DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

DESIGN AND IMPLEMENTATION OF A BLDC HUB MOTOR POWERED ROAD MARKING MACHINE

by
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January, 2018
İZMİR

DESIGN AND IMPLEMENTATION OF A BLDC HUB MOTOR POWERED ROAD MARKING MACHINE

A Thesis Submitted to the
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M.Sc. THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"DESIGN AND IMPLEMENTATION OF A BLDC HUB MOTOR POWERED ROAD MARKING MACHINE"** completed by **AHMET SÜHA KILIÇOĞLU** under supervision of **ASST. PROF. DR. AYTAÇ GÖREN** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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Ahmet Süha KILIÇOĞLU

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ABSTRACT

Today’s road marking machines use internal combustion engines in order to supply power for the traction and the painting systems. This thesis aims to equip a road marking system with a fully electric drive. The system is also supported with solar panels for prolonged usage time per charge.

Commercial vehicles using clean energy is getting more and more important day-by-day. When it comes to urban use of vehicles, this challenge also combines with safer fuel needs.

Also, most of the commercial vehicles are used at low/off-traffic hours, at night, so that low noise is another problem that should be solved. To solve the problems mentioned, usage of forward speed of electrical drive is a useful solution.

Road marking machines work at around 4 km/h and they are not allowed to go faster than 15 km/h so the speed scatter is so narrow. Constant and low speed allows use of heavier batteries like lead-acid so the system gets more affordable than the light battery using counterparts. The designed system can work continuously for 4 hours without solar cells.

Keywords: Road marking machine, solar-cells, battery electric drive, electric motors

FSDA TEKERLEK MOTORLU BİR YOL ÇİZGİ MAKİNASI TASARIMI VE UYGULAMASI

ÖZ

Günümüzde Yol Çizgi Makineleri yürüyüş ve boyama sistemleri için içten yanmalı motorlar kullanmaktadırlar. Bu tez bir yol çizgi makinesinin tam elektrikli sürüş özelliğine kavuşmasını hedeflemektedir. Sistem fotovoltaik panellerle desteklenerek tek şarjda çalışma süresi uzatılmıştır.

Temiz enerji kullanan sanayi araçlarının sayıları günden güne artmaktadır. Araçların şehirde kullanılması konusu, daha güvenli yakıt kullanımı gereksinimini de beraberinde getirmektedir.

Ayrıca, birçok ticari araç düşük trafik yoğunluğunun olduğu saatlerde, gece saatlerinde, kullanılmaktadır. Bu sebeple sesli çalışma sorun oluşturmaktadır. Bahsedilen sorunları çözmek için elektrik motoru mantıklı bir seçenektir.

Yol çizgi makineleri 4km/h de boyama yapmakta ve 15km/h den daha hızlı gitmelerine izin verilmemektedir; bu nedenle sürat bandı çok geniş değildir. Sürekli ve düşük sürat daha ağır pillerin, kurşun asit gibi, kullanılması olasılığını sağlamaktadır. Ağır piller daha ucuzdur. Tasarlanan sistem güneş pilleri olmadan 4 saat çalışabilmektedir.

Anahtar kelimeler: Yol çizgi makinesi, şarjlı elektrikli araç, elektrik motorları, güneş hücresi

CONTENTS

LIST OF FIGURES

LIST OF TABLES

Page

CHAPTER ONE
INTRODUCTION

1.1 General Information

As researches show, gasoline engines emit more than twice CO_2 than electrical counterparts according to Union of Concerned Scientist. Thus, due to today's environmental conditions more vehicles are being turned into electrical powered.

In order to not to experience a resistance in the market, an old-fashioned model structure will be modernized.

The current system was primarily designed as a diesel-powered machine. Thus, for the new system's calculations will use the old system's weight and geometrical values. While calculating, and realizing the real vehicle, some data, like battery weight are estimated. After the calculation corrected, before final system design calculation.

In order to design the system with the low speed requirements brushless permanent magnet motors used because of their high efficiency and low maintenance requirements. Due to narrow max to min speed scatter band a fixed gear-box is added. Gear-box will decrease the speed of the motor and increase the torque output. The system will be used in parking areas and streets, the usage duration is estimated from 3 to 6 hours.

To extend the usage duration per charge solar panels were added to the design. Panels will also provide emergency power. In the following chapters the reasons for choosing the electrical motor is to be explained. At the final chapter a discussion is made on the future improvement possibilities and impacts of the improvements that could be realized. In this study, objective is to determine the most suitable way to convert the internal combustion powered road marking machine to battery electric type. Different motor types and assembly possibilities introduced for the solution.

1.2 Uses of Electrical Motors for Vehicles

The first recorded electric car was built in 1837 by chemist Robert Davidson from Aberdeen, Scotland. After that, He built a larger train engine named Galvani, demonstrated at the Royal Scottish Society of Arts Exhibition in 1841. The locomotive was seven tons and had two direct-drive reluctance motors. Motors had fixed electromagnets affecting on iron poles connected to a wooden barrel on each pivot, and simple brushes.

The real struggle was the lack for high capacity batteries and high efficiency electronic parts like being used in today’s motor drivers. Due to lack of technology the electrical vehicle projects had to wait for decades.

Figure 1.1 depicts some of the first electrical vehicle examples. Those vehicles could not have an impact to the industry as their internal combustion counterparts.

Figure 1.1 Pictures of early electrical car designs from left to right (a) Thomas PARKER LONDON, 1884; (b) Bundesarchiv, 1953; (c) The Henry Kilowatt, 1961 (Wikipedia, 2016)

The current technology enables the use of electrical motors in many types of vehicles. As can be seen in Figure 1.2 they are being used such as excavators to airplanes and space roves.

Figure 1.2 Pictures of some fully electric vehicles. From left to right (a) Alké® ATX® (b) Hitachi® ZX35B (c) Airbus® Group E-Fan® (Alké ®, Hitachi®, Airbus®, n.d.)

1.3 Drive Types of Land Vehicles

Mainly there are four drive types; namely Fuel, Hybrid (Internal Combustion with and an electrical motor), Plug-in Hybrid (Hybrid system with an external charge capability) and fully electric. There are also other types of power sources like fuel cells and solar cells.

Fuel Types uses an internal combustion engine to drive the vehicle. Hybrid vehicles additionally have an alternator to power the electric motor. Plug-in Hybrid versions can either be charged from a wall socket and the battery can also be charged via the internal combustion engine so they have smaller batteries compared to the fully electrical versions. Fully electrical versions must either be charged from the wall socket or their batteries can be swapped with a charged one.

Additionally, the hybrid, Plug-in hybrid and fully electrical versions’ range can be extended by adding fuel cells (Hydrogen, Natural Gas etc.) and/or solar cells. This range extension can also be achieved by battery swapping in battery electric vehicles.

The different drive types of electrical vehicle drives depicted on Figure 1.3. As can be seen from the depiction the hybrid vehicles have more complex designs thus, leads more frequent maintenances.

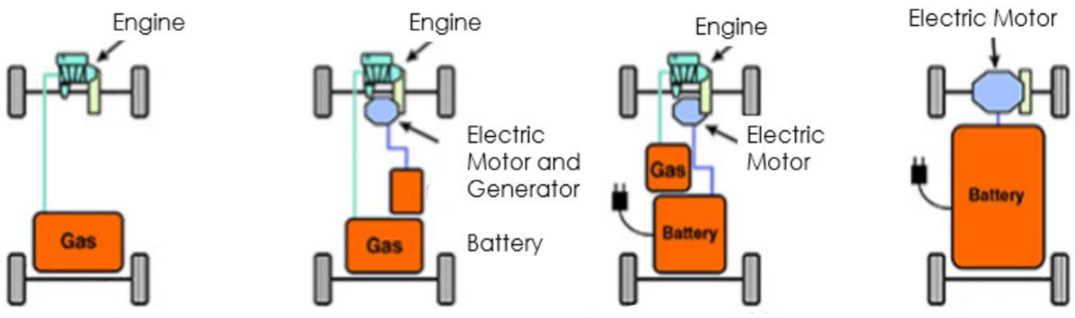


Figure 1.3 Main drive types for land vehicles. From left to right (a) Internal Combustion (b) Hybrid (c) Plug-in Hybrid (d) Fully Electric (EPRI, n.d.)

1.4 Efficiency of Electrical Drive

The comparison between the Fuel, Hybrid and Fully Electrical vehicles shows that using fully electrical vehicles. Figure 1.4 shows a study done by Duarte, Rolim, & Baptista (2016) on "How battery electric vehicles can contribute to sustainable urban logistics".

This research work evaluates the adequacy of BEV in urban logistics in Lisbon, based on a real-world application. Vehicle second-by-second data was collected during regular operation of both the internal combustion engine vehicle (ICEV) and the BEV (for 7 and 3 months respectively). From the municipal decision makers' point of view, based on this experience of up to 60 km per day in an urban context, BEVs are consequently an appropriate solution to address the air quality problem in city centers.

When analyzing the environmental affects in terms of energy and pollutant emission. The BEV presents an efficiency improvement of 76% on energy per distance driven, as well as savings in the TTW stage of 267g of CO_2/km and 0.364 g of NO_x/km due to zero local emissions.

The low carbon emission is a direct effect of the energy consumption shown in Figure 1.4. As shown in the chart the energy conversion ratio is 4 times of the electrical vehicle so the carbon emission is much greater.

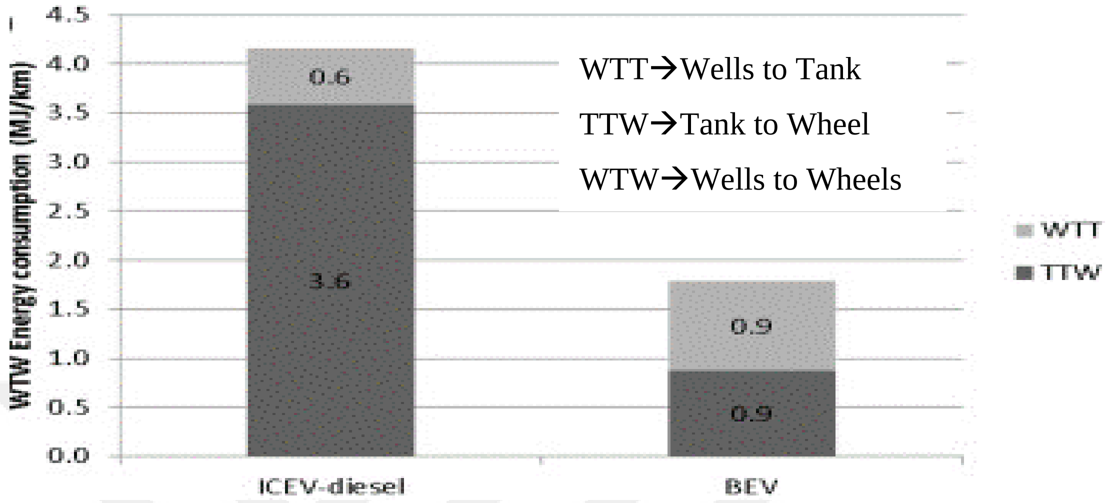


Figure 1.4 Wells to Wheels Energy Consumption (Mj/km) (Duarte, et. al., 2016)

1.5 Cost for Fuel

The study is done by Anair, & Mahmassani in 2012 on electric vehicles that do not use gasoline. Their contribution to oil usage is very scarce; due to fact that 1 percent of the electricity is produced via crude oil products in U.S.. For this calculation gasoline price per gallon is assumed as $3.50, and countrywide electricity cost is presumed as 11 cents/kWh. Also, a discount rate of 3 percent also taken into account to increase savings, aggregated lifetime mileage of 166,000 miles, and yearly travel that starts from 15,000 miles per year and decreases by 4.5 percent per year over 15 years.

Nissan LEAF (0.34 kWh/mile) is a typical demonstration of today's small to mid-sized electrical vehicle efficiency. More yearly mileage, and more efficient electric devices with more efficient electricity production can increase cost-savings estimates. The Figure 1.5 demonstrates the fuel consumption for different types of drives in U.S.A..

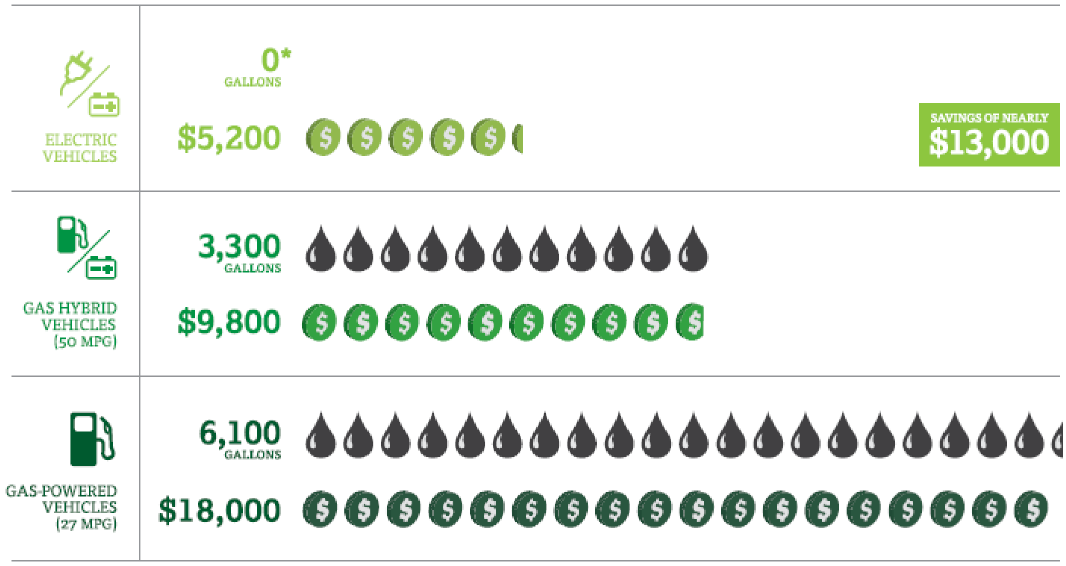


Figure 1.5 Life time gasoline consumption and fuel costs. (Anair, et. al., 2012)

1.6 Economic Impacts and Payback Duration for Electrical Vehicles

For not being widely spreaded and not being mass produced the EV vehicles' list prices are more expensive than Internal Combustion Vehicles.

The first expense gets to be amend by the advantages of the electrical design.

EV's have less moving parts this leads to cheaper mechanical maintenance. Also, the tax rates are lower due to low carbon emission programs of the governments. As far as the users concerned the electricity is easier to achieve thru many different sources, even homemade via sun and wind.

Figure 1.6 of Green Car Reports depicts a typical 50-year usage that compares an internal combustion and electrical engine driven vehicles. As the study suggest using solar electrical cars saves more than twenty times that spend on gasoline car. In the comparison, the setup expenses for solar charging system and yearly fuel coast increase were also include.

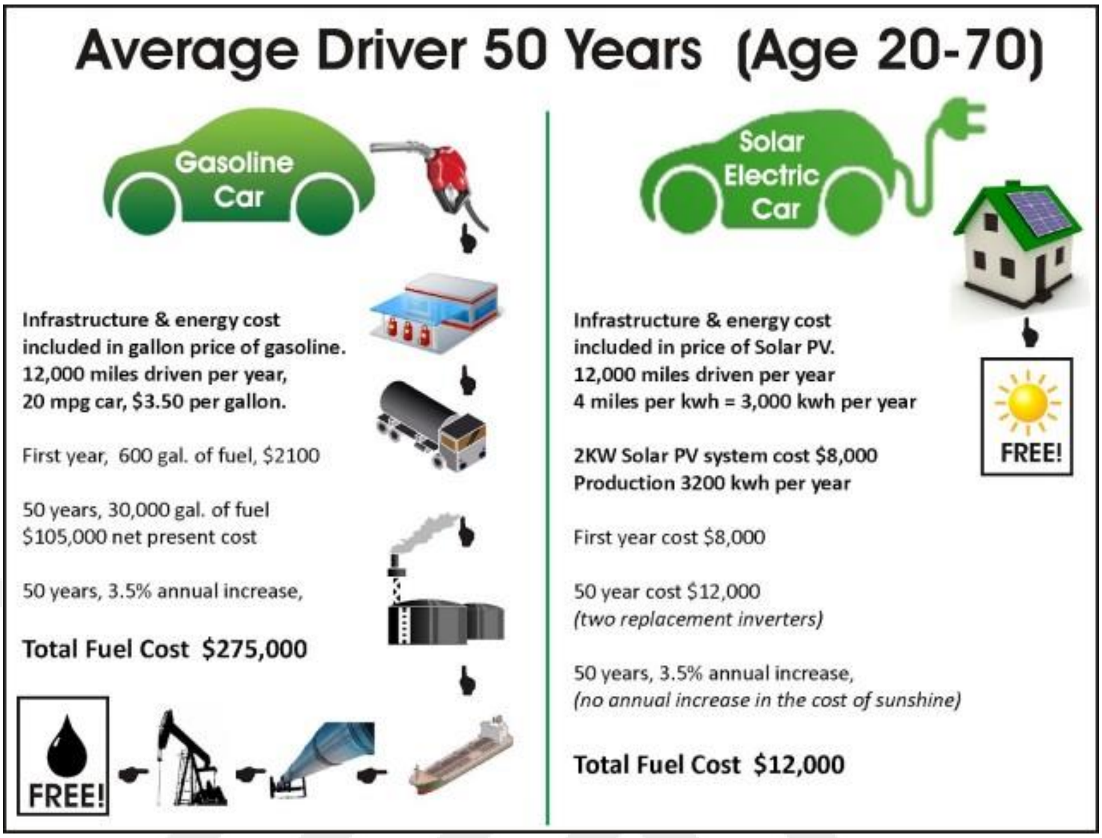


Figure 1.6 Comparison of ICE with EV for Long Time Use (Gordon-Bloomfield, 2012)

1.7 Environmental Carbon Foot Print Comparison

Currently electricity is being produced by both renewable and fossil fuels. Figure 1.7 depicts the energy sources for producing electricity in U.S.A in 2010.

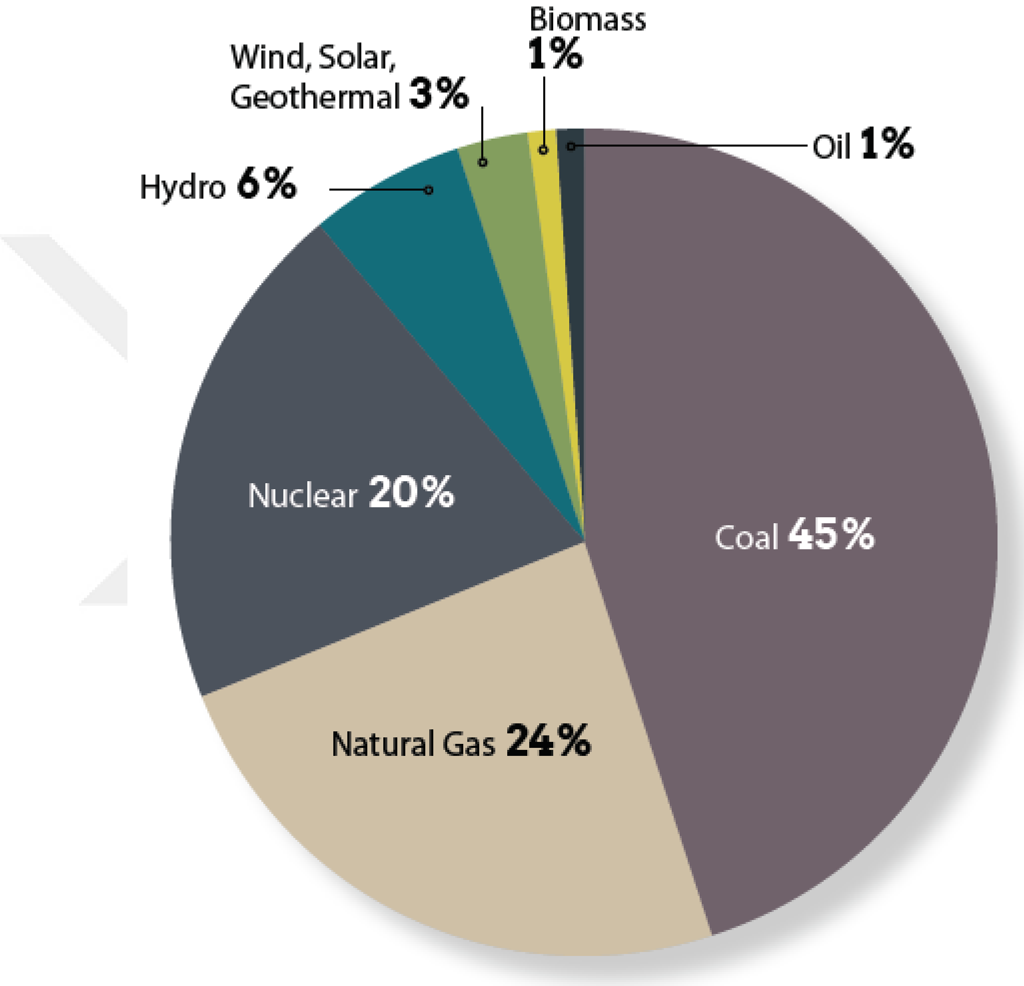


Figure 1.7 Estimates are based on calendar year 2010 data available from the U.S. Energy Information Administration (Anair, et. al., 2012)

The use of renewable power is still growing thus leads to clener Electrical Vehicals (EVs) in future.Germany is one of the leading countries on this matter. The writing on Clean Technica web site is as follows ;

> “On April 30 2017, Germany established a new national record for renewable energy use. Part of that day (during the long May 1 weekend), 85% of all the electricity consumed in Germany was being produced from renewables such as wind, solar, biomass, and hydroelectric power. Patrick Graichen of Agora Energiewende Initiative says a combination of breezy and sunny weather in the north and warm weather in the south saw Germany’s May 1 holiday weekend powered almost exclusively by renewable resources.
>
> Renewables in Germany“Most of Germany’s coal-fired power stations were not even operating on Sunday, April 30th, with renewable sources accounting for 85 per cent of electricity across the country,” he said. “Nuclear power sources, which are planned to be completely phased out by 2022, were also severely reduced.” (Hanley, 2017)

Figure 1.8 depicts the current corrected corbon foot print in U.S.A . The study uses the data given in Figure 1.7 . To calculate corrected footprint the eletriciry is generated by means of fossil fuels like natural gas.

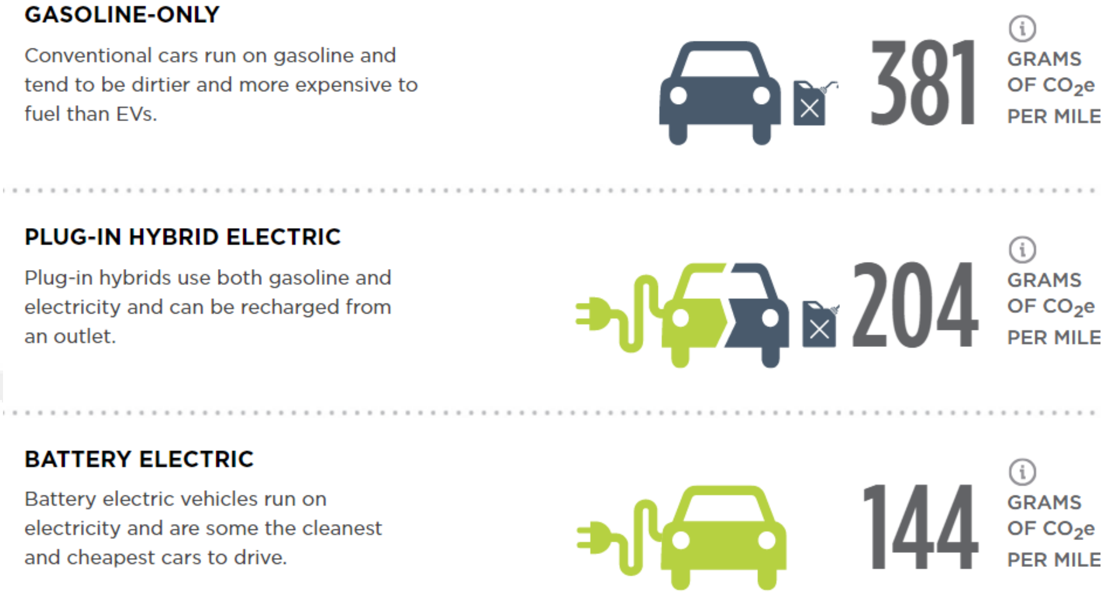


Figure 1.8 How Clean is Your Electric Vehicle? (UCSUSA, n.d.)

Following research that evaluates the adequacy of BEV in urban logistics in Lisbon, based on a real-world application. Vehicle second-by-second data was collected during regular operation of both the internal combustion engine vehicle (ICEV) and the BEV (for 7 and 3 months respectively). The BEV tested 60 km per day, and the main target is to determine the effects over air pollution.

When analyzing the environmental impacts in terms of energy and pollutant emission, the BEV presents an efficiency improvement of 76% on energy per distance driven, as well as savings in the TTW stage of 267 g of CO^2 per km and 0.364 g of NOx/km due to zero local emissions as shown in Figure 1.9.

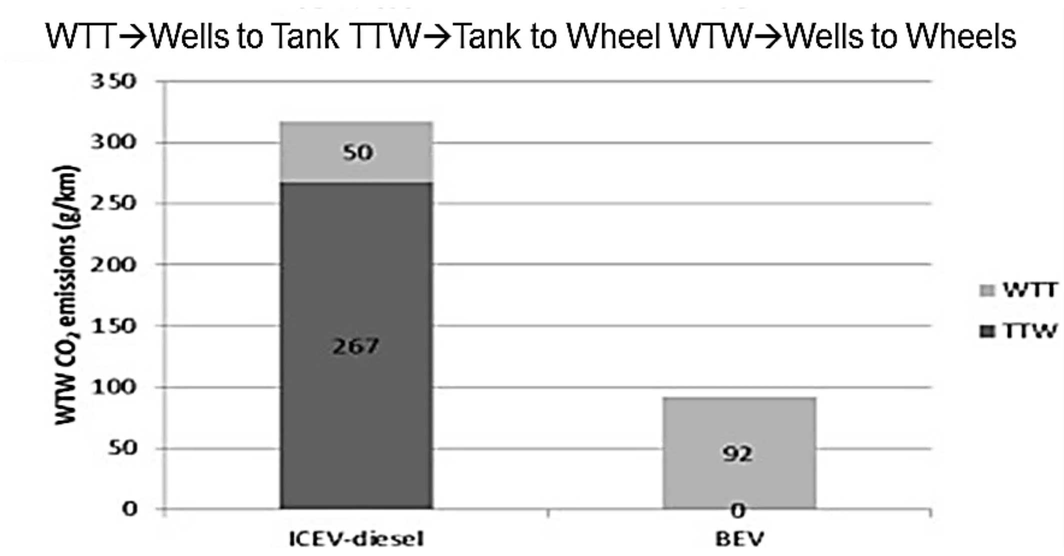


Figure 1.9 Corrected Carbon Emission Chart (Duarte, et al., 2016)

1.8 Power Comparison between Electrical Motors and I.C. Engines

Electrical motors have nearly fixed torque values after their specific stall revolutions. But due to the following power equations 1.1 and 1.2 as the power increses the amper flux increses.

$$P = \frac{R_{eq.} I^2}{1000} = \frac{v I}{1000} \tag{1.1}$$

$$P = \frac{T n}{9.549} \tag{1.2}$$

Equation 1.1 depicts power in unit kilowatt in terms of equivalent resistance (r) in ohms and ampere (i) and/or volt (v). Equation 1.2 power in unit kilowatt in terms of torque (t) in newton-meter and revolution per minute (n).

By using the Equation 1.1 and 1.2 the ampere requirement can be calculated. In Figure 1.10 the comparison between an electrical vehicle (Tesla ® Roadster 215kW at 5133 rpm) and a 6-cylinder high performance ICE.

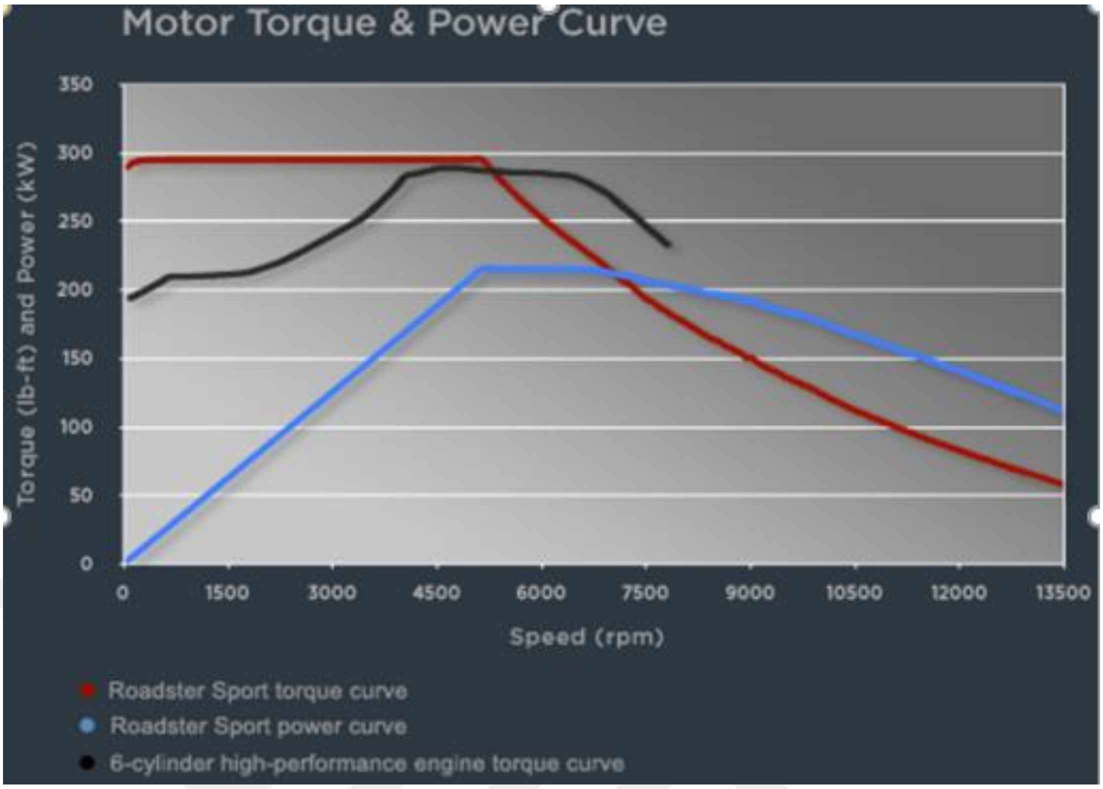


Figure 1.10 Tesla Motors® Roadster Torque and Power Comparison (Tesla Motors, n.d.)

Due to fixed voltage rate of the motor and nearly fixed torque output, the ampere requirement increases linearly. In the past lack of deep cycle, Li-Ion and Li-Po kind of batteries the power output was limited. By the help of increasing battery technology, the operation range and output power has been increased.

CHAPTER TWO
ELECTRICAL SYSTEMS AND APPLICATIONS

2.1 Main Types of Electrical Motors Used as Drive Motors

There are six groups for electrical motors, Alternating Current Motors (Single-phase, Three-phase (Induction), Three-phase (Sync)), Universal Motors, Brushed Direct Current Motors, Brushless Direct Current Motors (BLDC), Stepping Motors, and Servo Motors (A.C. Servo and D.C. Servo).

Generally, there are two types of motors being used on electrical vehicles in terms of working principles. There are certain advantages and disadvantages of both Alternating Current Induction and Brushless Direct Current Motors (BLDC).

Both types need a motor driver in order to control their torque and revolution, thus speed. Nevertheless, the controller has different characteristics.

The main difference that separates them from Brushed (or slip ringed) versions is they are not electrically connected to the rotating shaft (Rotor). BLDC are magnetically connected thus increases the mechanical efficiency of both of the systems.

2.1.1 Induction Motors

With their simple design and suitable for most of the basic areas the induction motors are used vastly. They have less components compared to the brushed motors. This leads to less maintenance requirements along with low prices. In the industrial areas from driving belts, pulleys, conveyors to cooling fans, pumps and compressors, induction motors have wide usage.

In order to manage the speed control variable-frequency inverters should be used. Since the speed of the motor is proportional with the frequency of the alternated current.

Despite their positive features there is a down sides too. The main problem of this type of motor is their efficiency, which is around forty percent. This can be improved with vector control motor drivers. Nevertheless, vector control drivers are expensive and should be designed specifically for the motor and the area of use.

The working principal is more similar to BLDC motor than DC motors. As for D.C. motors, the torque is realized through the in axial currents of the rotor with radial magnetic flux of the stator. The DC motors uses brushes to feed the rotor to create electromagnetic induction, the induction motors create an induction of electrical flux that creates magnetic flux that is forcing the rotor to push to the opposite direction of the magnetic field that created itself due to balance the energy dynamically.

The cheaper price is caused by the design and assembly simplicity, even if both of the motors uses similar amount of materials compared for similar sizes. Simple design, as shown in Figure 2.1, also helps to lower the assembly prices.

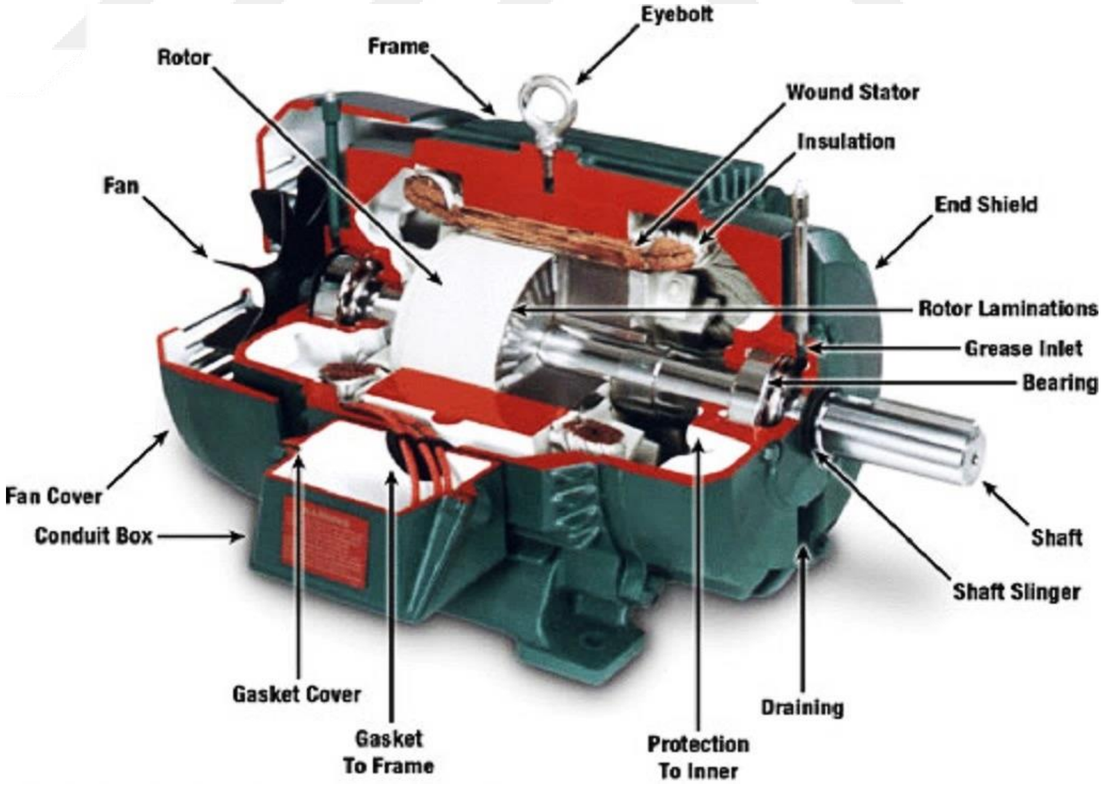


Figure 2.1 Cut-away Section of an Induction Motor (Electric motor theory., n.d.)

The alternating current passes through the stator wounding and creates an alternating magnetic field that creates an alternating electrical field over the rotor. The electrical field induces another magnetic field that tries to drive out the stator's magnetic field due to the minimum energy principle. Minimum energy principle, pushes the whole system to be in a more stable state of being. By the effect of the reciprocating current the rotor needs to rotate in order to tune into the always shifting nature of the system.

2.1.2 Brushless Direct Current Motors

The main reason of development of the BLDC motor are caused by the high performance, high reliability and low maintenance requirements of the computer and aerospace industries.

They can vary in size; today small versions can be made with power and control electronics combined. Thus, they can be used to replace the old brushed DC motors. Lack of windings on the rotor, which is mainly consisted of powerful magnets, the heat is mainly created on the stator. This helps the cooling and enables higher specific outputs, higher efficiency.

Due to not having a commutator (Brush) higher speeds can be achieved. Also, most of the BLDC motors have less rotor inertia then a conventional DC motors, this leads to better torque-inertia.

BLDC motors can be categorized as a type of self-synchronous permanent magnet motor. The main specification of BLDC motors is, their rotor magnets and stator windings are positioned to have a trapezoidal shaped flux density in the air-gap. The stator's power feed is done thru an inventor that creates rectangular shaped pulses, the switching is controlled by a rotor position sensor. This allows to control the BLDC motor smoothly regardless of the speed.

The self-synchronous motors have sinusoidal air-gap flux. Thus, they require more accurate position sensors to create a smooth torque. According to Madaan, P. working mentality can be depicted as follows.

BLDC motors, in principle, as direct current motors with commutator; like internal shaft position feedback. As DC motors uses brushes coupled with commutators, feedback is gained via this mechanism. Where brushless DC motors uses various sensors. Generally optical encoders and hall sensors are preferred.

Hall-effect is the working principle of the hall sensors. When a conductor that carries current is current-carrying conductor is exposed to the magnetic field, charge carriers faces a force, based on the voltage matured thru the both sides of the conductor.

If the order of the magnetic field is reversed, so as the developed voltage reverse its direction. Hall-Effect sensors detect the positions of the poles whether N or S. While passing through the sensor the magnets generate HIGH or Low-Level Signals.

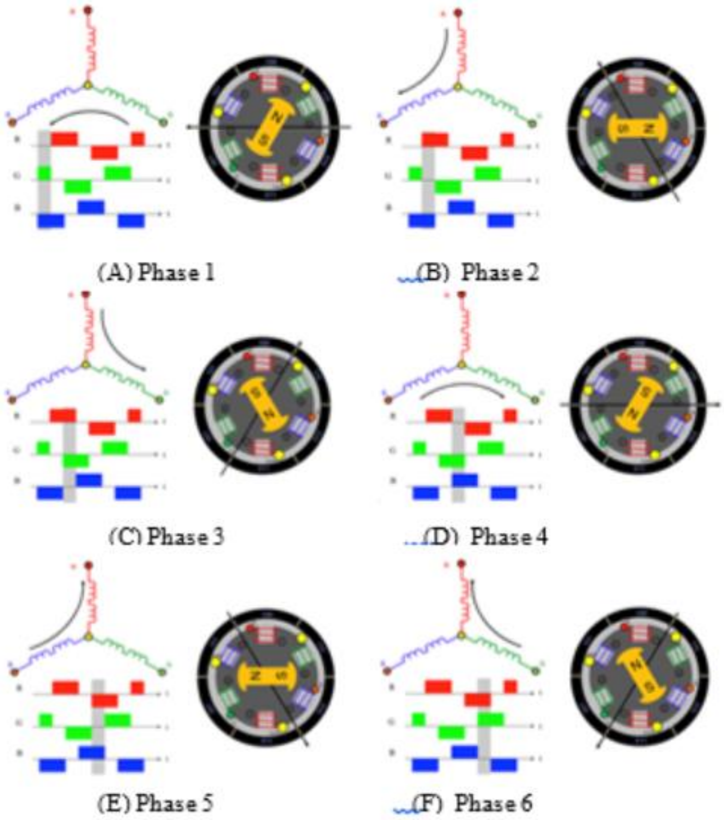


Figure 2.2 Working Diagram of BLDC Motors (Madaan, 2013)

The Figure 2.2 is explained by Madan as follows:

"(A) the GREEN winding labeled "001" is energized as the NORTH pole and the BLUE winding labeled as "010" is energized as the SOUTH pole. Because of this excitation, the South Pole of the rotor aligns with the GREEN winding and the North Pole aligns with the RED winding labeled "100". In order to move the rotor, the "RED" and "BLUE" windings are energized in the direction shown in Figure2.2, (B).

This causes the RED winding to become the North Pole and the BLUE winding to become the South Pole. This shifting of the magnetic field in the stator produces torque because of the development of repulsion (Red winding – NORTH-NORTH alignment) and attraction forces (BLUE winding – NORTH-SOUTH alignment), which moves the rotor in the clockwise direction." (Madaan, 2013)

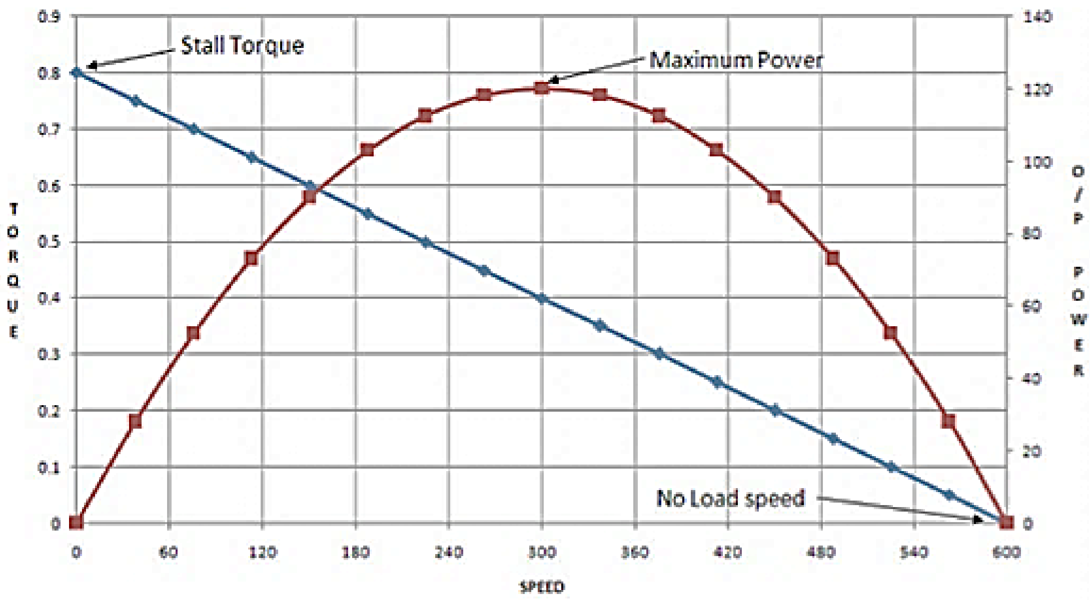


Figure 2.3 Typical Power-Torque-Speed Diagram of a BLDC Motor Brushless dc motors – part i: construction and operating principles cypress semiconductor (Madaan, 2013)

As can be seen from the Figure 2.3 as the speed increases, the torque decreases (while the input power is static) and maximum power can be delivered when the speed is half of the "no load" speed and torque is half of the stall torque. In practical use, there are two kinds of BLDC motors Disk type motors are cylindrical shaped and the rotary part is at the center.

Following chapters will demonstrate the basic construction differences advantage and disadvantages.

2.1.2.1 BLDC HUB Motors (Outer Rotor Types)

The Hub motors (Rim Motors) have their rotary parts, rotors, as the outer ring for this they can be used as tire motors. They may also be used to convert Internal Combustion Powered vehicles due to their compact design. The cutaway section can be seen in Figure 2.4.

Figure 2.4 Protean Electric HUB Motor Cut-away (Protean, n.d.)

Hub motors' design creates certain advantage and disadvantages compared to BLDC Disc motors;

Advantages of HUB Motors

- They can be installed simply without a drastic modification.
- They are readily available.
- Hub motors are fairly reliable
- Hub motors are fairly stealthy in their appearance and near-silent operation.
- Easy to obtain large torque.
- Speed is stable during constant rotation.

Disadvantages of HUB Motors

- Unsprang weight in the wheel.
- Not great mountain climbers due to lack of gear box can be heavy.
- Harder to break, due to high rotational inertia.
- Magnets can be damaged by centrifugal force.

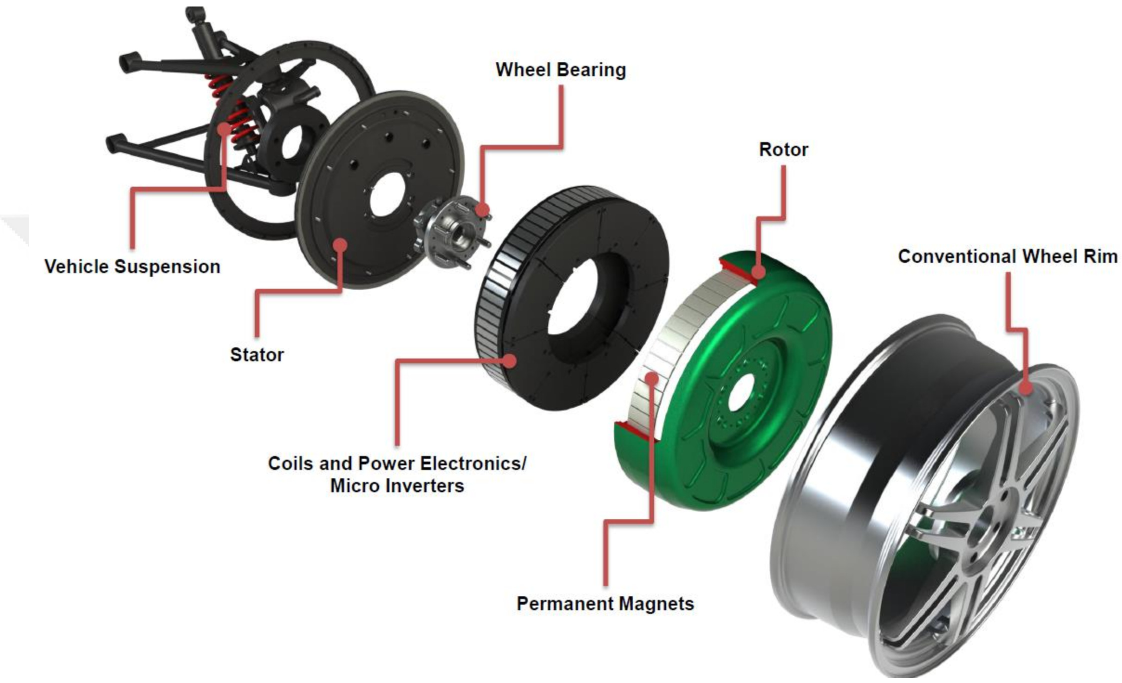


Figure 2.5 Protean Electric HUB Motor Exploded View (Protean, 2013)

In Figure 2.4 and 2.5 the main components of the motor are depicted. The rotor can either be screwed to the rim or the permanent magnets can be adhered to the rim directly.

2.1.2.2 BLDC DISC Motors (Inner Rotor Type)

The construction of disc motors resembles many similarities with A.C. motors as their rotor is inside of the stator and both of their bodies are cylindrical.

In Comparison with HUB motors the advantages and disadvantages can be listed as:

Advantages

- The rotor is small and can respond quickly.
- The coil is located on the outside and the level of heat dissipation is high.
- Torque values can be increased with a redactor.
- Lower speeds can be achieved via a redactor.
- Easier to break due to lighter centrifugal force.

Disadvantages

- Difficult to obtain large torque.
- Magnets can be damaged by centrifugal force.

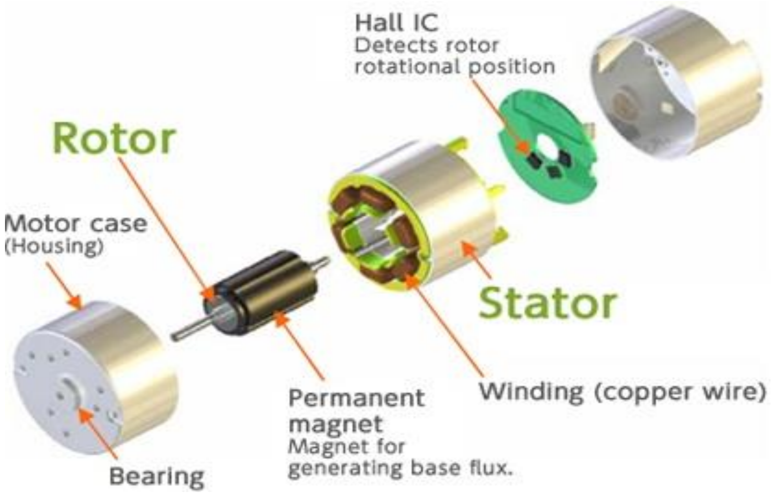


Figure 2.6 Exploded View of BLDC Disc Motor (Nidec, n.d.)

The main design difference of BLDC motors with A.C. motor (without slip rings) is BLDC motors uses permanent magnets instead of induction rods in their rotors. The components are shown in Figure 2.6.

2.1.3 Comparison of the Motor Types

All of the mentioned motor types have their advantages and should be chosen according to the needs of the design.

In principle, only direct current can be stored within the batteries. The drives of the motors and even the commutator of the Brushed D.C. motors converts direct current to an alternating current that flows through the windings.

The electrical, magnetic and mechanical characteristics define the total behaviors of the motors. Like people all of the motors are good but their shades of abilities, shape their usefulness in certain areas of work.

Table 2.1 briefly compares motor types and their areas of applications. As can be seen from the Table, only BLDC and AC Three-Phase (Synchronous and Induction) motors are being used as drive motors.

Table 2.1 Comparison of Motor Types (Nidec, n.d.)

Motor / Item	AC motor			Universal motor	Brush DC motors	Brushless DC motor (BLDC)	Stepping motor	Servo motor	
	Single-phase	Three-phase (Induction)	Three-phase (Sync)					AC servo	DC servo
Power type	AC			AC/DC	DC	DC (including driver)/Driver	Drivers	Drivers	Drivers
Efficiency	40-60%	60-70%	70-80%	50-60%	60-80%	80%-	60-70%	50-80%	60-80%
Size (same output)	Large	Intermediate or large		Large	Small	Small	Intermediate	Small or intermediate	Small
Noise	Small			Large	Large	Small	Intermediate	Small	Large
Speed range	Narrow	Wide		Intermediate	Wide	Wide	Wide	Intermediate	Narrow
Response	Slow			Slow	Intermediate	Intermediate	Intermediate	Fast	
Service life	Long			Short	Short	Long	Long		Short
Price	Low		Intermediate	Low	Low	Intermediate or high	Intermediate	High	
Applications	Washing machines	Cranes	Compressors	Vacuum cleaners	Electric toys	Air conditioners	Robots	Conveyors	Printers
	Air blowers	Conveyors	Dishwashers	Electric tools	Electric tools	Dishwashers	Small home appliances	Robots	Plotters
	Vacuum cleaners	Air conditioners	Washing machines	Juicers	Automobile electric components	Washing machines	Air-conditioning equipment	Machine tools	Working machines
	Pumps	**Drive Motor on Electrical Vehicles**	**Drive Motor on Electrical Vehicles**		Small home appliances	**Drive Motor on Electrical Vehicles**			
		Industrial machinery				Small home appliances			
Judgment	Cost focused	Versatility focused		Cost focused	Cost focused	Efficiency focused Versatility focused	Versatility focused	Performance focused	

As the Table 2.1 depicts Asynchronous motors are cheaper than BLDC Motors but they have lower efficiencies. In order to increase the efficiency of A.C. Asynchronous Motors, a special kind of driver (Vector Control) needs to be used.

2.2 Main Types of Motor Controllers (Motor Drivers) Used on Vehicle Drive Motors

Control of motor torque and velocity or speed are operating mode selections available to most basic DC drives and to some flux vector type AC drives. With some products, Velocity mode operation can include capacity for regeneration.

2.2.1 DC Drives – Torque Control

To control DC motors torque, a DC drive will regulate armature current. The block diagram is given in Figure 2.7.

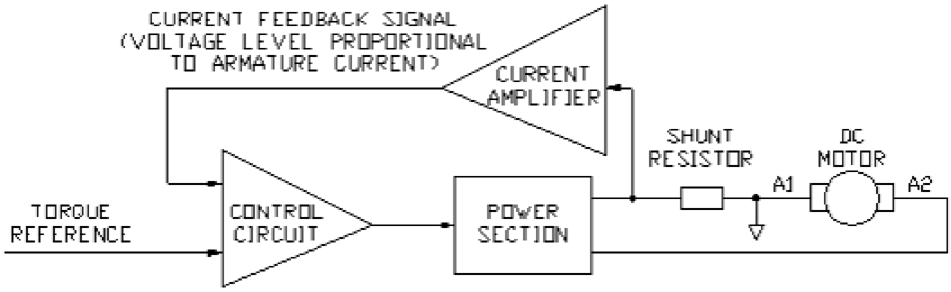


Figure 2.7 Armature Current Control (Motor control basics, n.d.)

Unregulated armature voltage allows it to be set to any torque/current value. To prevent over speed errors driver should be equipped with voltage limiter.

2.2.2 AC Drives – Torque Control

AC drives control voltage, current, frequency and rotational position to give it torque regulation capability. Encoders used to control torque. Even a controlled torque wouldn't be linear. An outside torque reference might be used for more controlled torque.

2.2.3 DC Drives – Velocity (Speed) Control

To regulate DC motor speed, the drive will normally control the armature voltage. How well it does this depends on what feedback signal is used to represent the motor speed. Refer to the Section C, “Open Loop and Closed Loop Control”. Common selections for some DC drives are as follows:

2.2.3.1 AFB – Armature feedback

2.2.3.2 TFB – Tachometer feedback

2.2.3.3 EFB – Encoder feedback

2.2.3.1 AFB – Armature Feedback

This type of drive is based on DC generators. When a DC motor is rotated, it will generate a back emf that is proportional to the speed of rotation. This emf is directly affected by magnetic flux the block diagram is given as Figure 2.8.

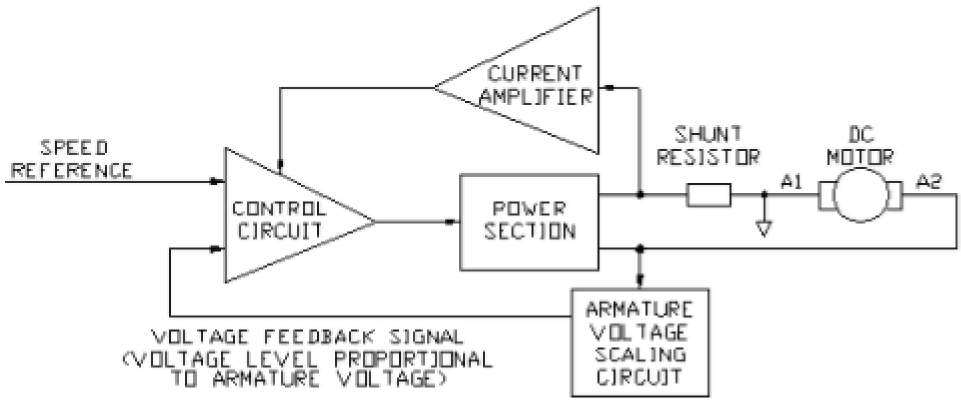


Figure 2.8 Armature Feedback (Carotron, n.d.)

Back EMF is in pulse shape, so can be measured as pulses. By this feedback the motor speed can be controlled via a constant voltage. The primary benefit of armature feedback is that no additional drive or motor components are required.

One problem of this type of drive is load may drop the speed of the motor by several percent. This is caused by internal resistant and can be compensated by IR Compensation resistant. IR Comp. senses the load change, similar as a governor of an ICE, and increases the voltage. Each settings of the IR Comp are for a specific motor.

2.2.3.2 TFB –Tachometer Feedback

Rotational feedbacks such as Tachometers and encoders are used for close loop controls. Tachometers give voltage output proportional to motor speed. Some standard DC ratings are 7, 50 and 100 VDC/1000RPM; Standard AC ratings are 45 and 90 VAC/1000RPM. Block diagram of tachometer control is shown in Figure 2.9.

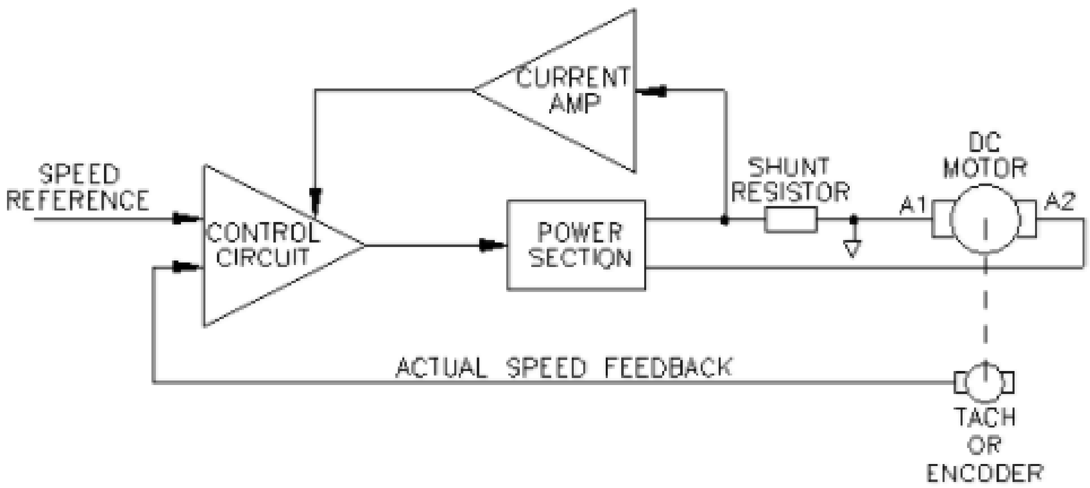


Figure 2.9 Tachometer or Encoder Feedback (Carotron, n.d.)

2.2.3.3 EFB – Encoder Feedback

Encoders don’t get effected by heat, voltage losses or load changes. This makes them more reliable for speed traction.

2.2.4 AC Drives – Velocity (Speed) Control

AC Inverter drives can have multiple control types. Inverter controlled motors can be set to a constant power; where the motor speeds can be pushed further than base speed with lower torque output.

Some examples are:

2.2.4.1 V/F Control

2.2.4.2 V/F Control with PG or Tachometer Feedback

2.2.4.3 Vector Controls

2.2.4.3.1 Open Loop Vector

2.2.4.3.2 Closed Loop or Flux Vector

2.2.4.1 V/F Control-Voltage/Frequency Control

Commonly used type of AC drive also called volts per Hertz. This type is preferred because of its simple and cheap design.

2.2.4.2 V/F Control with Pulse Generator Feedback Control

Pulse generation, generally an encoder, is used to measure rotation speed. Vector control variable frequency drives have high performance which can be compared with DC converters.

2.2.4.3 Vector Controls

Vector control, also called field-oriented control (FOC), is for a variable frequency drive control method. Three-phase AC motor's stator currents are defined as two orthogonal parts to be visualized as vector, one for the magnetic flux the other for the torque, drive calculates current counterpart for the vectors.

Generally, Proportional Integral controllers keep the reference current at the reference value. The PWM (Pulse width modulation) of vector drive adjusts transistors switching according to the reference stator voltage adjusted by the PI control.

Field oriented control is designed for smooth operation over the full speed range. This type also generates full torque at zero speed and high dynamic performance. Due to cost reduction it brings, this type is getting more attractive. Especially, today's development of higher performance microprocessors with lower prices. The VFD control types are depicted in Figure 2.10.

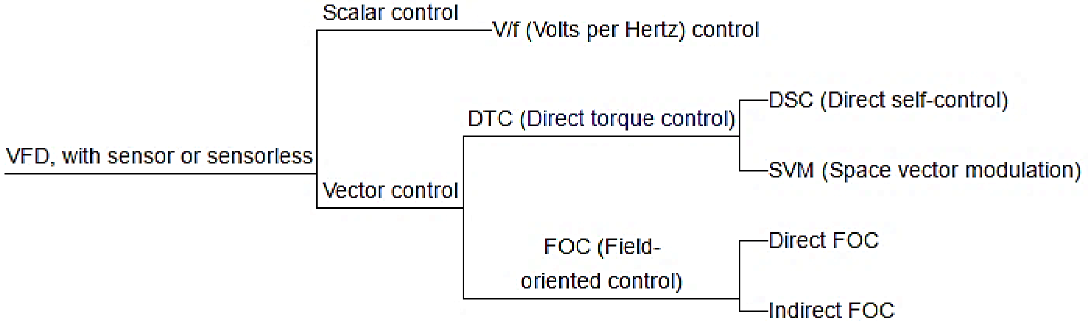


Figure 2.10 Overview of key competing VFD control platform (Wikipedia, n.d.)

2.2.4.3.1 Open Loop Vector. Open loop vector, sometimes called sensorless vector, utilizes a more complex control algorithm to give precision speed control, quick response and higher torque at low speed. Block diagram is shown in Figure 2.11.

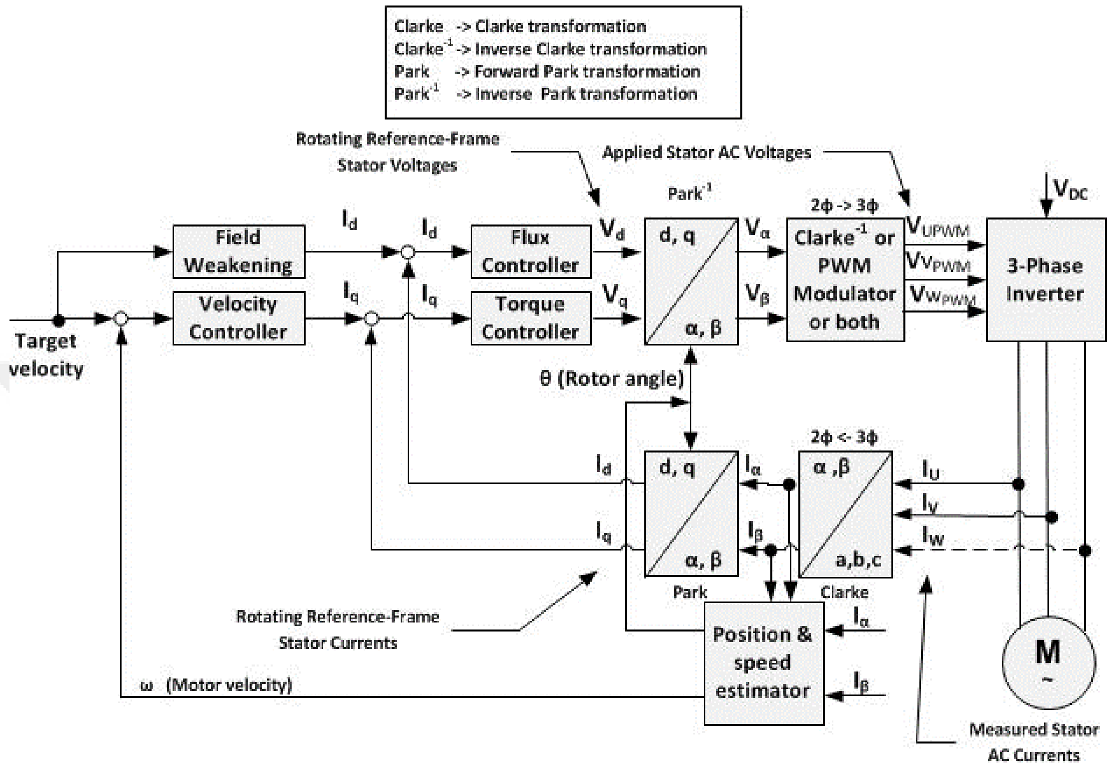


Figure 2.11 Sensorless Field-oriented control (FOC) Block Diagram (Wikipedia, n.d.)

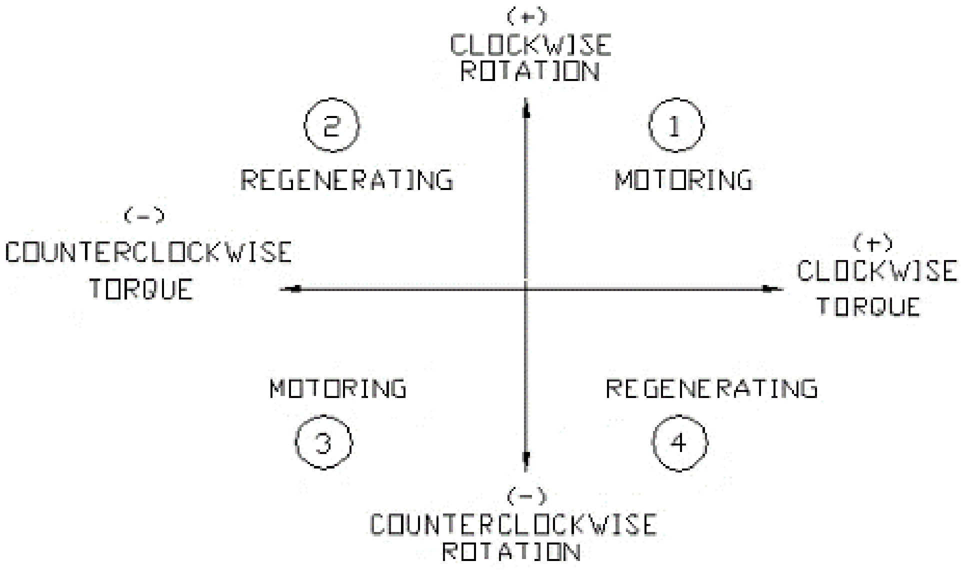
2.2.4.3.2 Open Loop Vector. Flux Vector or closed loop vector requires encoder feedback. Gives precise speed and full rated torque control over a wide speed range – sometimes even at zero RPM.

2.2.5 Regeneration

Regenerator turns both AC and DC motors into a generator when needed. If the motor speed is higher than the measured speed, regeneration mode is automatically switches on.

Normally motors can provide motoring (Positive) torque, but this type of drive enables the braking (negative) torque in each direction of the rotation. Thus, four-quadrants.

The generated energy can be refilled to the batteries or line capacitors. This will increase overall efficiency of the motor- drive system. The four quadrants are depicted in Figure 2.12



QUADRANT	ROTATION	TORQUE	MOTORING OR REGENERATING
1	(+)	(+)	MOTORING
2	(+)	(-)	REGENERATING
3	(-)	(-)	MOTORING
4	(-)	(+)	REGENERATING

Figure 2.12 Four Quadrant Operation (Carotron, n.d.)

2.3 Comparing Different Types of Electric Motor Power Trains

The effectiveness of the motor and driver can be affected by the design of the power train as well. There are multiple possible designs for powertrains for electrical motors.

In this research, the motors have regenerative charging and the battery life also taken into account. Various driving scenarios conducted to minimize the energy consumption.

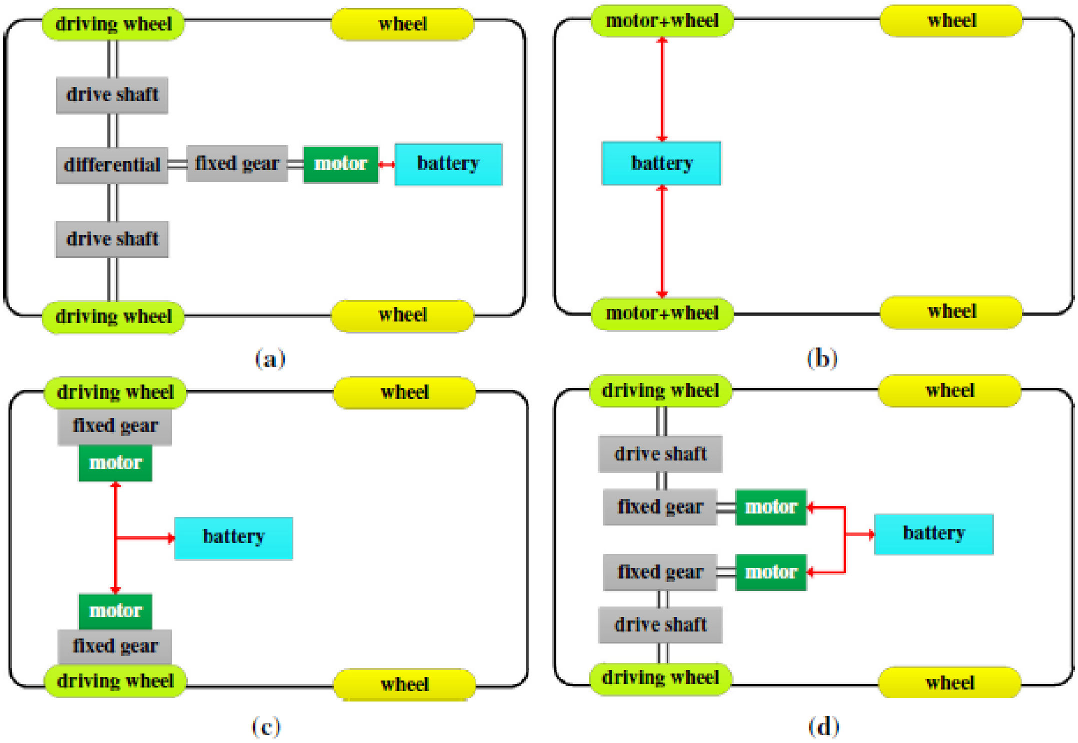


Figure 2.13 Illustration of four typical EV powertrain topologies (Wang, Xu, & Yang, 2014)

Figure 2.13 depicts four types of drives namely (a) central drive powertrain, (b) wheel-hub drive without reducer powertrain, (c) wheel-hub drive with reducer powertrain, (d) close-wheel drive powertrain.

The simplest type is HUB motor without a reduction as shown in Figure (b). This type of drive reduces the mechanical losses and widely adopted by scooters and e-bicycles. The down side of this driver topology appears while driving in low speeds where the engine efficiency is low.

To increase the low speed efficiency, HUB motors can be equipped with redactors as shown in Fig. 2.14 (c). Due to the added unsprang mass of the fixed gear redactor, both handling and comfort conditions would be decreased.

The type shown in Fig. 2.14 (d) uses a fixed gear as type (c); nevertheless, this type of drive connects the wheels to the gearbox with universal joints. Universal joints eliminate the unsprang mass problem so the comfort wouldn't be reduced.

The increasing use of renewable energy sources to produces grid line electricity using electrical vehicles will lower the emissions increasingly. The test conducted with two different types namely, the Highway Fuel Economy Test (HWFET), the high speed and low acceleration condition, and New York City Cycle (NYCC), the low speed and high acceleration condition, driving cycles.

For this experiment the brief expectations can be listed as,

(1) Wheel-Hub drive is the most efficient type amongst all. Also, aggressive driving can reduce the efficiency.

(2) The HUB wheel drive without a redactor has the highest ownership cost due to the higher torque requirement directs to a bigger motor size.

In short, the type A is central drive, B is Wheel-HUB drive, Type C is Wheel-HUB drive with a redactor and type D is close-wheel drive powertrain. The Highway Fuel Economy Test (HWFET) cycle is a chassis dynamometer driving schedule developed by the US EPA for the determination of fuel economy of light duty vehicles.

The test characteristics for HWFET are

- Duration: 765 seconds
- Total distance: 10.26 miles (16.45 km)
- Average Speed: 48.3 mi/h (77.7 km/h)

Where The New York City Cycle (US EPA NYCC) depicts urban drive characteristics as listed below,

- Duration: 598 seconds
- Distance: 1.18 miles = 1.89 km
- Average speed: 7.1 mi/h = 11.4 km/h
- Maximum speed: 27.7 mi/h = 44.6 km/h

This research conducted by Wang B, et al. (2014) on Energy Conversion and Management. The results depicted in Figure 2.14 should be studied in order to see using conditions.

In addition to this research the design requirements can drastically affect the adequacy for the whole system. While considering the correct type of drive train firstly torque and secondly speed must be considered first then the system efficiency and price should be considered. The vehicle cannot accomplish task that is designed for without torque and speed. Nevertheless, an inefficient and pricy vehicle would not be sold easily.

The Figure 2.14 depicts the efficiencies of the drive topologies listed in Figure 2.13. Power train C has the higher efficiency and is more economical.

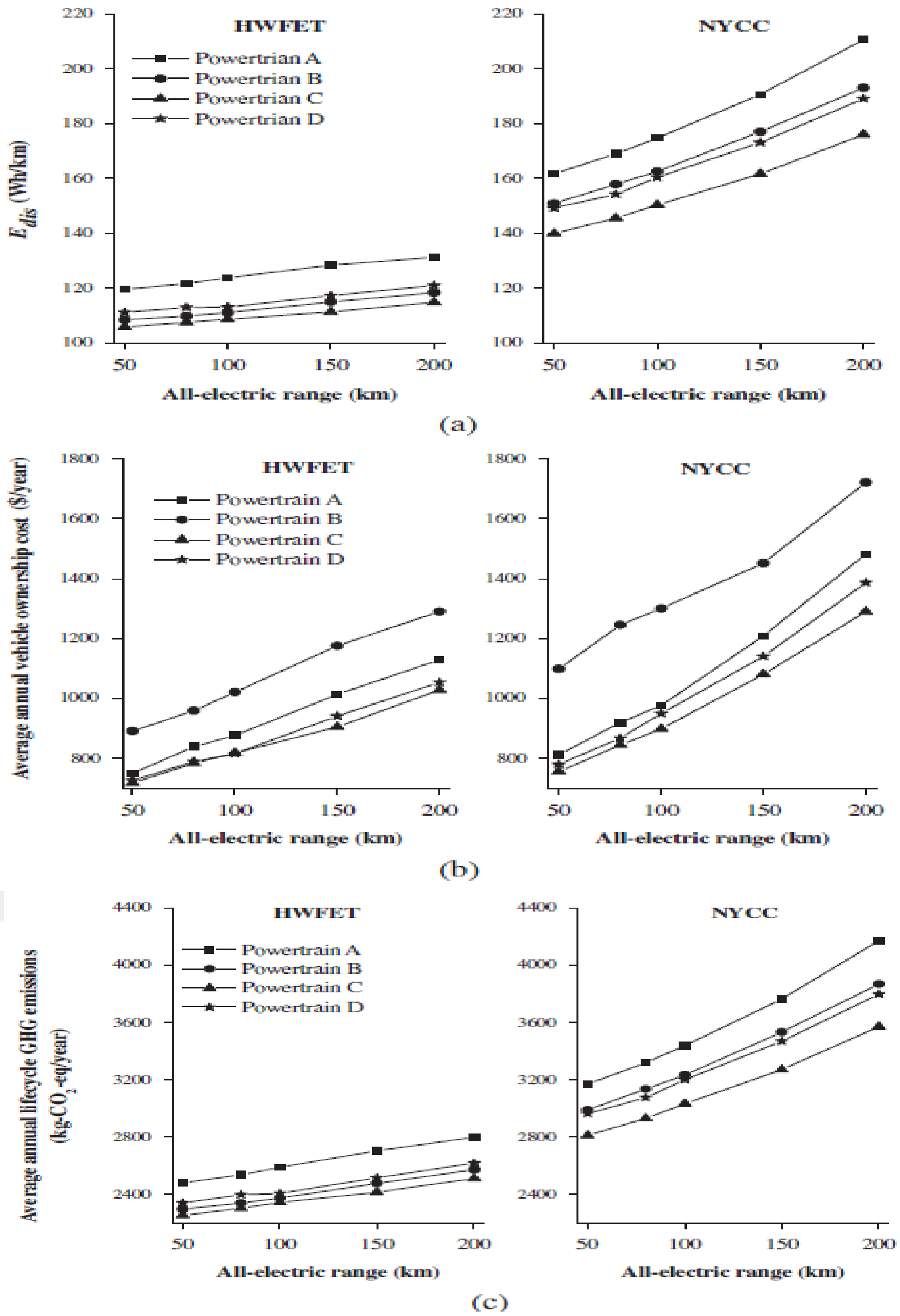


Figure 2.14 Sensitivity analysis under the Highway Fuel Economy Test (HWFET) and New York City Cycle (NYCC) driving cycles for a variety of all-electric ranges: (a) electric energy consumption, (b) average annual vehicle ownership cost, (c) average annual lifecycle GHG emissions (Wang, et al., 2014)

2.4 Battery Types for Vehicles

For a car, a wide variety of batteries can be found. In automobile, a battery is for starting the engine, using the headlights, and also for the radio. While the internal combustion engine and/or the regenerative charge is running, the batteries get charged. Nevertheless, they have a limited life. Thus, in time they would have to be replaced. There are many types of batteries to choose from, depending on choices and requirement of the usage environment. For example, deep cycle batteries might not be the best for all of the situations.

2.4.1 Wet/Flooded Battery

Due to low price the wet batteries widely used. This type of batteries uses freely submerged plates are used. Plates insulated from each other and the negative side is sealed in another bag. These types of batteries are maintenance free.

2.4.2 Calcium-Calcium Battery

The plates have calcium alloys to reduce the fluid losses and self-discharge rates. These types of batteries are not suitable for overcharge, since they can be damaged by it.

2.4.3 VRLA

The valve regulated lead acid battery (VRLA) has pressurized valves that contain gasses that reduces fluid losses.

2.4.3.1 VRLA Gel

Silicone based gel is used to thicken the fluid. This type is best for starter batteries for their higher peak amperage. But this type is not safe for hot temperatures.

2.4.3.2 VRLA AGM

The Absorbent Glass Matt (AGM) is a thin matt. This keeps the internal resistance low. Thus, lighter batteries compared to the other types of liquid batteries.

2.4.4 Deep Cycle

This type of batteries are for bringing power for prolonged durations. Deep cycle batteries generally used with forklifts, golf carts, small boats, small electric garden tractors, and other electric vehicles. These types of batteries are also being used for storing renewable energy generators' power as for wind turbines, and solar power plants. Due to thicker plates of this batteries they can store more energy, thus higher capacity can be achieved. Due to the high discharge rate that reduces the capacity, they are not preferred to be used on cars. Also, they are heavier than lithium batteries, so that is another down side.

For frequent recharges this type of batteries are correct. Deep cycle batteries prefer to overcome the challenging long and high drainages.

2.4.5 Lithium Batteries

2.4.5.1 Lithium Ion Battery

Some of the high-performance vehicles uses Lithium batteries. In an example Porsche 911 2010 uses as a starter battery.

The main advantages of this type of battery are;

- High energy density
- Less than half of self-discharge of NiCd batteries.
- Low maintenance, no memory effect and no periodic discharge requirement

The disadvantages of this type of batteries can be listed as fallows;

- Voltage and current limitation circuit is required
- Ages even if it's not in use. To reduce this effect storing in cold place at 40% charge is suggested
- Large amounts are subjected to regulatory controls.
- 40% higher manufacturing cost than NiCd batteries.

2.4.5.2 Lithium Polymer Battery

Lithium polymer batteries are an evolved type of lithium ion batteries. Instead of using liquid lithium-salt held in an organic solvent as Li-Ions, solid polymers are used.

Advantages of this type are;

- Low profile
- Economically and flexible form factors with economical prices
- Light weight without metal shells due to gel electrolytes
- Safer than Li-Ions

Disadvantages

- Lower energy density and less cycle counts than Li-Ions
- More expansive than Li-Ion batteries

2.4.6 The Nickel Batteries

2.4.6.1 The Nickel Cadmium (NiCd) battery.

NiCd batteries prefers pulse and fast charges. This type of cells are for hard, working conditions and safer than Li-Ion batteries.

Advantages;

- Fast and simple charge
- Over 1000 cycles of charges
- Long Shelf life
- Safe to transport by air
- Good low temperature performance
- Economical

Limitations are

- Low energy density
- Memory effect
- Environmentally unfriendly, contains some toxic materials
- High self-discharge

2.4.6.2 Nickel-Metal Hydride (NiMH) Battery

The NiMH type is more susceptible to heat and heavy loads than NiCd type of batteries. The environmentally safe design of the batteries makes this type more desirable than NiCd batteries.

Advantages can be listed as;

- ~35% higher capacity compared to NiCd
- Less memory effects
- Safe to transport via air
- Environmentally friendly

Disadvantages;

- The performance starts to deteriorate after ~250 cycles. Shallow discharges can reduce this effect
- High discharge currents can reduce battery life, nevertheless, it can support high discharges
- Suggested to be stored at around 40% charge at a cool place in order to keep long life
- Lower energy density than NiCd

2.4.7 Comparing the Battery Types

Table 2.2 demonstrates the general characteristics of the batteries. Users approach to new technologies generally be cold at first. This behavior prohibits the designer to change all off the parts at once.

Most of the industrial forklifts uses Lead Acid based (Deep cycle) batteries. This combined with inertia caused by the higher prices of Lithium batteries.

The Figures in Table 2.2 are based on average ratings of commercial batteries at time of publication. Specialty batteries with above-average ratings are excluded.

The following list depicts the notes on Table 2.2;

1. Combining cobalt, nickel, manganese and aluminum raises energy density.
2. Shallow discharge prolongs cycle life
3. To prevent memory effect maintenance required
4. Ultra-Fast discharge batteries are built for special purpose
5. NiCd loses 10% of charge via self-discharge within 24 hours of charge and loses 10% in every 30 days.
6. 1.25V is traditional, 1.20V is more common
7. Manufactures can rate voltage higher due to low internal resistance
8. High current pulses are possible
9. Do not charge Li-Ion below freezing
10. To prevent sulfation equalization or topping charge may be required
11. A cut off applied thru a protection circuit that disconnects the battery below 2.20V and above 4.30V on most Li-Ion batteries. Different values may apply to different compositions of batteries
12. Coulombic efficiency is higher with quicker charge
13. Li-Ion may have lower cost-per-cycle than lead acid

Table 2.2 Characteristics of commonly used rechargeable batteries (Battery University, 2017)

Specifications	Lead Acid	NiCd	NiMH	Li-ion[1]		
				Cobalt	Manganese	Phosphate
Specific energy (Wh/kg)	30–50	45–80	60–120	150–250	100–150	90–120
Internal resistance	Very Low	Very low	Low	Moderate	Low	Very low
Cycle life[2] (80% DoD)	200–300	1,000[3]	300–500[3]	500–1,000	500–1,000	1,000–2,000
Charge time[4]	8–16h	1–2h	2–4h	2–4h	1–2h	1–2h
Overcharge tolerance	High	Moderate	Low	Low. No trickle charge		
Self-discharge/ month (room temp)	5%	20%[5]	30%[5]	<5% Protection circuit consumes 3%/month		
Cell voltage (nominal)	2V	1.2V[6]	1.2V[6]	3.6V[7]	3.7V[7]	3.2–3.3V
Charge cutoff voltage (V/cell)	2.40 Float 2.25	Full charge detection by voltage signature		4.20 typical Some go to higher V		3.60
Discharge cutoff voltage (V/cell, 1C)	1.75V	1.00V		2.50–3.00V		2.50V
Peak load current Best result	5C[8] 0.2C	20C 1C	5C 0.5C	2C <1C	>30C <10C	>30C <10C
Charge temperature	–20 to 50°C (–4 to 122°F)	0 to 45°C (32 to 113°F)		0 to 45°C[9] (32 to 113°F)		
Discharge temperature	–20 to 50°C (–4 to °F)	–20 to 65°C (–4 to 49°F)		–20 to 60°C (–4 to 140°F)		
Maintenance requirement	3–6 months[10] (toping chg.)	Full discharge every 90 days when in full use		Maintenance-free		
Safety requirements	Thermally stable	Thermally stable, fuse protection		Protection circuit mandatory[11]		
In use since	Late 1800s	1950	1990	1991	1996	1999
Toxicity	Very high	Very high	Low	Low		
Coulombic efficiency[12]	~90%	~70% slow charge ~90% fast charge		99%		
Cost	Low	Moderate		High[13]		

2.5 Solar Cells

Solar cells or less commonly used as photovoltaic or photoelectric cells are a solid-state electricity generating devices. They use the photonic energy (light) to directly generate electricity by the photovoltaic effect.

The following are some of the different types of solar cells;

- Amorphous Silicon solar cell (a-Si)
- Biohybrid solar cell
- Buried contact solar cell
- Cadmium telluride solar cell (CdTe)
- Concentrated PV cell (CVP and HCVP)
- Copper indium gallium selenide solar cells (CI(G)S)
- Crystalline silicon solar cell (c-Si)
- Organic solar cell (OPV)
- Perovskite solar cell
- PhotoElectroChemical cell (PEC)
- Plasmonic solar cell
- Plastic solar cell
- Polycrystalline solar cell (multi-Si)
- Dye-sensitized solar cell (DSSC)
- Gallium arsenide germanium solar cell (GaAs)
- Hybrid solar cell
- Luminescent solar concentrator cell (LSC)
- Micromorph (tandem-cell using a-Si/μc-Si)
- Monocrystalline solar cell (mono-Si)
- Multi-junction solar cell (MJ)
- Nanocrystal solar cell
- Polymer solar cell
- Quantum dot solar cell
- Solid-state solar cell
- Thin-film solar cell (TFSC)
- Wafer solar cell, or wafer-based solar cell (synonym for crystalline silicon solar cell)

Mainly there are the following types of cells being used; namely Crystalline Silicon, (Monocrystalline, Polycrystalline), and Thin-Film Solar Panels. The term solar panels will be used to describe photovoltaic solar panels (the type that generates electricity), not solar thermal collectors.

2.5.1 Crystalline Silicon (c-Si)

Almost all of the solar cells are made of silicon. The purity of the silicon is the main difference in the solar cells. The alignment of the solar cells improves the efficiency of the photoelectric effect. Mainly, mono and poly crystalline solar cells can be found.

2.5.1.1 Monocrystalline Silicon Solar Cells

The mono, or single, crystalline cells can be distinguished by their even colors. This type of cells are made of silicone ingots that shaped cylindrical shaped and to lower the cost four sides are cut to make silicon wafers. Poly crystalline cells look rectangular with rounded edges.

Advantages:

- Highest efficiency that is around 15~20% and some special types can have even higher efficiencies
- This type of cells have the smallest size to energy output due to their high efficiency
- Their life time can be expanded up around 25 years
- Better low light performance than polycrystalline batteries

Disadvantages

- Higher price than Polycrystalline
- To make them work under partially covered conditions MPPT’s required. The shady part starts to drain energy from the energized part of the panel.
- The Czochralski process that used to produce the cells creates cylindrical ingots. Four sides are cut to make wafers so this process wastes some of the material
- They are more temperature resilient than polycrystalline types.

2.5.1.2 Polycrystalline Silicon Solar Cells

This type of cells produced without Czochralski process, so they can be made perfectly squire.

Advantages:

- Simpler and less costly than monocrystalline
- Less material wasted

Disadvantages

- Less efficient than monocrystalline cells, 13~16% efficiency is typical.
- Requires more space due to lower efficiency
- Their look is uneven so this might not be suitable for aesthetic applications

2.5.2 String Ribbon Solar Cells

Another type of polycrystalline cells, the difference is the manufacturing process. Temperature-resistant wires placed thru molten silicon creates very thin silicon ribbons.

Advantages:

- Half of the material required to produce than monocrystalline cells

Disadvantages

- Requires more energy to produce
- Lower efficiency at around 14%, so it requires more space

2.5.3 Thin-Film Solar Cells (TFSC)

This type of cells are made by depositing thin layer(s) of photovoltaic material on a substrate.

Mainly four types are available as follows

- Amorphous silicon (a-Si)
- Cadmium telluride (CdTe)
- Copper indium gallium selenide (CIS/CIGS)
- Organic photovoltaic cells (OPC)

The technology of the cells can directly affect the efficiency of the cells from 7 to 16% and even more on some special application. So, the actual output should be measured.

Advantages

- Simpler manufacturing
- Homogenous appearance that look better
- Flexible, elastic, designs can be made
- More resilient to heat and shading

Disadvantages

- Due to less efficiency they require more space
- Has less lifetime

2.5.3.1 Amorphous Silicon (a-Si) TFSC

This type is mostly used on pocket calculators due to low power output. Around 1% of the material of monocrystalline is used but production method “stacking” is not cheap. The efficiency can be around 7%

2.5.3.2 Cadmium Telluride (CdTe) TFSC

This type is more cost efficient than crystalline silicon although the efficiency is around 10~15%. More than 5 GW of solar panels of this type have been installed worldwide.

2.5.3.3 Copper Indium Gallium Selenide (CIS/CIGS) TFSC

With less toxic materials than Cadmium type cells and around 10~12% efficiency. This type is a promising type of solar technology in combination with environmental concerns.

2.5.4 Comparison of Solar Cells

Like all of the systems, there are different advantages and disadvantages of the solar cell types thus leads to different suitable areas of application for each. Table 2.3 briefly depicts the characteristics of them.

Table 2.3 Comparison of Solar Cells (EAI, 2016)

Cell material	Module efficiency	Surface area needed for 1 kW_p	Advantages	Disadvantages
Monocrystalline silicon	15-18 %	7-9 m²	- most efficient PV modules - easily available on the market - highly standardised	- most expensive - waste of silicon in the production process
Polycrystalline silicon	13-16 %	8-9 m²	- less energy and time needed for production than for monocrystalline cells (= lower costs) - easily available on the market - highly standardised	- slightly less efficient than monocrystalline silicon modules
Micromorph tandem (aμ-Si)	6-9 %	9-12 m²	-	- more space for the same output needed
Thin film: Copper indium diselenide (CIS)	10-12 %	9-11 m²	- higher temperatures and shading have lower impact on performance - lower production costs	- more space for the same output needed
Thin film: Cadmium telluride (CdTe)	9-11 %	11-13 m²	- higher temperatures and shading have lower impact on performance - highest cost-cutting potential	- more space for the same output needed
Thin film: Amorphus silicon (a-Si)	6-8 %	13-20 m²	- higher temperatures and shading have lower impact on performance - less silicon needed for production	- more space for the same output needed

Due to their lightness, monocrystalline cells are preferred on mobile uses to increase the energy gain from the limited area and lower the weight of the vehicle. The efficiency of individual solar cells is higher than for entire solar panels/modules. In order to increase the efficiency MPPTs can be used.

2.6 Maximum power point Tracking MPPTs

Maximum power point Traction (MPPT or PTT) is a way of maximizing the power output from wind turbines and photovoltaic plants, under continuously changing systems. The method can be applied to most of the systems with variable power output.

MPPT's for the PV systems help to increase the efficiency of the system. As the sunlight varies, the voltage and current that drained from the solar cell should be changed to create maximum Power, wattage.

To determine the Maximum Power Point, I-V Curve should be analyzed. MPPT is responsible to test the output in order to determine the load of the Maximum Power point. Some of the MPPTs are integrated to power converter or manager systems.

Some MPPTs are integrated to DC to AC power inverters that leads more efficient PV power systems. For the following formulations some symbols would be used to define, the power at the MPP as P_{mpp} the product of the MPP voltage as V_{mpp} MPP current as I_{mpp}.

2.6.1 Working Principles of the MPPTs

The environment directly effects the Photovoltaic cells, mainly the temperature and the light density. The Fill Factor, FF, depicts the nonlinear character of the PV. The power output is determined with the Short circuit current I_{sc} and open circuit voltage $V_{oc.}$ The optimal power can be calculated with Equation 2.1.

$$P=FF*V_{oc}*I_{sc} \tag{2.1}$$

Most of the time Equation 2.1 would be enough to calculate the behavior of the PV. The power output of the electrical output can be calculated with Ohm's Law as show in Equation 2.2. Where V is volt and I is current in amperes.

$$P=V*I \tag{2.2}$$

A PV cell, at Its efficient curve, acts as a constant ampere provider. Nevertheless, at the MPP window the current and voltage has an inverse exponential relationship.

The MPP of the system is where the "knee" of the I-V curve. The Knee can be calculated thru Equation 2.3 a and b. Where 2.3a depicts the optimized power zone as the derivative of the I-V current is equal to the opposite of the I-V Ratio, this is equal to Characteristic resistance. This point can also be depicted as Equation 2.3.b that can be gained thru equation 2.3.c

$$dI/dV = I/V = R_{Characteristic} \tag{2.3.a}$$

$$dP/dV=0 \tag{2.3.b}$$

$$R=V/I \tag{2.3.c}$$

The level of illumination changes the characteristic resistance ($R_{Characteristic}$) dynamically as the other environmental factors like temperature and aging of the cells. The MPP load resistance is automatically set to produce maximum power output. The effect of the voltage change can be seen on Figure 2.15.

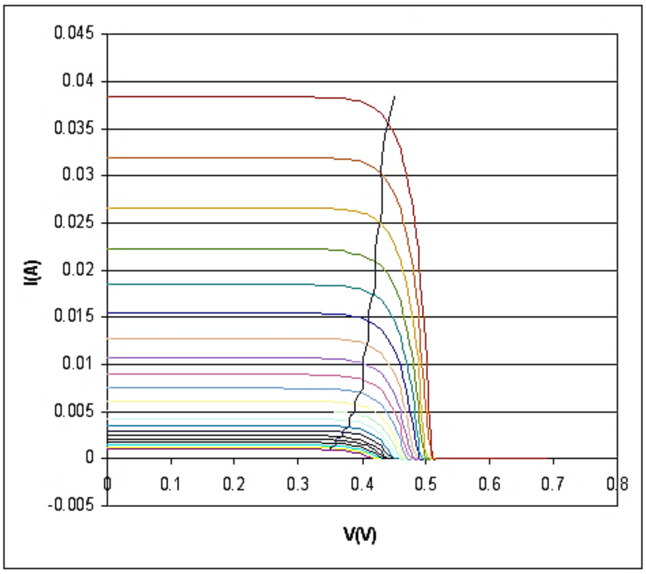


Figure 2.15 Photovoltaic solar cell I-V curves where a line intersects the knee of the curves where the maximum power transfer point is located (Wikipedia, n.d.)

2.6.2 Types of MPPTs

2.6.2.1 Perturb and Observe

In this method the voltage adjusted slowly to increase the power output and stopped after the point where the increase of power is no more. The constant change might cause oscillating power output. This method is easy to implement and can lead to high efficiencies if properly applied.

2.6.2.2 Incremental Conductance

In this method, the controller measures incremental changes of voltage and current to determine the effects on the voltage. This way, the controller can interfere with the power output; nevertheless, it requires more calculation. Like the perturb and observe method (P&O) this may result in resonating power output.

The change is calculated via Equations 2.3. The incremental method computes the MPPT via incremental conductance (*dI/dV*) to the array conductance *(I/V*). When the dI*/dV* = *I/V* (Eq.2.3.a) the output voltage gives MPPT.

This method observes maximum power point dP/dV = 0 (Eq.2.3.b) and the power (Eq.2.4). The current from the array is expressed is Equation 2.4.

$$P = I(V)V = I^2 R \quad (2.4)$$

$$dP/dV = VdI/dV + I(V) \quad (2.5)$$

$$dI/dV = -I(V)/V \quad (2.6)$$

That leads to Equation 2.5, by the point where the power is equal to zero, the equation 2.6 can be gained. This equation expresses the Maximum power point where the incremental conductance is equal to the opposite sign of the instantaneous conductance.

2.6.2.3 Constant Voltage

The constant voltage method momentarily cuts the output power in order to measure the open-circuit /zero current voltage (V_{OC}). Thru this, a fixed open circuit voltage ratio is calculated and applied. This can be via empirical knowledge or by expected operation conditions.

The operating voltage is adjusted near MPP via adjusting the array voltage via matching it to the reference voltage (V_{ref}). (Eq.2.7)

$$V_{ref}=kV_{OC} \tag{2.7}$$

2.6.2.4 Comparison of methods

Perturb and Observe (P&O), and Incremental Conductance (IC) methods can be counted as true maximum power point method, due to them being a type of “hill climbing” method. Where the maximum power point of the operating conditions is calculated.

P&O method oscillates the power output even under constant conditions. Nevertheless, IC can determine the MPP without oscillating around the power output with more rapid and sensitive results. Even so, IC method, may response irrational and oscillate the power output under rapid changing environment. IC has a lower sampling frequency due to more complex algorithm than P&O method.

Constant voltage method, the current is set to zero, momentarily, in order to measure the open circuit voltage. Then, the voltage is set to a predetermined percentage of the measured voltage, usually 76%. While measuring thru open circuit the energy may be wasted. Although, this approximation and fixed ratio is not always correct, this system is simple and economic, also can reach to 95% efficiency.

2.7 Electrical Management

Electrical Management controls multiple points of the system providing battery management, regeneration, charging, DC-DC conversion for some components uses different voltages than the others. Also, motor driver can be a part of this system.

Battery management systems (BMS) are used for managing the rechargeable batteries, via an electronic interface. They prohibit the batteries/battery packs from operating outside its Safe Operating Area. They also balance the battery packs, monitors the environment of the batteries and reports the gathered data.

A battery pack built together with a battery management system with an external communication data bus is a smart battery pack. A smart battery pack must be charged by a smart battery charger.

2.8 General Components of an Electrical Vehicle

Commonly, the electrical flow chart can be depicted as Figure 2.16 the systems can also have an external power input (Grid Voltage) for external charge that connected to Battery Management System thru an AC-DC converter. Also for the auxiliary systems like headlights, horns, additional motors (Windshield Wipers, Air Conditioning, etc.) need DC-DC converter that is connected to the batteries. Regeneration is managed by a suitable and compatible Motor Controller-Motor couple.

Some additional systems like a battery cooler and/or heater can be added according to the design needs. (Tesla Model S). To sum up, the system design, pricing and accustomedness directs the system component and shapes the whole vehicle.

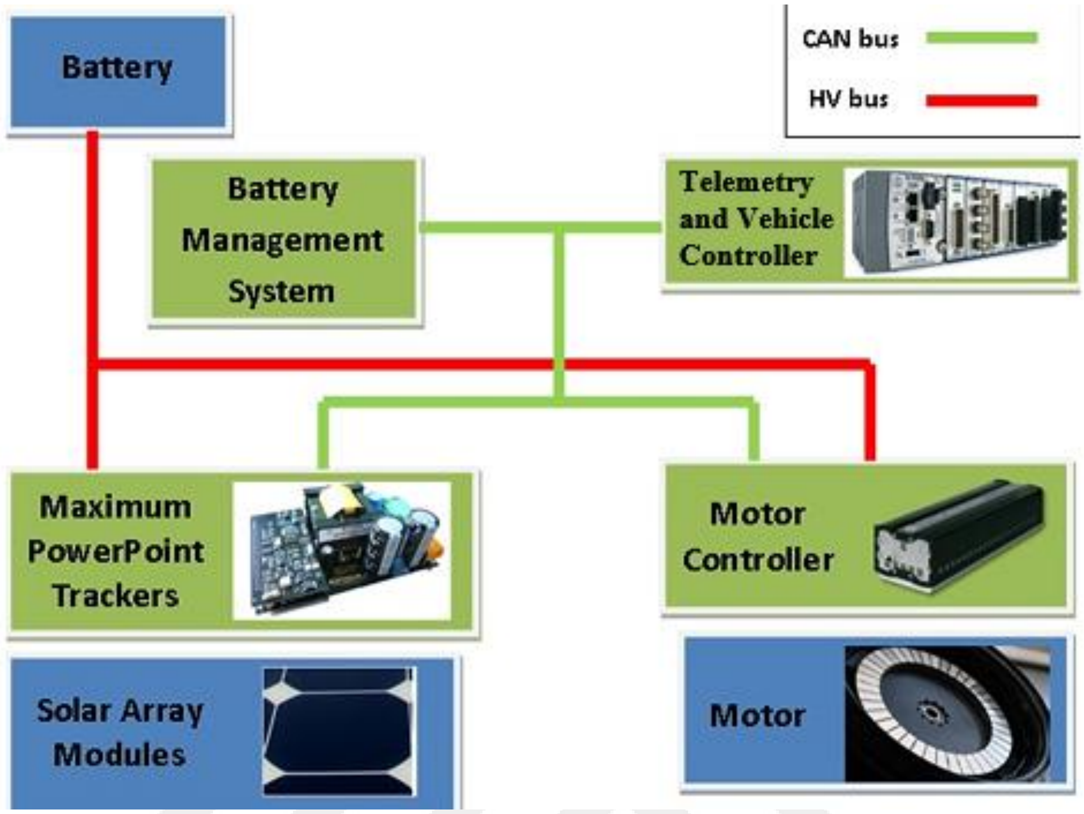


Figure 2.16 Electric Vehicle Components (McClymont, (n.d.).)

CHAPTER THREE
DESIGN OF AN ELECTRICAL ROAD MARKING MACHINE

3.1 The Current System

ALTEKMA® ALT-180 is an Internal Combustion Engine (ICE) Powered City type airless road marking machine. Current system specifications are depicted in Table 3.1.

Table 3.1 Altekma® ALT-180 Current (I.C.E. Type) Specification (Altekma®, n.d.)

Country of Origin	*Turkey*
Engine	*Kubota D1305 21,7KW*
Pump Flow Rate	*Graco 15 lpm Pump*
Max. Pressure	*138 bar*
Paint Tank Capacity	*180 liters*
Glass bead tank capacity	*60 liters*
Solvent Tank Capacity	*20 liters*
Speed-Max. Climbing	*15 km/h -%15 (~ 8,5°)*
Paint Gun	*3 Unit Airless Gun*
Glass Bead Gun	*Standart Delivery 3 units*
Manuel Hand Gun	*1 Unit Gun with 15m Hose*
Hydraulic Oil Tank Capacity	*60 liters*
Fuel Capacity	*40 liters of Diesel*
Guide Pointer	*Manual*
Line Control System	*Touch Technology*
Empty / Total weight	*1025 kg / 1465 kg*
Dimensions: LxWxH	*3500x1500x2500 mm*

The painting system normally run at 4 km/h for painting and 15km/h is the legal maximum speed. The fast speed option is only used while relocating for short distances; actual relocation is done by help of support and transportation vehicles. The support vehicles supply for fuel, paint, traffic cones for freshly painted areas, maintenance (if needed), and food-water supply for working crew.

The road markers can work at night time but the road must be dry; if it starts raining or snowing the work gets cancelled. Also, the system can be used near a support building; like an airport running track, a parking lot or a construction site. This allows the possibility to refueling when needed.

Current design is only powered by an internal combustion engine and the vehicle uses a hydraulic pump for thruster hydraulic motors and paint mixers also a compressor for pneumatic systems.

In Figure 3.1 the current system design can be seen. The system has one seat for the operator to drive the vehicle and control the painting mechanism.

Figure 3.1 ALTEKMA® ALT-180 Current (I.C.E. Type) Design (Altekma®, n.d.)

As can be seen from Figure 3.1 the Alt-180 is a compact road marker designed for confined spaces like narrow roads. The main painting mechanisms doesn't use compressed air, this increases the safety of the system and lowers the maintenance requirements as well.

The Properties of the Current System can be listed as follows:

The road markers are preferred to be used at night due to lower traffic conditions. The current system has some points that needs improvement as listed below:

- The road markers preferred to work at night time when the traffic is lower. Current design is loud due to internal combustion engine.
- Due to ICE, the vehicle emits exhaust fumes and this is not preferred near people and inside cities.
- As mentioned in previous chapter the ICE has more moving parts than electrical motors, thus leads longer and more expansive maintenance.
- Diesel fuel quality can change in some areas, this can lead to unexpected engine failures. Also storing and refueling the fuel is a dangerous process.

3.2 The New System's Design Characteristics

Internal combustion engines have been used for internal combustion engines. As researches show gasoline engines emit more than twice CO2 than electrical counterparts. (Union of Concerned Scientist) Thus, due to today's environmental conditions more vehicles are being turned into electrical powered.

In order to not to experience a resistance in the market, an old-fashioned model structure will be modernized. The current system was primarily designed as a diesel-powered machine.

Thus, for the new system’s calculations will use the old system’s weight and geometrical values. While calculating, and realizing the real vehicle, some data like battery weight are estimated. After the calculation corrected, before final system design calculation.

For the sake of designing the system with the low speed requirements brushless permanent magnet motors used because of their high efficiency and low maintenance requirements. Study on the economic and environmental benefits of different EV powertrain topologies, Energy Conversion and Management. (Wang B., et al., 2014)

Due to narrow max to min speed scatter band a fixed gear-box is added. Gear-box will decrease the speed of the motor and increase the torque output. The system will be used in parking areas and streets, the usage duration is estimated from 3 to 6 hours.

To extend the usage duration per charge solar panels added to the design. Panels will also provide emergency power, for when the grid power is out of reach.

3.3 Concerning Predesign

New system's main design parameters would be determined through a predesign study. From the outcome of predesign, new design will be done.

The vehicles pre-design values depicted below:

- Total mass of vehicle M_{total}=3500[kg],
  2200[kg] of this is reserved for batteries, solar panels, controllers, cables etc.
- Nominal and maximum speed of the vehicle, while climbing, $V_{nominal}$=4±1[km/h]; $V_{max\text{-}predesign}$=10[km/h].
- Maximum angle of climb is a=9 ° (~16%)
- Air drag coefficient is $C_w=0.6$
- *Projection area of the vehicle is* $A=1.5x2.5[m^2]$
- Rollin resistance is f_r=0.02 for rubber tire radius of r_{tire}=0.295[m] (https://en.wikipedia.org/wiki/Rolling_resistance)
- ρ_l = 1.228 kg/m^3; air density (Hirst M., 2008)

3.3.1 Formulations Used for Calculations

$$P_{st} = M_{total}.g.\sin\alpha.V \tag{3.1}$$

Equation 3.1 is for calculating hill climb power in Watts.

$$P_r = f_r.M_{total}.g.V \tag{3.2}$$

Equation 3.2 is the formulation for rolling resistance in Watts.

$$P_L = \frac{\rho_l.V^3.A.C_w}{2} \tag{3.3}$$

Equation 3.3 will be used for calculating air drag in Watts.

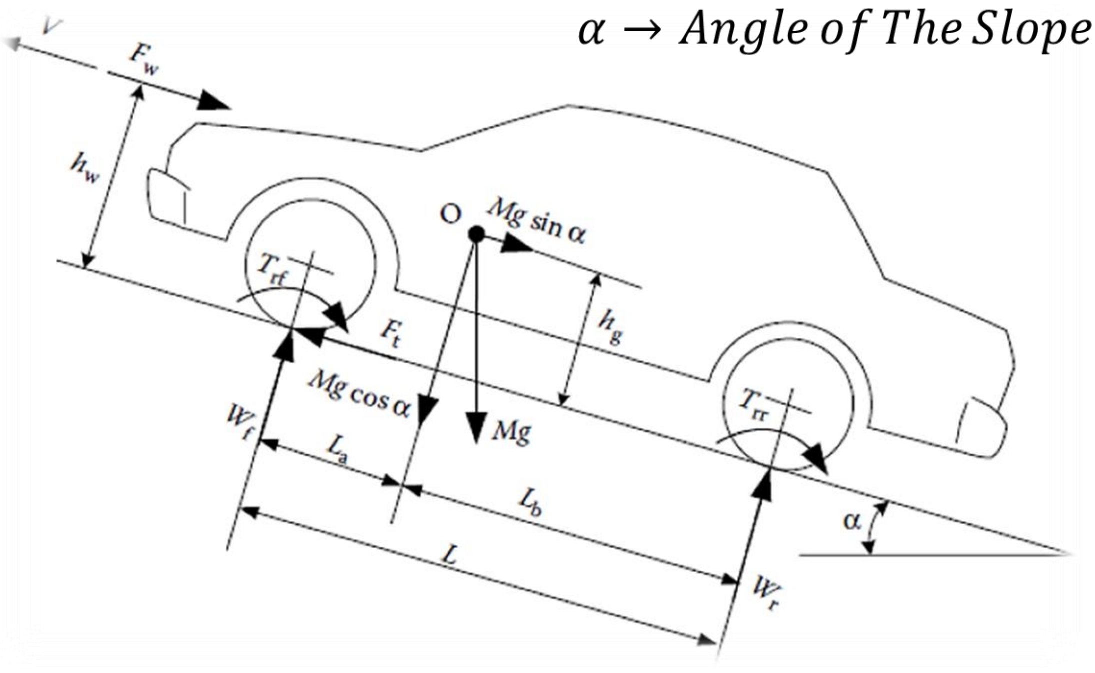


Figure 3.2 Depiction of a Vehicle on a Slope (NPTEL, n.d.)

3.3.2 Predesign Calculation

In this part system's power requirements, will be calculated for the pre-design. Maximum power requirement ($P_{max-predesign}$) is calculated when velocity of the vehicle is equal to maximum predesign velocity. ($v = v_{max-predesign}$)

$$P_{st\text{-}Max\text{-}Predesign} = M_{total}.g.\sin\alpha_{Climb}.v_{max} \quad \textit{deriveted from Eq.}3.1$$

$$P_{st\text{-}Max\text{-}Predesign} = 3500.(9.80665).(\sin 9).(2.\overline{77})$$

$$\underline{P_{st\text{-}Max\text{-}Predesign} = 14914.84[W] \ \textit{Needed Max Design}\ \text{Climbing}\ \textit{Power}}$$

$$\rho_l = 1.228\ kg/m^3; A = (1.5)(2.5) = 3.75[m^2]; C_w = 0.6$$

$$P_{L\text{-}Max\text{-}Predesign} = \frac{\rho_l.v_{Max}^3.A.C_w}{2} \quad \textit{deriveted from Eq.}3.3$$

$$P_{L\text{-}Max\text{-}Predesign} = \frac{1.228.(2.\overline{77}^3).3.75.0.6}{2}$$

To calculate Nominal Power Consumption

$$v_{\text{Nominal}-Predesign} = 4[km/h] \equiv 1.\overline{11}[m/s]$$

$$P_{st-\text{Nominal}-Predesign} = M_{total}.g.\sin\alpha_{Climb}.v_{\text{Nominal}} \quad \textit{deriveted from Eq.}3.1$$

$$P_{st-\text{Nominal}-Predesign} = 3500.(9.80665).(\sin 9)(1.\overline{11})$$

$$\underline{P_{st-\text{Nominal}-Predesign} = 5965.9[W] \leftarrow \text{Needed Nom. Design Climbing Power}}$$

$$\rho_l = 1.228\ kg/m^3; A = (1.5)(2.5) = 3.75[m^2]; C_w = 0.6$$

$$P_{L-\text{Nominal}-\text{Pr}\,edesign} = \frac{\rho_l . v_{\text{Nominal}}^3 . A . C_w}{2} \quad deriveted\ \ from\, Eq.3.3$$

$$P_{L-\text{Nominal}-\text{Pr}\,edesign} = \frac{1.228.(1.\overline{11}^3).3.75.0.6}{2}$$

$$\underline{P_{L-\text{Nominal}-\ predesign} = 1.89[W] \leftarrow Needed\ \text{Nom}.Design\,Wind\ Power}$$

$$P_{r-\text{Nominal}-\text{Pr}\,edesign} = f_r . M_{total} . g . v_{\text{Nominal}} \quad deriveted\ \ from\, Eq.3.2$$

$$f_r = 0.02\ Tire\,and\ Road\ Dependent\,res.coef.$$

$$P_{r-\text{Nominal}-\text{Pr}\,edesign} = (0.02)(3500)(9.80665)(1.\overline{11})$$

$$P_{r-\text{Nominal}-\text{Pr}\,edesign} = 762.7\left[W\right] \leftarrow Needed\ \text{Nom}.Design\,Roll\ \ Resist.Power$$

$$\underline{P_{L-max-\ predesign} = 29.61[W] \leftarrow Needed\ Max\,Design\,Wind\ Power}$$

$$P_{r-Max-\text{Pr}\,edesign} = f_r . M_{total} . g . v_{\max} \quad deriveted\ \ from\, Eq.3.2$$

$$f_r = 0.02\ Tire\,and\ Road\ Dependent\,res.coef.$$

$$P_{r-Max-\text{Pr}\,edesign} = (0.02)(3500)(9.80665)(2.\overline{77})$$

$$P_{r-Max-\text{Pr}\,edesign} = 1906.85\ \left[W\right] \leftarrow Needed\ Max\,Design\,Roll\ \ Resistance\,Power$$

To calculate nominal power requirements same formulations will be used, but this time with nominal speed. ($v = v_{nominal}$) So the following calculations could be reached.

$$P_{Max-Predesign} = P_{r-Max-\mathrm{Pr}edesign} + P_{L-Max-\mathrm{Pr}edesign} + P_{st-Max-Predesign}$$

$$P_{Max-Predesign} = 16.8\left[kW\right]$$

$$P_{\mathrm{Nom.}-Predesign} = P_{r-\mathrm{Nom.}-\mathrm{Pr}edesign} + P_{L-\mathrm{Nom.}-\mathrm{Pr}edesign} + P_{st-\mathrm{Nom.}-Predesign}$$

$$P_{\mathrm{Nominal}-Predesign} = 6.73[\mathrm{kW}]$$

3.4 Motor Selection

3.4.1 Selecting the Correct HUB Motor

By using the pre-calculations, the motor should maintain 6.73 [kW] nominal output while going with 4 [km/h] or 1.11[m/s]. Using the data of CAR HUB MOTOR 72V 7KW by Kelly Motors as an example motor that can support the nominal wattage needs with 83% efficiency.

The motor's maximum power output is 9 [kW], thus in order to achieve the max power requirement, 16.8 [kW], 2 motors should be used. The main problem of hub motors is faced while adjusting the speed.

Due to their construction it is impractical to implement a redactor so the motor speed should be used while calculating the speed. The only part to adjust the speed of the vehicle is the tire size.

$$\omega_{[rad/s]} = \frac{2 * \pi * rpm}{60} \tag{3.4}$$

$$v = r * \omega \tag{3.5}$$

Formulas 3.4 and 3.5 are used to calculate the vehicle speed. By using the motor test data provided by Kelly Motors the tire radius can be calculated from producer's motor curve graph.

The motor speed is 1300~1200 [rpm] from 1616 to 7000 [kW], so the calculations will be using 1200 rpm. The calculations are shown below;

$$\omega_{[rad/s]} = \frac{2*\pi*1200}{60} = 125.67\ [rad\ /\ s]$$

$$1.11 = r*125.67$$

So the tire radius is 0.00884[m] .

The tire size is 0.7”. This calculation is not the rim size, it also contains the tire as well. This size is implausible and impractical to put on a construction machine since it will have difficulty transporting and also the size is too small for the weight of the vehicle since the tire works as the first part of the suspension, too.

For actual working environment a 10” rim would be used, with tire on the rim the diameter would be around 0.295[m]. The motor speed could be reverse calculated by this information as such;

$$1.11 = \frac{0.295}{2} * \omega_{[rad/s]} \ ; \omega_{[rad/s]} = 7.53[rad\ /\ s]$$

$$7.53 = \frac{2*\pi*n}{60} \ ; n = 72[rpm]$$

As this calculation shows the motor should be equipped with a redactor in order to work for the purpose of driving this vehicle. So, the HUB type of electrical motors would not be practical. Other types should be investigated like a BLDC Disc motor.

3.4.2 Designating the Motor Type

As demonstrated in Chapter 3.4.1 the BLDC HUB motors are not suitable for this project. Therefore, other types of motors should be investigated. BLDC Disc motors are more suitable for their higher torque as Mentioned in Chapter 2. Also, BLDC motors doesn't need a specially designed vector control driver. Specially designed equipment has some failure risks that can only be prevented with extensive field tests. This will increase the price and make difficult finding spare parts. Marketing an electrical counterpart instead of an ICE may cause some inertia amongst the costumers. To prevent any kind of unknown failure mods only acknowledged, field tested and trusted parts should be used. (See Chapter 2.1 and 2.2 for details)

Due to the reasons explained below, BLDC Disc motors would be used in this system.

- They have been tested on the field, relatively easier to couple with a driver than A.C. Motors.
- Have higher efficiency than A.C. motors, can be equipped with redactors for slower speed easier than BLDC HUB motors.
- BLDC Disc motors are more protected from environment and other physical effects than BLDC HUB motors due to their placement on the inside of the vehicle.
- They can be assembled and disassembled without a need of a jackscrew unlike BLDC HUB motors.

As shown in the 3.3.2 Predesign calculations, needed power output of for traction for maximum speed while climbing $P_{max\text{-}predesign}$ is 16.8[kW]. The required power for the vehicle to move on a flat road $P_{nominal\text{-}predesign}$ is 6.73[kW].

The closest adequate motor for nominal power requirement is Kelly Motor's KL-6000M. The motor will be used with KLS7250D, 24V-72V, 400A, sinusoidal brushless motor controller. The motor specifications are depicted on Table 3.2

Table 3.2 Kelly Motor KL-6000M Specifications (Kelly Controller, n.d.)

	Motor Input			**Motor Torque**	**Motor Output**		
	Volts	Ampere	Watts	N.m.	rpm	Watts	Eff. %
1	73.15	4.984	364.6	0.24	3606	90.61	24.9
2	73.09	5.206	380.5	0.36	3599	135.7	35.7
3	73	7.442	543.3	0.72	3584	270.2	49.7
4	72.93	10.81	788.7	1.39	3557	517.7	65.6
5	72.85	15.45	1126	2.37	3524	874.4	77.7
6	72.77	22.15	1611	3.66	3474	1331	82.6
7	72.68	30.11	2189	5.23	3424	1875	85.7
8	72.56	38.89	2822	7.06	3364	2487	88.1
9	72.45	48.89	3542	9.11	3305	3152	89
10	72.33	59.43	4299	11.44	3244	3886	90.4
11	72.18	70.87	5116	13.99	3175	4651	90.9
12	72.04	84.14	6061	16.79	3108	5464	90.1
13	71.9	96.94	6970	19.77	3039	6290	90.3
14	71.71	111.1	7970	22.94	2970	7133	89.5
15	71.54	125.6	8992	26.28	2903	7988	88.8
16	71.38	139.8	9984	29.73	2835	8825	88.4
17	71.2	154.2	10980	33.25	2763	9619	87.6
18	71.03	169.1	12010	36.76	2705	10412	86.7
19	70.87	182.9	12960	40.24	2643	11135	85.9
20	70.69	196.6	13900	43.68	2581	11804	84.9
21	70.55	210.1	14820	47.05	2516	12394	83.6
22	70.41	221.7	15610	50.45	2437	12873	82.5
23	70.29	231.7	16290	53.67	2343	13167	80.8
24	70.16	241.2	16930	56.91	2250	13407	79.2
25	70.07	247.7	17350	60.03	2144	13475	77.7
26	70.13	242.9	17030	62.72	1965	12904	75.8
27	70.19	237.7	16680	68.83	1640	11819	70.9
28	70.23	235.1	16510	74.81	1357	10629	64.4
29	70.25	233.2	16380	80.38	1124	9459	57.7
30	70.45	216.4	15240	83.8	872	7651	50.2
31	71	174.4	12380	82.58	594	5136	41.5

The pre-design values only represent the power requirements for the estimated calculation values. By this calculation, a BLDC motor with 6[kW] nominal power output can be evaluated as possible candidate. (See Table 3.2 motor characteristic Table)

As can be seen from the Table 3.2 the motor can provide nominal pre-design power with 90% efficiency (Table 3.2 line 12) and maximum pre-design power with 84% efficiency (Table 3.2 line 21).

Figure 3.3 Kelly Motors ® KL-6000M 72V/6KW BLDC MOTOR (Kelly Controller, n.d.)

Specific performance points are depicted in Table 3.3. As can be seen from Table 3.3 nominal voltage rating of the motor is 72 Volts.

Table 3.3 Kelly Motor KL-6000M Key Specification Points (KL-9000M 72V/9KW BLDC motor, n.d.)

	V	A	W	N.m	rpm	W	%	S
(No_Load)	73.15	4.984	364.6	0.24	3606	90.61	24.9	0.000
(Eff_max)	72.18	70.87	5116	13.99	3175	4651	90.9	41.00
(Pout_max)	70.07	247.7	17350	60.03	2144	13475	77.7	97.00
(Torque_max)	70.45	216.4	15240	83.80	872	7651	50.2	117.0
(End)	71.00	174.4	12380	82.58	594	5136	41.5	121.0

3.5 Redactor Selection

After selecting the motor, torque values will be checked via Equation 3.6, where n is revolution of the motor, P is power and T is torque.

$$T_{[Nm]} = \frac{P_{[W]} x 9.549}{n_{[rpm]}} \tag{3.6}$$

By using the Equation 3.6 required Nominal and Maximum torques can be calculated.

$$T_{Max-Predesign} = \frac{P_{Max-Predesign} 9.549}{n_{Max-Predesign}}$$

$$T_{Max-Predesign} = \frac{(16800)9.549}{2516}$$

$$T_{\text{Nominal}-Predesign} = \frac{P_{\text{Nominal}-Predesign} 9.549}{n_{\text{Nominal}-Predesign}}$$

$$T_{\text{Nominal}-Predesign} = \frac{(6730)9.549}{3108}$$

$$T_{\text{Nominal}-Predesign} = 20.68[Nm]$$

$$T_{Max-Predesign} = 63.96[Nm]$$

Also, the motors lowest possible speed is around 2000[rpm] with 77% efficiency and 62[Nm] torque. Any lower speed can cause drastically lower efficiency so this speed will be accepted as the lowest speed.

In order to provide needed speed a gear box will be used. The required nominal velocity $v_{nominal}$ (4 [km/h]) will be used to calculate the required reduction. The speed can be calculated by using angular velocity ω with equation 3.4 and velocity v via equations 3.5.

Converted motor speed is for Low Speed (2000[rpm]) 209.44[rad/s] and for High Speed (3175[rpm]) is 332.48[rad/s]. The vehicles angular velocity with the tire radius of 0.295 [m] (10" tire) $\omega_{max\_predesign}$ is 0.44[rad/s] and $\omega_{nominal}$ is 0.18 [rad/s].

Since nominal speed is more important for the design criteria the gearbox should be calculated for nominal speed. For 2000rpm motor speed 1/52 gear ratio is needed to reach 4[km/h] speed. (Please see the Table 3.4 for selected gearbox characteristics.)

This redactor can provide 1/50 ratio with 68% efficiency and that leads to 4.44 [km/h] at 2000rpm and 7[km/h] at 3175 [rpm].

Table 3.4 Yılmaz Redactor ET050 (Yılmaz Redüktör. n.d.)

Ratio	Output Speeds	Input Speeds	Power Pe/Pt [kW] (For Service Factor fs=1.0) Pe=Mechanical Power/Pt=Thermal Power		
i	n2 [rpm]	n1[rpm]	Pe [kW]	Pt [kW]	η Efficiency
7.25	400	2900	2.7	1.8	0.89
9.5	305		2	1.6	0.87
12	242		1.8	1.3	0.84
14.5	200		1.6	1.2	0.83
19	153		1.2	1.1	0.82
25	116		0.97	1	0.8
29	100		0.94	0.76	0.73
38	76		0.68	0.72	0.71
50	58		0.53	0.64	0.68
62	47		0.45	0.57	0.64
83	35		0.3	0.59	0.65
100	29		0.26	0.44	0.54

The selected redactor would be used as 1 set with 2 parallelly connected redactors. This will increase its power capacity. Thus, it can withstand for short durations of higher power input. Due to the fact that the user will use the vehicle mostly on flat areas like airports, school backyards, and shopping centers calculated maximum power will be used infrequently. Selecting a heavier redactor that can nominally withstand 7kW would be an unnecessary load to carry with. Instead of this, this redactor can be replaced when needed.

Nevertheless, if the field test results recommend to replace the redactor, a belt pulley mechanism can be added and another, with lower ratio, redactor can be used for secondary reduction.

3.6 Recalculation of The Power Consumption for The Final Design Values

By using the new speed values, following values would be calculated. During climbing max speed can be lowered to 5[km/h], P max will be calculated for that value. Calculated power requirement for P_{max} is calculated by Equations 3.1, 3.2 and 3.3

- Power Require for climbing P_{st}=7457.4[W]
- Wind Resistance P_L=3.7 [W]
- Rolling Resistance Pr=953.4 [W]

In total maximum power output requirement add up to P_{max}=8414.55[W]. $P_{nominal}$ will be calculated for flat road for 4.5[km/h] via Equations 3.1, 3.2 and 3.3.

- Power Require for climbing P_{st}=0[W]
- Wind Resistance P_L=2.7 [W]
- Rolling Resistance Pr=858[W]

In total maximum power output requirement add up to $P_{nominal}$ 860.8[W]. The calculated values represent wheel output requirements so they should be corrected via efficiency in order to calculate the power usage. By using the efficiency values from the Table 3.2 and 3.4 also by adding another 90% general efficiency regarding cable, connection and other loses, the following Table 3.5 can be acquired.

Table 3.5 Efficiency Values for the Drive Motor

	Wheel Power Output		Mech. Eff.	Elec. Eff.	Other Loss
Pt max	8414.5	Watt	0.68	0.90	0.90
P nominal	860.8	Watt	0.68	0.77	0.90

By using the efficiency values in Table 3.5 actual energy consumption. Motor output are calculated as depicted in Table 3.6.

Table 3.6 Actual Power Consumption and Power Output

Actual Consumption			Motor Output	
Pt max	15276.95	Watt	13749.259	Watt
P nominal	1826.628	Watt	1406.5035	Watt

3.7 Auxiliary Power Requirement

Before calculating the power requirement for the system additional power consumption for the painting pump and air compressor should be calculated. For this calculation, the maximum power values would be halved as an empirical method.

The vehicle needs another electrical motor to run the painting equipment. That is 0.25[kW] for Hydraulic Oil Radiator, 6[kW] for Road Marking Paint Pumps, and 3 [kw] for Air Compressor for Paint Valves. So, maximum additional power requirement is 9.25[kW]. Effective requirement is accepted as 4.63[kW].

As can be seen from the Table 3.2 list no. 13, the motor specifications are adequate. Thus, the system would be equipped with two identical motors. The painting equipment needs 3000[rpm], therefore, the second motor will directly drive the painting system.

The second motor will consume 5.12[kW] due to 90.3% electrical efficiency, not having any mechanical reduction brings zero mechanical losses.

3.8 Calculation of The Battery Packs

Noting that in previous chapter, P_{max} is higher than the motor capacity, the max speed while climbing a hill with 16% slope will be reduced to 5 [km/h].

For the current calculations, actual consumption of the motor is added up to 15.3[kW] for P_{max} and 1.8[kW] for $P_{nominal}$ by using the electrical efficiency values 0.90% and 0.77%, respectively.

To calculate the battery capacity for moving the vehicle 20% P_{max} and 80% $P_{nominal}$ work load estimated, the equivalent of this is 4516.7 [Watts], and 5120[W] will be consumed by painting systems. Motor voltage rate is 72[V] and 4-hour work duration is expected, so by calculating the ampere usage per hour is calculated. The required power consumption can be seen on Table 3.7.

Table 3.7 Total Power Consumption

Actual Consumption			Working Ratio	Corrected Consumption [Watt]	Total Consumption [Watt]
Pt max	15277	Watt	20%	4517	9639
P nominal	1827	Watt	80%		
P painter	5122	Watt	100%	5122	

The lead acid batteries cannot be used due to their lack of deep-cycle capabilities. Deep-Cycle, traction batteries, used because they can be used up to 80% of their capacities. The calculated data can be seen on the following Table 3.8.

In the Table 3.8, there are 5 different battery groups calculated. First the batteries grouped to gain at least 72V. This is needed in order to lower the amperage drawn per battery and also per cable.

Table 3.8 Battery Comparison

List Number	Voltage Per Battery [V]	Capacity per Battery [Ah]	Weight [kgf]	Batteries per Set	Set Weight (Battery Only) [kgf]	Accepted Set	Effective Energy Capacity in Watts (80% of Total Capacity)	Total Weight [kg]	Working Hours for Total Consumption		Effective Weight The Smaller The Better
									9639	Watts	[kg/h]
1	24	300	285	3	855	3	51840	2565	5.4		477
2	24	360	326	3	978	2	41472	1956	4.3		455
3	80	360	1021	1	1021	2	46080	2042	4.8		427
4	80	300	856	1	856	2	38400	1712	4.0		430
5	80	620	1510	1	1510	1	39680	1510	4.1		367

The battery values in the Table 3.8, have been taken from different companies like HBA Batteries, İnci Batteries, Mutlu Batteries. The general weight and sizes compared with some other brands and found to be similar.

In Table 3.8, all five groups of batteries' energy capacity calculated and 80% of the total capacity taken into account. (Effective Energy Capacity) Than by using this value proportioned with total consumption in Table 3.7 (9639 [W]).

Effective Weight on Table 3.8 depicts the weight of the battery packs that needs to be carried in order to run one hour. The smaller the value, the lighter the battery pack for the same working duration. Also, battery packs/sets (List Number 1, 2, 3, 4) need additional cables to be connected; thus, there will be additional weight.

The Effective Weight on Table 3.8 is solely based on battery weight, the battery on Number 5 is the lightest and so it has been chosen (İnci Battery, Battery Code 1502503). The size of the battery is 1025*708*784 in millimeters and it weighs 1510 kg. Cell type of the selected battery is 4 PzS 620. (İnci Battery, n.d.)

Generally, Traction batteries of PzS type are applied for loader engine's feed circuit, stacker trucks, and electric carts as well as for the other types of floor vehicles.

Design of Vladar PzS Cells is given by the producer as:

- **Electrodes:** positive electrode - tubular plate, negative electrode - pasted grid plate made of low antimony-lead alloy (Sb content up to 2%).
- **Separation:** is made of polymeric materials; the separator prevents premature dislodging of active mass and helps to keep electrolyte on the whole electrode height. Thanks to that there is lower loss of capacity during battery's operational life time.
- **Sludge area:** each cell has a sludge area below the plate; this area is big enough to keep sludge during all battery's life time.
- **Case and lid** are made of hit resistant copolymer propylene.
- **Battery box** is included to delivery set and is made of a sheet metal with unique multilayer hit and corrosion resistant polymer coating.
- **Electrolyte:** water solution of sulfuric acid with density 1.270±0.005g/cm^3.
- **Safety plugs** prevent penetration of spark into a cell.
- **Connectors:** a) are made of solid copper for bolt connection, b) flexible cable, c) are lead and cast.
- **Temperature range:** -20 to +45° C

(Vladar, n.d.)

3.9 Solar Power Supply

In order to increase the duration of the vehicle solar cells are added. Solar cells also work as a second way of charging if the vehicle stuck with depleted batteries.

The vehicle provides enough area for 6 solar panels each with 300[w] capacity. The Solar Panels are Hyundai HiS-M300MI (300W) Solar Panel. Providing 90% efficiency while charging the batteries with the solar panels, the panels can charge the system 0.17 hours of run time (on corrected load) and extends 4 hours of service time up to 4.7 hours in daytime usage.

The Designed vehicle's model is depicted on Picture I. The top of the vehicle is covered with the solar panels, the total panel weight is 174kg (29kg each).

The panels will be supported with Linear Technology LT8490 - High Voltage, High Current Buck-Boost Battery Charge Controller with Maximum Power Point Tracking (MPPT). (Linear Technology, (n.d.).)

The estimated reserve weight of 2200 kg is more than needed, but in order to compensate possible extra weight of the cables and fittings this value has not been reduced in the calculations. The solar power capacity is shown in Table 3.9..

Table 3.9 Total Working Duration with Solar Cells

Panel Power [W]	Panel Quantity	Solar Power [W]	Efficiency (90% Pannel and 90% Charger)	Corrected Power [W]	Amperage at 72V	Charge Time for 1 Hour for Driving in Nominal Load [h]	Combined Usage Duration [h]	Duration for Fully Charge 80 V 620 Ah Battery from 20% to 100% [h]
300	6	1800	81%	1458	20.25	0.15	4.7	21.8

In Table 3.9, vehicle’s working duration with solar cells can be seen. The Table also depicts the duration needed to fully charge, it would roughly take two days. Fully charge duration calculated from 20% charge of the battery since the battery shouldn’t be depleted more than 20% in order to not to permanently damage the battery.

CHAPTER FOUR

SUMMARY AND FURTHER DEVELOPMENT POSSIBILITIES

4.1 Specifications of Designed Vehicle

The thrust is provided by a single 6kW BLDC electrical motor. The torque and speed adjustments are done through a fixed gear with dual shaft output.

The new system has lower noise levels than diesel versions. The system has less maintenance requirements and less moving parts. Lowering the number of the moving parts leads to higher efficiency and longer product life. The road marker can climb a 15% hill slope with 5 [km/h] speed and can work for 4 hours without being recharged at night time.

Figure 4.1 depicts the new design derivate from Altekma Alt-180. The new design is equipped with solar panels.

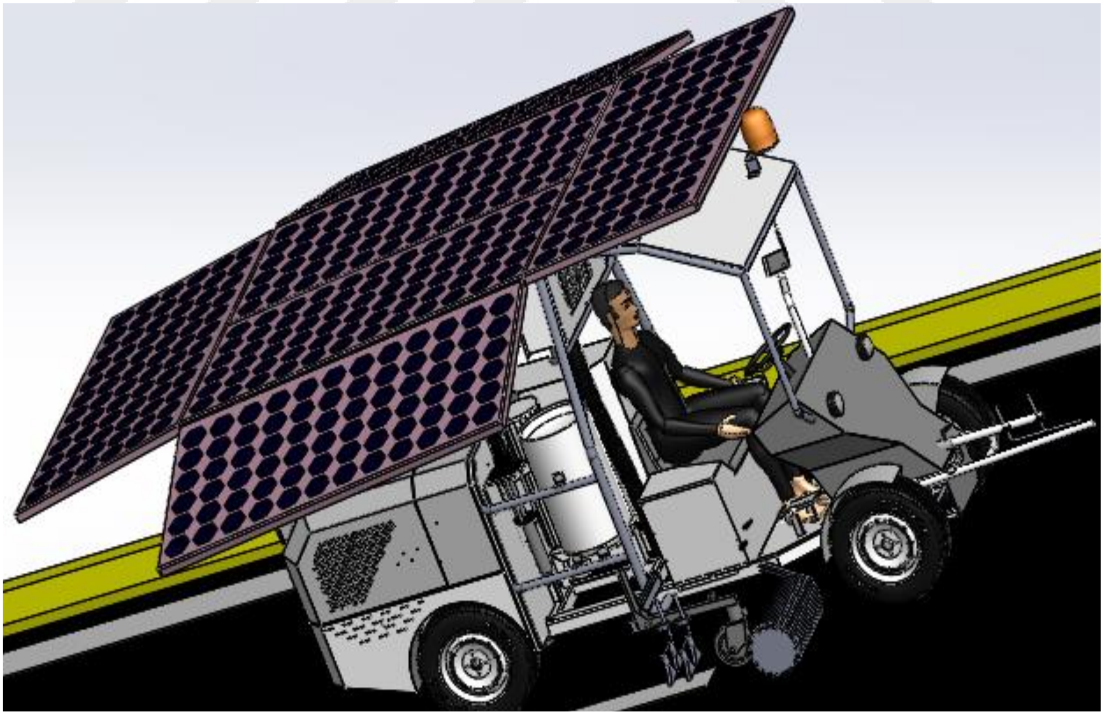


Figure 4.1 Designed Road Marking Vehicle

Table 4.1, sums up the comparison of the design vehicle with the required values. The design parameters are in the requested tolerances.

Table 4.1 Designed Vehicle Comparison with ICE Counterpart

Definition	Requirement	Design Value	Unit	Notes
Maximum Speed (Max.)	10	7	[km/h]	The vehicle needs additional redactor for faster movement. Current redactor has been chosen for Nominal speed efficiency.
Nominal Speed (Min.)	4	4.5	[km/h]	Exact requirement met.
Climbing Percentage	16%	16%	-	Vehicle can climb the slopes while painting without any setbacks.Climbing speed is 5 [km/h]
Working Duration	4	4.1	[h]	The required working duration can be extended with a larger capacity battery if needed . Also, battery can be swapped like done with forklift batteries , since it also is a standard forklift battery.
Working Duration with Solar Cells	4	4.7	[h]	Solar cells further extends the range of the vehicle.
Transportation Range at 7 [km/h] (Without Painting)	N/A	61	[km]	This value depicts the maximum transportation range of the vehicle. Ptmax=21.4 [kW] , Pt nominal =2.85 [kW] ; the ratio is 20% and 80% respectively. So , the total consumption is 6.6 [kW]
Transportation Range at 7 [km/h] [km] (Without Painting) with Solar Cells	N/A	81	[km]	Solar cells further extends the range of the vehicle.
Painting Range	N/A	15	[km]	This value depicts the maximum painting range of the vehicle. Ptmax (while climbing) , Pt nominal; the ratio is 20% and 80% respectively.
Painting Range with Solar Cells	N/A	17	[km]	Solar cells further extends the range of the vehicle.

The battery pack can be changed by a fork-lift. The current system is designed as first type and future models will be equipped with ion batteries that are lighter and environmental friendly if disposed.

The designed system is not equipped with a differential due to low speed (4 [km/h]). Hub motors are not found to be suitable with this system's high torque low speed requirements so a BLDC disk motor is selected with a gear box that provides dual shaft outputs for each of the rear tires.

The designed system can provide lower noise and carbon pollution thus will increase urban application range to more silent and clean areas. For example, working at night time hospital parking lots and universities at daytime.

To sum up, this paper the conversation of a diesel-powered road marking machine to electric powered type has been calculated. Also, practical applications considered and analyzed.

Table 4.2, summarizes the equipment of the Electrical Road Marking Machine. Key Features are depicted in Table 4.2. The detailed specifications are given in appendixes chapter.

The Selected motor driver can provide regenerative charging. Also, the MPPT can run without any additional software support and can charge 80 V batteries directly. Another DC-DC converter can be added for lights and other consumers but this is optional and not directly connected with the vehicle's capacity so it will not be considered in this work.

Table 4.2 Electrical Road Marking Machine Parts

Definition	**Brand**	**Model**	**Used Numbers**	**Key Features**	**Notes**
Motor	Kelly Motors	KL-6000M	2	BLDC 6kW	One of the motors is for driving the vehicle the other one is for painting equipment's.
Motor Driver	Kelly Motors	KLS7250D	2	-	One for each motors.
Solar Panels	Hyundai	HiS-M300MI	6	300W	6 panels placed on top of the vehicle.
MPPT CHARGER	Linear Technology	LT8490	1	80V Charge	Panels are serially connected. Using micro MPPTs is more efficient but this device can provide direct charging of the battery.
Battery	İnci Battery	1502503	1	80V 620Ah	This is a standard forklift battery , that can be swapped to charge outside of the vehicle while the vehicle is running.
Reduction	Yılmaz Redactor	ET050	1	-	This is used for drive thrust. The motor speed is too much for direct drive. By this device the motor runs at 90% of efficiency while running at nominal speed.

4.2 Further Development Possibilities

The designed vehicle is designed for current day costumers. Current customers are not familiar with composite vehicles and lithium batteries. In order to not to face an inertia on marketing this vehicle is designed with easily accessible and relatively known parts for the end users. Parts like Forklift Batteries (Traction Battery) and metal based chassis. This choice is also made by considering the current prices of the materials.

Fiber-reinforced composites (FRPs) could reduce the weight of a passenger car by 50% and improve its fuel efficiency by about 35% without compromising performance or safety according to Institute for Advanced Composites Manufacturing Innovation.

If the vehicle is produced with composite material 750 kg of 3500 kg of total weigh will be reduced. Because only 1025 kg of the weight is dry weight.

Also, if 6 of Shenzhen Herewin 80V 60Ah Lithium-Ion Phosphate would be used. Total Battery weight is 390 kg, this is also being reduced from the total weight of the vehicle and the new design's total weight would sum up to 1392.5 kg.

The comparison between New and Old Design is depicted in Table 4.3. Although the new designed vehicle is lighter, it needs 3600 $ more only for the batteries.

Table 4.3 New Design Comparison

Design	Voltage Per Battery [V]	Capacity per Battery [Ah]	Weight [kgf]	Accepted Set	Effective Energy Capacity in Watts (80% of Total Capacity)	Total Weight [kg]	Consumption Of The Design		Working Hours for Total Consumption	Effective Weight The Smaller The Better [kg/h]	Aprox. Total Price
Old	80	620	1510	1	39680	1510	9639	Watts	4.1	367	$6,026
New	80	60	65	6	28800	390	6922	Watts	4.2	94	$9,600

The new design combined with the solar cells has more range than the old design. Table 4.4 depicts the comparison of the solar cells between old and new design.

Table 4.4 New Design Solar Cell Comparison

Design	**Panel Power [W]**	**Panel Quantity**	**Solar Power [W]**	**Efficiency**	**Corrected Power [W]**	**Amperage at 72V**	**Charge Time for 1 Hour for Driving in Nominal Load**	**Combined Usage Duration [h]**	**Fully Charge Duration [h]**
New	**300**	**6**	**1800**	**81%**	**1458**	**20.25**	**0.15**	**4.7**	**21.8**
Old	**300**	**6**	**1800**	**81%**	**1458**	**20.25**	**0.21**	**5.0**	**15.8**

Table 4.5 compares the two design specifications for end users. As it shows the new design has more capacity of transportation. Also, due to smaller sized battery pack, more batteries can be installed and batteries can be swapped more easily.

Table 4.5 Comparison of the Designs for End Users

Definition	New Design	Old Design	Unit	Notes
Maximum Speed (Max.)	7	7	[km/h]	The vehicle needs additional redactor for faster movement. Current redactor has been chosen for Nominal speed efficiency.
Nominal Speed (Min.)	4.5	4.5	[km/h]	Exact requirement met.
Climbing Percentage	16%	16%	-	Vehicle can climb the slopes while painting without any setbacks. Climbing speed is 5 [km/h]
Working Duration	4.2	4.1	[h]	The required working duration can be extended with a larger capacity battery if needed . Also, battery can be swapped like done with forklift batteries , since it also is a standard forklift battery.
Working Duration with Solar Cells	5.0	4.7	[h]	Solar cells further extends the range of the vehicle.
Transportation Range at 7 [km/h] (Without Painting)	112	61	[km]	This value depicts the maximum transportation range of the vehicle.
Transportation Range at 7 [km/h] [km] (Without Painting) with Solar Cells	136	81	[km]	Solar cells further extends the range of the vehicle. New Design's range is more than 19 Hours , this is not practically valid since the daytime is not that long most of the times.
Painting Range	15	15	[km]	This value depicts the maximum painting range of the vehicle. Ptmax (while climbing) , Pt nominal; the ratio is 20% and 80% respectively.
Painting Range with Solar Cells	18	17	[km]	Solar cells further extends the range of the vehicle.

As the Table 4.5 depicts the system’s effective range hasn’t changed since battery capacities kept similar. If more range required more batteries can be added. For example, with 12 batteries the range, without solar panels, can be extended as much as 7.8 Hours or 28 km.

Nevertheless, the transportation range is drastically affected due to the lightness of the vehicle the total power requirement has been reduced to 1.8 kW, drive only, solely by reducing the weight of the vehicle.

This improvement should be done as a renewed model after the first release of the electrical road marking machine. This would prevent the thought marketing rejection due to accustoming to I.C.E. vehicles.

CHAPTER FIVE
CONCLUSION

In this research, a diesel-powered road marking machine upgraded into today's requirements. The designed system has all the capabilities of the previous system. The painting equipment are also being powered by an electrical motor. Both of the motors and drivers are identical.

By using the identical motors and motor drivers provide easier maintenance and user training. That would allow the diesel-type operators to be instructed faster.The designed system can provide required speed and maneuverability values. Due to low speed, 4 km per hour, differential is not being used.

The system has solar support, which can be used in emergency as-well-as in daily use. System's batteries can be found on the market easily and can be changed without a special training but the standard traction battery changing procedure.

Electrical vehicles are more efficient in aspects of periodic maintenance as well as in fuel savings. Also, environmentally the electrical drive doesn't emit toxic gasses. Environmental, and economic positive impacts of converting a road marking machine into a fully electrical vehicle have been studied.

All of the parts can be found in the market today. This will help finding spare parts, trained crew and also the replacements. Adding to that, due to using standard parts, the price and time for building the vehicle is more affordable.

In this study BLDC motors chosen over AC motors, because BLDC motors have higher efficiency at lower speeds, thus need less reduction ratio.

The designed electrical vehicle will provide the same performance as the I.C.E. counterpart while emitting no tailpipe gases. Due to provided solar panels the vehicle can be charged during the day thus can be used without an external charger. Especially, *the New Design* version can be fully charged in less than 16 hours, see Table 4.4.

In today's market purchasing an electrical vehicle might be more expansive than internal combustion counterpart. Due to the rooted habits, demand on electrical vehicles are less than I.C.E vehicles, thus electrical vehicle components are being produced less than I.C.E. components, and are more expansive. In order to overcome this problem two different solution have been suggested in this research.

The first design uses a traction battery, the cost of this single battery pack is nearly the half of the second designs' pack of Li-Ion batteries. Nevertheless, second design has the possibility of further extension of the range with adding 2 more Li-Ion batteries.

The extended battery range is only possible with lighter batteries, as shown in the second design. While the market demand increases and the new types of light batteries invented, Li-Ion battery prices decrease so as the price gap between the traction and Li-Ion batteries decrease as well.

In this study the benefits of converting a road marking machine into an electrical road marking machine analyzed. The suggested designs use parts easily accessible in the market. As the rooted habits get to be reshaped the benefits gained from them will become widespread.

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APPENDICES

A.1 Kelly KL-6000M 72V/6KW BLDC MOTOR Specifications

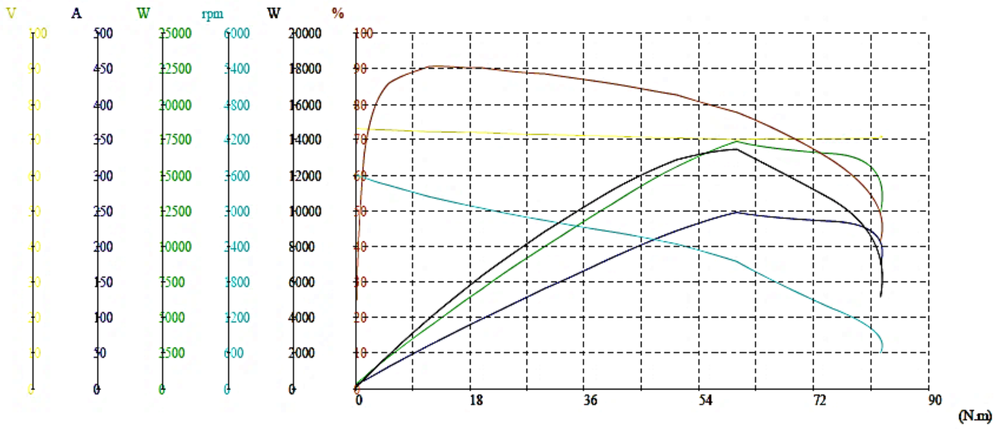

Figure A.1 *Kelly KL-6000M Performance Data*

(from http://kellycontroller.com)

A.2 Kelly KLS7250D,24V-72V,400A, Sinusoidal Brushless Motor Controller Specifications

KLS controller is supposed to reduce the noise of BLDC motor, especially for hub motor. The BLDC motor must be based on 3 hall sensors. Customers can program the KLS controller on PC software or Android App. You may need a Z-TEK USB to RS232 cable for programming the controller if you want to program the controller on Android Tablet.

General functions:

(1) Extended fault detection and protection. Customers can read the error code in PC software or Android Tablet also.

(2) Monitoring battery voltage. It will stop driving if the battery voltage is too high and it will progressively cut back motor drive power as battery voltage drops until it cuts out altogether at the preset "Low Battery Voltage" setting.

(3) Built-in current loop and over current protection.

(4) Configurable motor temperature protection range.

(5) Current cutback at low temperature and high temperature to protect battery and controller. The current begins to ramp down at 90℃ case temperature, shutting down at 100℃.

(6) The controller keeps monitoring battery recharging voltage during regen braking.

(7) Maximum reverse speed and forward speed can be conFigured between 20% and 100% respectively and separately.

(8) A 4pin connector to RS232 port and a Z-TEK USB to RS232 cable allows for configuration, programming and software upgrades using the Tablet which must be based on Android OS now. People can do the same things on PC software by using a standard USB to RS232 cable instead.

(9) Provision of a +5 volt and +12 volt output to supply various kinds of hall sensors.

(10) 5 switch inputs which are activated by connection to 12V. Default to throttle switch, brake switch, reversing switch, forward switch and Boost switch.

(11) 2 analog 0-5V inputs that default to throttle input, and motor temperature input

(12) Copy signal of one of hall sensors.

(13) Configurable boost switch. Enables the maximum output power achievable if the switch turned on.

(14)12V brake switch input used different port from motor temperature sensor. You can use both brake switch and motor temperature sensor functions at the same time on the latest version. Pin 25 is 12V brake switch input port. Pin1 is motor temperature sensor input port.

(15) Optional joystick throttle. A bi-symmetrical 0-5V signal for both forward and reversing.

(16) Configurable motor over-temperature detection and protection with the recommended thermistor KTY84-130 or KTY84-150.

(17) 3 hall position sensor inputs. Open collector, pull up provided.

(18) Brake analog regen mode. This regen mode doesn't need brake switch to support any more. Only available from software version 0106.KLS controller cannot support reflashing.

(19) Enhanced regen brake function. A novel ABS technique provides powerful and smooth regen. The regen can happen at any speeds until zero speed.

(20) KLS-D controller included the fuse and shunt on the case.
(21) Cruise control.
(22) KLS-D can support Broadcast type CAN Bus function. It is 250Kbps.CAN bus is not included in KLS-D controller by default.

Caution! The regen is not a safe function. Usually you may use the mechanical brake.

Features:

1) Intelligence with powerful microprocessor.

2) Synchronous rectification, ultra-low drop, fast SVPWM and FOC to achieve very high efficiency.

3) Electronic reversing.

4) Voltage monitoring on 3 motor phases, bus, and power supply.

5) Voltage monitoring on voltage source 12V and 5V.

6) Current sense on all 3 motor phases.

7) Current control loop.

8) Hardware over current protection.

9) Hardware over voltage protection.

10) Configurable limit for motor current and battery current.

11) Low EMC.

12) Battery protection: current cutback, warning and shutdown at configurable high and low battery voltage.

13) Rugged aluminum housing for maximum heat dissipation and harsh environment.

14) Rugged high current terminals, and rugged aviation connectors for small signal.

15) Thermal protection: current cut back, warning and shutdown on high temperature.

16) Configurable 60 degree or 120 degree hall position sensors. Controller can do auto_Identification angle for different degrees of hall sensors.

17) Configurable high pedal protection: the controller will not work if high throttle is detected at power on.

18) Current multiplication: Take less current from battery, output more current to motor.

19) Easy installation: 3-wire potentiometer will work.

20) Standard PC/Laptop computer to do programming. There is one more choice for customers to program KLS controller. Standard Tablet with Android OS to do programming. Need a Z-TEK USB TO RS232 cable for connecting the controller to App program in Tablet.
21) User program provided. Easy to use. No cost to customers.
22) Support motors with any number of poles.
23) Up to 70,000 electric RPM standard. (Electric RPM = mechanical RPM * motor pole pairs; Motor pole pairs=Motor poles/2).

General Specifications:

•Frequency of Operation: 20kHz.
•Standby Battery Current: < 0.5mA.
•5V or 12V Sensor Supply Current: 40mA.
•Controller supply voltage range: PWR, 18V to 90V for controllers rated equal or lower than 72V.
•Supply Current, PWR, 30mA Typical.
•Configurable battery voltage range, B+. Max operating range: 18V to 1.25*Nominal Voltage.
•Standard Throttle Input: 0-5 Volts (3-wire resistive pot), 1-4 Volts (hall active throttle).
•Throttle Input: 0-5 Volts. Can use 3-wire pot to produce 0-5V signal.
•Main Contactor Coil Driver<2A.
•Full Power Operating Temperature Range: 0℃ to 70℃ (MOSFET temperature).
•Operating Temperature Range: -40℃to 100℃ (MOSFET temperature).
•Motor Current Limit, 30 seconds boost: 400A, depending on the model.
•Motor Current Limit, continuous: 160A, depending on the model.
•Max Battery Current: Configurable.
(http://kellycontroller.com)

A.3 Linear TechnologyLT8490 - High Voltage/Current Buck-Boost Battery Charge Controller with Maximum Power Point Tracking Specifications

Description

The LT®8490 is a buck-boost switching regulator battery charger that implements a constant-current constant voltage (CCCV) charging profile used for most battery types, including sealed lead-acid (SLA), flooded, gel and lithium-ion. The device operates from input voltages above, below or equal to the output voltage and can be powered by a solar panel or a DC power supply. On-chip logic provides automatic maximum power point tracking (MPPT) for solar powered applications. The LT8490 can perform automatic temperature compensation by sensing an external thermistor thermally coupled to the battery. STATUS and FAULT pins containing charger information can be used to drive LED indicator lamps. The device is available in a low profile (0.75mm) 7mm × 11mm 64-lead QFN package.

Applications

- Solar Powered Battery Chargers
- Multiple Types of Lead-Acid Battery Charging
- Li-Ion Battery Charger
- Battery Equipped Industrial or PorTable Military Equipment

Features

- V_{IN} Range: 6V to 80V
- V_{BAT} Range: 1.3V to 80V
- Single Inductor Allows V_{IN} Above, Below, or Equal to V_{BAT}
- Automatic MPPT for Solar Powered Charging
- Automatic Temperature Compensation
- No Software or Firmware Development Required
- Operation from Solar Panel or DC Supply
- Input and Output Current Monitor Pins
- Four Integrated Feedback Loops
- Synchronizable Fixed Frequency: 100kHz to 400kHz
- 64-Lead (7mm × 11mm × 0.75mm) QFN Package

(http://www.linear.com/product/LT8490)

A.4 Hyundai HiS-M300MI (300W) Solar Panel Specifications

DC Electrical Characteristics

- STC Power Rating 300W
- PTC Power Rating 269W [1]
- STC Power per unit of area 14.4W/ft^2 (154.6W/m^2)
- Peak Efficiency 15.46%
- Power Tolerances 0%/+3%
- Number of Cells 72
- I_{mp} 8A
- V_{mp} 37.7V
- I_{sc} 8.3A
- V_{oc} 45.7V
- NOCT 46°C
- Temp. Coefficient of I_{sc} 0.05%/K
- Temp. Coefficient of Power -0.43%/K
- Temp. Coefficient of Voltage -0.146V/K
- Series Fuse Rating 15A
- Maximum System Voltage 600V

Mechanical Characteristics

- Type Polycrystalline Silicon
- Output Terminal Type Multicontact Connector Type 4
- Output Cable Wire Gauge 12 AWG
- Output Cable Wire Type PV Wire
- Output Cable Wire Length 47.2in (1,200mm)
- Frame Color Clear
- Length 77.4in (1,965mm)
- Width 38.9in (987mm)
- Depth 2in (50mm)
- Weight 63.9lb (29kg)
- Installation Method Rack-Mounted

Warranty and Certifications

- 80% Power Output Warranty Period 25yrs
- 90% Power Output Warranty Period 10yrs
- Workmanship Warranty Period 10yrs
- UL 1703 Fire Classification data not available
- Compliances UL 1703, IEC 61215, IEC 61730, TUV
- CSI Listed Yes

1. California Solar Initiative (CSI) list of Eligible Modules (http://www.solardesigntool.com/components/module-panel-solar/Hyundai/2412/HiS-M300MI/specification-data-sheet.html)

A.5 Herewin Li-Ion 80V 60Ah LiNiCoMnO2, LiFePO4 Battery Specifications

- Charge voltage 94.9V
- Nominal voltage 83.2V
- Nominal capacity 300Ah @0.5C Discharge
- Charge current Standard charge: 0.2C charge about 6.5hours
- Rapid charge: 0.5C charge about 4.5hours
- Standard Charging method 0.2 CC(constant current) charge to 94.9V, then CV(constant voltage 94.9V) charge till charge current decline to 0.02C
- Max. charge current 100A
- Max. discharge current 100A
- Discharge cut-off voltage 65V
- Cell & Method (3.7V20Ah) 25S3P
- Operating temperature Charging: 0°C ~ 60°C
Discharging: -20°C ~60°C
- Storage temperature -10°C ~ + 45°C
- Battery Weight Approx. 65kg

(https://www.alibaba.com/product-detail/Deep-cycle-large-battery-80V-60Ah_60661448234.html?spm=a2700.7724838.2017115.3.e4RAsf)