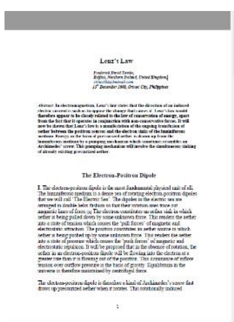
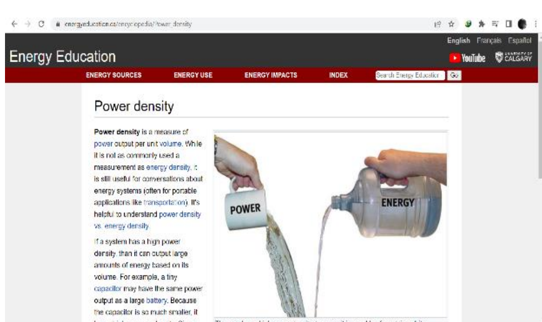
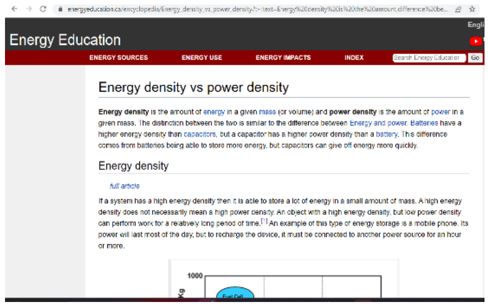
Home
Tools

[9] 
Lenz's Law
The Electron-Positron Dipole

[10] 
Energy Education
ENERGY SOURCES
ENERGY USE
ENERGY IMPACTS
INDEX
Power density
Power density is a measure of power output per unit volume. While it is not as commonly used a measurement as energy density, it is still useful for conversations about energy systems (often for portable applications like transportation). It's helpful to understand power density vs. energy density.
If a system has a high power density, then it can output large amounts of energy based on its volume. For example, a tiny capacitor may have the same power output as a large battery. Because the capacitor is so much smaller, it has a higher power density. Since
POWER
ENERGY
The mug has a high power density, because it is capable of emptying all its

[11] 

energyeducation.ca/encyclopedia/Energy_density_vs_power_density#:~:text=Energy%20density%20is%20the%20amount,difference%20be...

Energy Education

ENERGY SOURCES ENERGY USE ENERGY IMPACTS INDEX

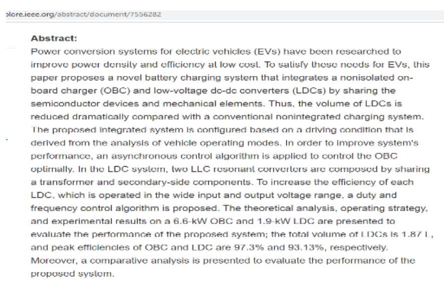
Energy density vs power density

Energy density is the amount of energy in a given mass (or volume) and **power density** is the amount of power in a given mass. The distinction between the two is similar to the difference between Energy and power. Batteries have a higher energy density than capacitors, but a capacitor has a higher power density than a battery. This difference comes from batteries being able to store more energy, but capacitors can give off energy more quickly.

Energy density

full article

If a system has a high energy density then it is able to store a lot of energy in a small amount of mass. A high energy density does not necessarily mean a high power density. An object with a high energy density, but low power density can perform work for a relatively long period of time.[1] An example of this type of energy storage is a mobile phone. Its power will last most of the day, but to recharge the device, it must be connected to another power source for an hour or more.

[12] 

plore.ieee.org/abstract/document/7556282

Abstract:
Power conversion systems for electric vehicles (EVs) have been researched to improve power density and efficiency at low cost. To satisfy these needs for EVs, this paper proposes a novel battery charging system that integrates a nonisolated on-board charger (OBC) and low-voltage dc-dc converters (LDCs) by sharing the semiconductor devices and mechanical elements. Thus, the volume of LDCs is reduced dramatically compared with a conventional nonintegrated charging system. The proposed integrated system is configured based on a driving condition that is derived from the analysis of vehicle operating modes. In order to improve system's performance, an asynchronous control algorithm is applied to control the OBC optimally. In the LDC system, two LLC resonant converters are composed by sharing a transformer and secondary-side components. To increase the efficiency of each LDC, which is operated in the wide input and output voltage range, a duty and frequency control algorithm is proposed. The theoretical analysis, operating strategy, and experimental results on a 6.6-kW OBC and 1.9-kW LDC are presented to evaluate the performance of the proposed system; the total volume of LDCs is 1.87 L, and peak efficiencies of OBC and LDC are 97.3% and 93.13%, respectively. Moreover, a comparative analysis is presented to evaluate the performance of the proposed system.

[13] Greenhouse gases (also known as GHGs) are gases in the earth's atmosphere that trap heat. During the day, the sun shines through the atmosphere, warming the earth's surface. At night the earth's surface cools, releasing heat back into the air. But some of the heat is trapped by the greenhouse gases in the atmosphere. That's what keeps the earth's temperature at an average 14˚C (57˚F).