Current Status of Art

Project Title: The EV 2.0

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The E.V 2.0 is a project meant to provide a cleaner and more intelligent means of transportation than internal combustion engines (ICE) vehicles and this is only possible by having a key understanding into how this can be achieved (using an electric motor to produce torque that compares to that of ICEs) and what already exists (the variation and evolution of electric vehicles based on design requirements such as acceleration, range, cost etc.) which will then lead us to consider changes in the range, cost and power generated and the overall use of our EV. There are three main types of motors; the brushed dc motor, the brushless dc motor and the ac induction motor. The DC brushed electric motor uses an electromagnet known as an armature with a commutator and brushes to transfer power from the DC power source to the motor, providing the turning motion. The brushless DC motor provides a solution to the lifespan and maintenance cost of the dc brushed motor by replacing the commutator and brush assembly with a controller that maximizes the torque production. The AC induction motor provides a better range of torque consistently over a wider range of time using AC power to generate a magnetic field to produce its turning force.Based on the research and analysis, we have decided to go with the AC induction motor for our propulsion system because it meets the changes in our design requirements for cost, efficiency, mileage and torque production. The relevant products manufactured by key companies in the industry of electric vehicles focus on specific design requirements. These requirements address the acceleration of the vehicle, the range of the vehicle per full charge, time needed to charge battery to adequate level, the energy density and efficiency of the battery, the weight of the vehicle, the type of electric motor used, and the overall cost of the vehicle. Based on research on relevant products we refined our initial design requirements for the EV 2.0 by making changes to the mileage at full charge and the rest-to-60mph acceleration time.

State of the Art: Principle/ Theory

The main technology behind electric propulsion systems is that of electric motors. Electric motors provide the necessary thrust to move the vehicle and its passengers using electricity from a stored power source (battery). The main principle behind the way electric motors work is that of using electromagnetism to generate mechanical motion. An electric motor uses the forces of attraction and repulsion of a magnet to generate the rotational motion that moves an object. It does this by allowing electric current to flow through a loop of wire which then produces a magnetic field across the loop. Once this loop is encompassed by the magnetic field of a different magnet, it will rotate, producing torque that will lead to mechanical (kinetic) motion. The intensity torque that is generated is dependent on the current, voltage and efficiency of the motor. It is calculated using the formula;

$$\tau = (I * V * E * 60)/(rpm * 2\pi)$$

where I = current, V = voltage, E = efficiency, and rpm = revolutions per minute.

To help increase the torque and reduce the rpm requirements, multiple poles are used to help maximize the torque. The voltage and current requirements are supplied power source (battery).

The motors are made up of six parts, namely:

1. Armature or rotor
2. Commutator
3. Brushes (except if brushless)
4. Axle
5. Field magnet
6. Power supply

From these parts, we get two main type of motors namely;

- DC Motors: These are motors that convert direct current into mechanical energy and of this type of motors, there are two types;
    - DC Brushed Motors: These generate torque straight from the DC power supplied to the motor using the principle of internal commutation, utilizing rotating electromagnets and permanent magnets. Brushes or springs (usually made of carbon) are used to carry the electrical current to the rotating motor in the permanent magnets' field. They have a low initial cost and high reliability but have a high maintenance cost, coupled with a low life-span if they are used in high intensity functions such as in electric cars.
    - DC Brushless Motors: These operate in a similar way as brushed DC motors. With the advent of cheap computers and power transistors, it became possible to "turn the motor inside out" and eliminate the brushes. In a brushless DC motor (BLDC), you put the permanent magnets on the rotor and you move the electromagnets to the stator. Then you use a computer (connected to high-power transistors) to charge up the electromagnets as the shaft turns. They have a higher initial cost and use more complicated controllers than their brushed counterparts but at the same time, have higher efficiency, with a longer lifespan and little or no maintenance.
- AC Induction Motors: These motors use ac power to generate a magnetic field that turns in sync with the AC oscillations. This implies that the induction motors stator field is changing relatively to the rotor, allowing for more consistent torque over a wide time frame. These motors use Lenz's law as one of their guiding principles. Because of this difference in rotations in the ac induction motor, currents can be induced during regenerative braking that help charge the batteries. It usually requires an inverter to convert the DC power of the batteries to AC power for the motor. It is highly efficient and has a moderately high initial cost compared brushed dc motor and brushless dc motor. It has little to no maintenance and can produce more and varying torque than its dc counterparts.

<u>Relevant Products</u>

Electric vehicles are undoubtedly the future of personal transportation as car manufactures like Ford, Nissan and Tesla are committing a lot of resources to the research and development of electric vehicles in anticipation of an increased market for electric vehicles in the future. The demand for electric vehicles is expected to increase due to the fact that electric vehicles are more efficient and greener than gasoline-powered cars and the electricity needed to power them can be obtained from various energy sources such as wind, solar and biofuel. The number of electric vehicles available in the market is growing gradually and each car model has a unique electric propulsion system. An electric propulsion system is a system which makes use of electrical power generated by motors to accelerate a propellant (the vehicle in this case). The electric propulsion system of electric vehicles consists of batteries, controller, electric motor(s) and transmission. Car manufacturers are constantly working on improving the performance of the electric propulsion system of their cars.

The Tesla Model 3 can move from rest to 60mph in less than 6 seconds and reach a top speed of 130mph. It can go up to 220 miles on a single charge which is about twice the range of one of its competitors. The Model 3 can be charged to half its battery capacity in about 20 minutes at a Tesla supercharger station. It has one battery pack - 50 KWh or 70 KWh and with new advancement in battery technology, it is 400 lbs lighter than older models. This is one of the design changes made by Tesla to make Model 3 their fastest model. Unlike gasoline-powered cars, electric vehicles have low cooling needs since they do not have internal combustion engines that generate a considerable amount of heat. A major feature Tesla changed in the production of the Model 3 is the type of motor used in the electric propulsion system of the car. A permanent-magnet (PM) electric motor is used in the Model 3 instead of the AC induction motors used in the older models produced by Tesla because they realized that PM motors are more efficient than induction motors. All electric vehicle manufacturers must choose the best electric motor that will meet their design specifications. Some vehicles use DC motors while others use AC motors. There are also different versions of DC motors and AC motors. Moreover, the manufacturers also need to decide on the number of motors to use in their electric car models.

The performance of the latest Ford Focus Electric model (another EV in the market) is quite different from the Tesla Model 3 as its electric propulsion system has different design specifications. It has a 143 horsepower permanent magnet electric motor and a range of about 115 miles which is better than its predecessor. The batteries have become denser and thus can hold more energy per volume which shows rapid advancement in electric vehicle technology. The size of the car curtailed the size of the battery which is why they made it denser i.e. pack more energy in a unit volume instead of increasing its size. A lot of research is being conducted on how to make the batteries energy-denser. The Ford Focus uses a 23 KWh Lithium-ion battery that can be fully charged in 3.6 hours at 240 volts. It can reach 60 mph from rest in 9.9 seconds and a top speed of 84 mph. In general, the specifications of the Tesla Model 3 are better than the Ford Focus Electric as the Tesla Model 3 has a higher top speed, range and acceleration among other things. However, this does not prove that the performance or efficiency of the Tesla Model 3 is better than that of the Ford Focus Electric. The Focus is $29000, which is $6000 less than the cost of the Model 3. One could infer that the price difference is the reason the specifications of the Model 3 are better. The electric propulsion system of the Model 3 is made up of better but more expensive components.

The various electric vehicles that exist are dependent on the components in its electric propulsion system. It is also affected by the type of batteries, the type and power of the electric motor and other components used. As a manufacturer, you have to choose the best components to use in the vehicle design that would meet your design requirement keeping the budget in mind. So, the main issue most manufacturers face today is how to increase the performance of their vehicles without significantly increasing the market price of the vehicles.

Refined Design Requirements

Based on the changes to our original design requirements, the AC induction motor would be best for our electric propulsion system. In terms of cost, they are less expensive than DC brushed motors and less expensive than DC brushless motors. They also have a better efficiency than brushed DC but less than brushless DC motors. This is because they have no magnets and the magnetic fields they induce are adjustable meaning at lower loads, the inverters they use can reduce voltage use, reducing magnetic losses and increasing efficiency. Also as the machine size grows, losses in energy do not necessarily grow with AC induction motors meaning they can give consistent performance over a wider range of scenarios. AC induction motors have little to no maintenance required, and if used right, can last for close to a lifetime. AC induction motors also make the integration of regenerative braking (to charge the batteries) seamless. These properties of AC induction motors will allow us meet our adjusted design requirements and achieve our goals for the EV 2.0.

Our design requirements included:

1. The electric vehicle should be able to produce enough torque to transport load (vehicle and passengers) of up to 6000 pounds.
2. The electric vehicle should have a mileage of at least 90 miles at full charge
3. The electric vehicle should be able to accelerate to 60 mph from rest in 15 seconds.
4. The electric vehicle should be at least 50% efficient in converting the electrical energy stored in the batteries to torque.

However, upon performing research into the state of the relevant products within the electric vehicle industry, we can make changes to the original design requirements such as:

1. The electric vehicle should still be able to produce enough torque to transport a load of up to 6000 pounds.
2. The electric vehicle should have a mileage of at least 75 miles on full charge
3. The electric vehicle should be able to accelerate to 60 mph from rest in under 20 seconds.
4. The electric vehicle should still be able to be at least 50% efficient in converting the electrical energy of the batteries to mechanical energy.

Based on the research we performed into the state of the relevant products, we found that the average curb weight of a 5-person electric vehicle is 4000 pounds. When we account for the weight of the passengers (assuming 200 pounds per person) and the extra load from what could be in the trunk (about 600 pounds) we can conclude we need the vehicle to produce enough torque to transport load of up to 6000 pounds. We also concluded that the vehicle should have a mileage of at least 75 miles per full charge after a comparison with top cars like the Tesla Model S which has a range of about 300 miles but costs about $90,000. Assuming that the budget for this vehicle will be about $20,000 we can project the mileage to be about 75 miles per full charge. The amount needed for an engine that produces the horsepower needed to accelerate the car to 60 mph is high. The Tesla Model S engine, which costs about $15,000, has a HP of approximately 550 hp and the car reaches 60mph from rest in 6 seconds. Comparing and scaling down to our budget of $20,000, we want an engine with 200 hp which will take about 20 seconds to reach 60 mph. We also decided that the efficiency of the vehicle should still remain at 50%.