Design and Development of an Extended range Electric Hybrid Scooter

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Abstract— **Rapid depletion of fossil fuels has forced the necessity of an alternate energy vehicle. Electric vehicles serve as promising technology for the future world transportation arena. Due to minor drawbacks the electric vehicles cannot match up with the fossil fuel powered vehicle which made the invention of hybrid technology. The range of an electric vehicle is comparatively shorter than other vehicles. If this drawback is minimized then electric vehicles could easily conquer the automobile industry. Concentrated efforts are mainly towards implementing a concept called as Electric – Electric hybrid system by which one system will be charged while the other system provides propulsive power to the vehicle. The electric hybrid scooter purely runs in electricity and thus it becomes almost nonpolluting.**

Keywords- Electric – Electric hybrid System- range -Electric hybrid scooter- Fuel economy.

I. Introduction

Internal combustion engines are relatively less efficient in converting the on-board fuel energy to propulsion as most of the energy is wasted as heat. On the other hand, electric motors are efficient in converting the stored energy in driving a vehicle, and electric drive vehicles do not consume power while coasting. Some of the energy loss in braking is captured and reused by regenerative braking. With the help of regenerative braking one fifth of the energy loss can be regenerated. Typically petrol engines effectively use only 15% of its fuel content to move the vehicle. Whereas an electric drive vehicle has an on-board efficiency of about 80%. But due to reasons such as cost, inability to reach higher speeds electric drive vehicles failed to capture markets. Contrary to this petrol vehicles can cover longer distances with higher speed but it cannot cover shorter distance with slow speed (say in traffic) in an efficient way.

By increasing the range of electric vehicles they could easily capture the automobile industry. Hybrid technology is the most promising technology that could be implemented for increasing the EV range as current electric vehicle industries are switching towards this concept for increasing the vehicle range. In this paper, the concept of Electric-Electric hybrid system which incorporates two separate Brushless DC motors for its propulsion.

The Brushless DC (BLDC) motors are fixed to the Hub of both front and rear wheel. The reason for choosing BLDC motor is its compactness, noiseless operation and motor generating principle.

II. Theory of Hybrid Vehicle

A. *Parallel hybrid vehicle*

In parallel hybrid vehicle, the internal combustion engine and the electric motor are connected to mechanical transmission and can transmit power simultaneously to drive the vehicle [1]. The commercialized parallel hybrid vehicles use a single small electric motor and a small battery pack. Parallel hybrid vehicles are capable of regenerative braking and the internal combustion engine present in it is capable of supplemental charging of the battery.

B. *Plug-in hybrid vehicle*

A Plug-in hybrid electric vehicle(PHEV), also called as Plug-in hybrid, is a hybrid electric vehicle with rechargeable batteries that can be restored to full charge just by connecting to an external power source. A Plug-in hybrid electric vehicle shares the characteristics of both conventional hybrid electric vehicle having an electric motor and an internal combustion engine [2]; and of an all-electric vehicle, having a plug to connect to an electric grid.

III. SPECIFICATIONS

The specifications of the Electric - Electric hybrid scooter designed are as follows:

Motor power:	1000W
Number of motors:	2
Motor Torque:	33 N-m @ 150 rpm
Vehicle max. Speed:	40 km/hr.
Front Brake:	Drum Brake
Motor type:	Brushless DC Motor
Battery capacity:	12 V, 24 Ah
Charging time:	8 hours
Battery type:	Sealed lead acid batteries
Power for charging:	220 V
Carrying capacity:	2 adults+1 child
Electrical system:	12 V

Head lamp:	12 V, 35 W
Turn signal indicator:	1.7 W
Side indicator lamp:	12 V, 10 W

TABLE1. HUB MOTOR SPECIFICATIONS

Sl. No	Features	Description
1.	Rated Voltage	48V DC
2.	Rated Power	1000W
3.	Controller current limit	33A, 12 MOFET controller
4.	No Load speed	518 rpm
5.	Max. Torque	>50 Nm
6.	Max. Power	>1000W
7.	Max. Efficiency	82%

TABLE2. MOTOR CONTROLLER SPECIFICATION

Sl. No	Features	Description
1.	Rated Voltage	48 V
2.	Current limit	33A
3.	Suitable motor power	1000W
4.	Value Added Features	Cruise Control
		Low voltage cut off
		Anti-theft alarm
		Motor lock
		Brake cut off

IV. COMPONENTS

A. Electric Motor

Hub motors are an interesting development which could offer benefits such as compactness, noiseless operation and high efficiency for electric vehicles. These motors have stators fixed at the axle, with the permanent magnet rotor embedded in the wheel.

The traditional "exterior rotor" design has the hollow cylindrical rotor spinning around a stator axle. There is a "radial air gap" between the stator and rotor [3]. The stator consists of stacked laminated steel plates with wound coils. Pulse width modulated (PWM) current is used to supply current to the stator. Hub motors must run at relatively low speed – equal to the actual rotation of wheel if there is no final gearing stage. The benefit is about a 10% increase in efficiency due to the lack of transmission.

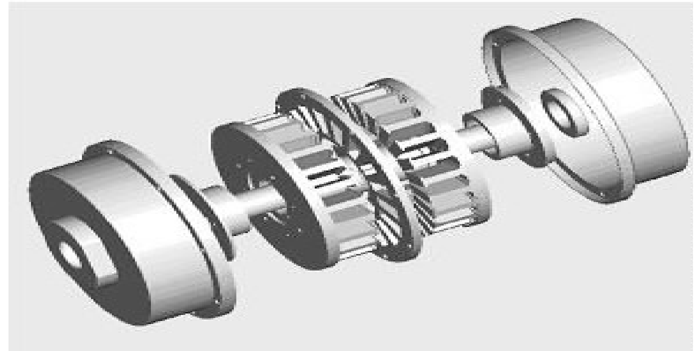

Figure1. Exploded view of a BLDC motor

Reason for choosing BLDC Motor:

The main reason for choosing a hub motor is that it does not require a transmission system which helps in reducing the transmission losses. Since it has no brushes to wear out the life of motor is increased. It has a greater traction control. The back emf created by BLDC motor can easily be stored in the batteries.

Figure 2. 1000W BLDC hub Motor

B. Motor Controller

The controller connects the power source to the motor. It controls speed, direction of rotation, and optimizes energy conversion. While batteries produce constant voltages which decrease as they are used up, some controllers require a DC-to-DC converter to step down this changeable voltage to the motor's expected constant operating voltage, but other controllers incorporate a DC-to-DC converter and can accept a varying voltage. Converter efficiencies are typically greater than 90% [4].

The voltage control is achieved by "chopping" the source current - the voltage is switched on and off, with the ratio of on to off determining the average voltage. Chopping is performed by power electronic circuitry such as diodes and thyristors and silicon control rectifiers (SCR). Controllers also effect regenerative braking, by which the motor is acted as a generator to recharge the batteries.

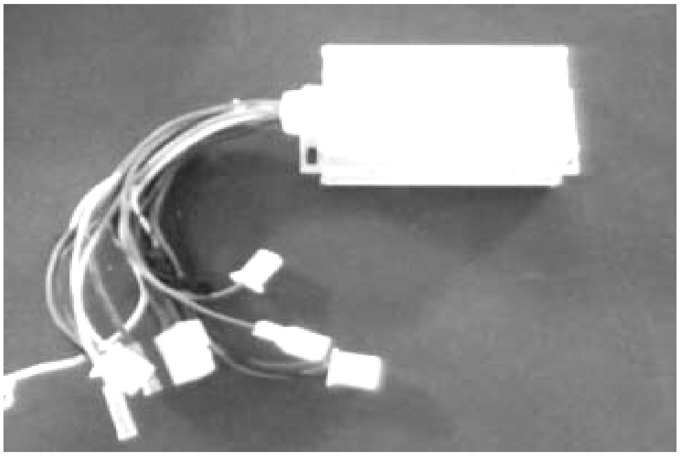

Figure 3. 48V Motor controller

a) Hall sensors

The commutation of a BLDC motor is controlled electronically by using hall sensors. To rotate the BLDC motor, the stator windings should be energized in a sequence for which the rotor position is to be sensed. Rotor position is sensed using three Hall Effect sensors embedded into the stator. Whenever the rotor magnetic poles pass near the Hall sensors, they give a high or low signal, indicating the N or S pole is passing near the sensors. Based on the combination of these three Hall sensor signals, the exact sequence of commutation can be determined.

C. Battery

The Lead acid battery is the power source to the electric drive. While most of the electric vehicles are choosing Lead acid battery a variety of other alternative batteries can also be used. Lead acid based are chosen for the following reasons:

1. High power
2. Energy density
3. Durable

Sealed Lead Acid Batteries

Sealed Lead acid battery has a good Energy density and power density ratio. It has about 80% of charge /discharge efficiency [5]. Lead acid batteries, used currently in many electric vehicles, are potentially usable in hybrid applications. Lead acid batteries are inexpensive, safe, and reliable. But cold temperature performance, short calendar and cycle life are still impediments to their use. Advanced lead acid batteries are being developed for hybrid electric vehicle applications.

V. CONSTRUCTION

The electric – electric hybrid scooter consists of two electric motors which are connected to the front and rear wheel, each with a separate battery backup.

Figure 4. Constructional details of electric – electric hybrid scooter

The connection is given between the vehicle control unit and the motor control unit with appropriate interfaces. The charging and discharging of battery is done simultaneously. The propulsion power is provided by an unit of motor and battery pack while the other motor acts a generator and charges the battery pack in its unit. For instance if the rear wheel motor provides the propulsion power the front wheel motor will act as a generator and charges its battery pack.

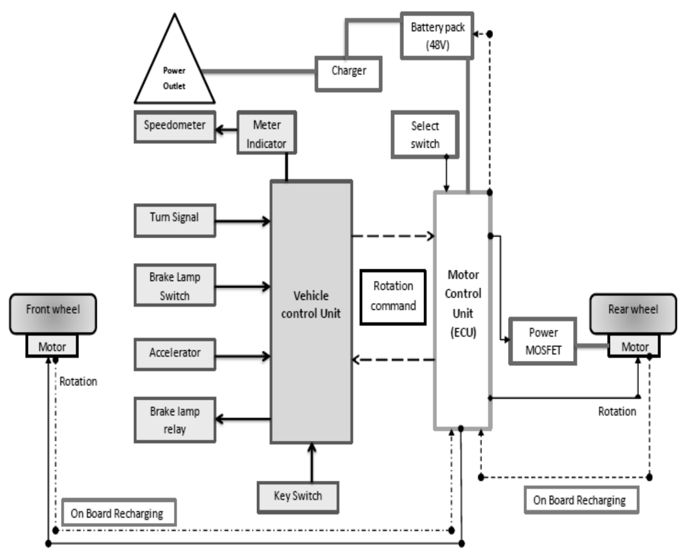

Figure 5. Control system of the model

VI. POWER CALCULATION

The power required at the wheels of a vehicle is obtained from the following equations [6]:

$$P_{total} = P_{grad} + P_{accel} + P_{rolling} + P_{aero} \quad (1)$$

$$P_{grad} = mgv \sin \theta \quad (2)$$

$$P_{accel} = mav \quad (3)$$

$$P_{rolling} = C_r \cdot mgv \quad (4)$$

$$P_{aero} = 0.5 \times \rho \times A \times v^3 \times C_a \quad (5)$$

Where,

P_{grad} is the Gradient power (W)
P_{accel} is the Acceleration Power (W)
$P_{rolling}$ is the Rolling Power (W)
P_{aero} is the Air – drag Power (W)

m is the mass of the vehicle (kg).
g is the acceleration due to gravity (m/s^2).
v is the velocity (m/s).
θ is the gradient.
a is the acceleration (m/s^2).
C_r is the Rolling friction coefficient.
A is the frontal Cross sectional Area (m^2).
C_a is the aerodynamic drag coefficient.
ρ is the density of air (kg/m^3).

Gradient power (P_{grad}):

$$P_{grad} = mgv \sin\theta$$

Where,

m = 50kg.
θ = 15 degrees.
v = 9.72 m/s.
g = 9.81m/s^2.

$$P_{grad} = 50 \times 9.81 \times 9.72 \times \sin 15 = 143.02 \text{ W}$$

Acceleration Power (P_{accel}):

$$P_{accel} = mav$$

Where,

m = 50kg.
v = 9.72 m/s.
a = 1m/s^2.

$$P_{accel} = 50 \times 9.72 \times 1 = 486 \text{ W}$$

Rolling Power ($P_{rolling}$):

$$P_{rolling} = C_r \cdot mgv$$

Where,

m = 50kg.
v = 9.72 m/s
C_r= 0.015.
g = 9.81m/s^2.

$$P_{rolling} = 0.015 \times 50 \times 9.81 \times 9.72 = 71.51 \text{ W}$$

Air – drag Power (P_{aero}):

$$P_{aero} = 0.5 \times \rho \times A \times v^3 \times C_a \quad (5)$$

Where,

ρ = 1.17 kg/m^3.
A = 0.5 m^2.
C_a = 0.9.
v = 9.72 m/s.

$$P_{aero} = 0.5 \times 1.17 \times (9.72)\text{\^{}}3 \times 0.5 \times 0.9 = 241.75 \text{ W}$$

$$P_{total} = P_{grad} + P_{accel} + P_{rolling} + P_{aero}$$
$$P_{total} = 143.02 + 486 + 71.51 + 241.75$$
$$P_{total} = 941.75 \text{ W} \sim 1000\text{W} \quad (6)$$

Based on the total power requirement, a 1000W, brushless DC motor is chosen.

VII. MODES OF RECHARGING

A. *Regenerative Braking*

Regenerative braking is a technique by which the power lost at the time of braking is regenerated and can be used further. It involves the usage of electric motor as a generator. While driving the vehicle in city start-and-stop conditions where brakes are applied often the regenerative braking system can be used effectively.

B. *Plug-In Recharge*

The widely used option for recharging the battery is Plug-in recharging. The battery is fully charged by plugging it to an external power source. The methods of charging are as follows [7]:

a) Constant-Voltage charging

Constant-voltage (often called constant-potential) chargers maintain nearly the same voltage input to the battery throughout the charging process, regardless of the battery's state of charge. Constant-voltage chargers provide a high initial current to the battery because of the greater potential difference between the battery and charger. As the battery charges its voltage increases quickly. Though the battery reaches partial charge quickly, obtaining a full charge requires prolonged charging.

b) Constant-Current Charging

Constant-current charging means that the charger supplies a relatively uniform current, regardless of the battery state of charge or temperature. Constant-current charging helps in charging batteries that are connected in series. At these high rates of charge there will be some venting of gases. Positive grid oxidation will occur at elevated temperatures or extended overcharge times. Constant-current charger permits full charge yet prevents excessive grid oxidation.

c) Float Charging

Float charging is most commonly used for backup and emergency power applications where the discharge of the battery is not frequent. During float charging the charger, battery, and load are connected in parallel. Float chargers are typically constant-voltage chargers that operate at a low voltage. Operating the charger at a low voltage, usually less than 2.4 V per cell, keeps the charging current low and thus minimizes the damaging effects of overcharging.

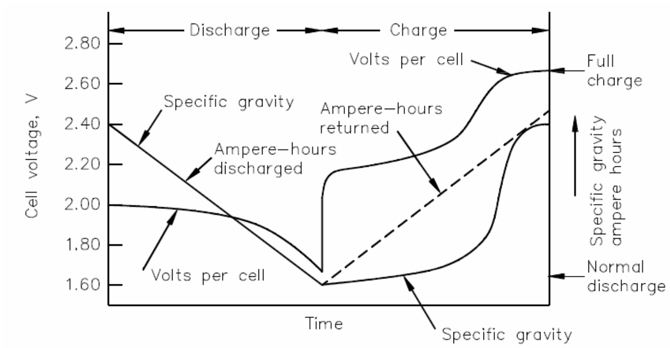

Figure 6. Graph between cell voltage and time

C. Motor Generating

When a BLDC motor rotates, each winding generates a voltage known as back electromotive Force or back EMF, which opposes the main voltage supplied to the windings according to Lenz's Law [8]. The polarity of this back EMF is in opposite direction of the energized voltage. Back EMF depends mainly on three factors:

- Angular velocity of the rotor
- Magnetic field generated by rotor magnets
- The number of turns in the stator windings

$$\text{Back EMF (E)} \propto NlrB\omega \qquad (7)$$

Where:

N is the number of winding turns per phase,
l is the length of the rotor,
r is the internal radius of the rotor,
B is the rotor magnetic field density and
ω is the motor's angular velocity

The rotor magnetic field and the number of turns in the stator windings remain constant. The only factor that governs back EMF is the angular velocity or speed of the rotor and as the speed increases, back EMF also increases. The motor technical specification gives a parameter called, back EMF constant, that can be used to estimate back EMF for a given speed. The potential difference across a winding can be calculated by subtracting the back EMF value from the supply voltage. The motors are designed with a back EMF constant in such a way that when the motor is running at the rated speed, the potential difference between the back EMF and the supply voltage will be sufficient for the motor to draw the rated current and deliver the rated torque. If the motor is driven beyond the rated speed, back EMF may increase substantially, thus decreasing the potential difference across the winding and reducing the current drawn. The last point on the speed curve would be when the supply voltage is equal to the sum of the back EMF and the losses in the motor, where the current and torque are equal to zero.

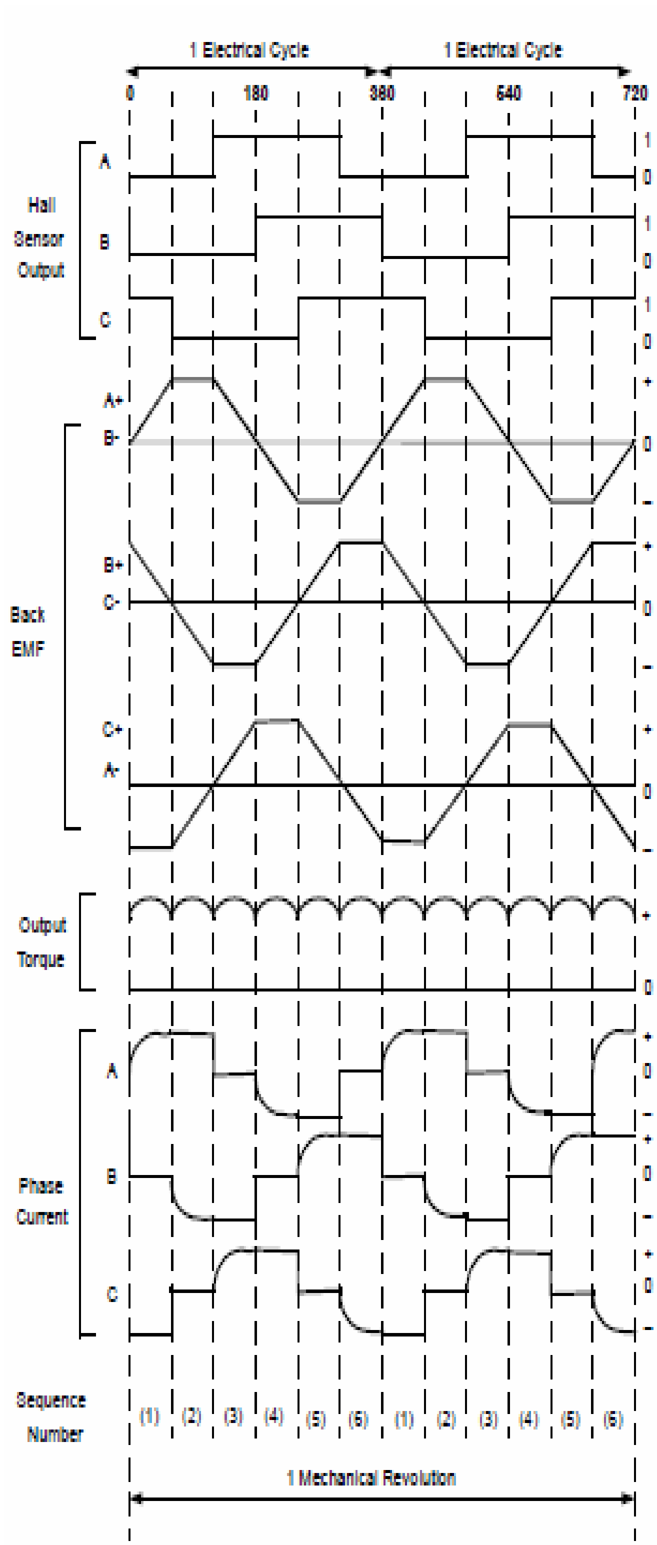

Figure 7. Hall sensor signal, Back EMF, Output torque and Phase current

VIII. COMPARATIVE ANALYSIS

TABLE1. COMPARISON BETWEEN PROPOSED AND CURRENT ELECTRIC SCOOTER

Sl.no	Characteristics	Proposed model	Current electric scooter
1.	Regenerative braking	Yes	Yes
2.	Plug-in recharge	Yes	Yes
3.	On board recharging	Yes	No
4.	Method	Discharge of charge + on board recharge	Discharge of charge
5.	Range	Extended range	Ordinary range
6.	No.of Motors	2	1
7.	Hybrid system	Yes	No

TABLE2. COMPARISON OF EFFICIENCIES

Sl.no	Description	ICE Vehicle	Electric Vehicle
1.	Tank-to-wheel Efficiency	IC engine Efficiency: 20%	Motor Efficiency: 82%
		Overall Efficiency: 15%	Overall Efficiency: 75%
2.	Well-to-Tank Efficiency	Efficiency of Oil Production: 83%	Electricity production from natural gas: 40%
		Natural Gas production Efficiency: 95%	Electricity transportation efficiency over the grid: 92%

IX. PERFORMANCE CURVES

A. Motor Performance

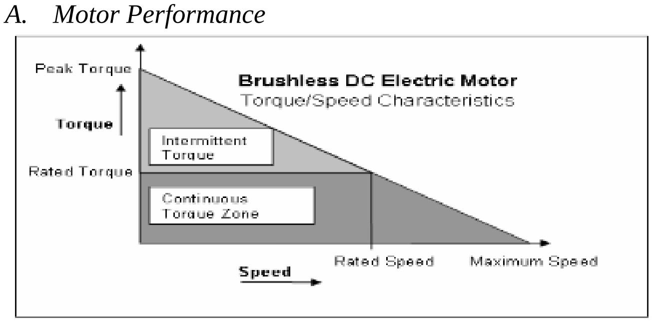

Figure 8. Torque/Speed characteristics of BLDC motor

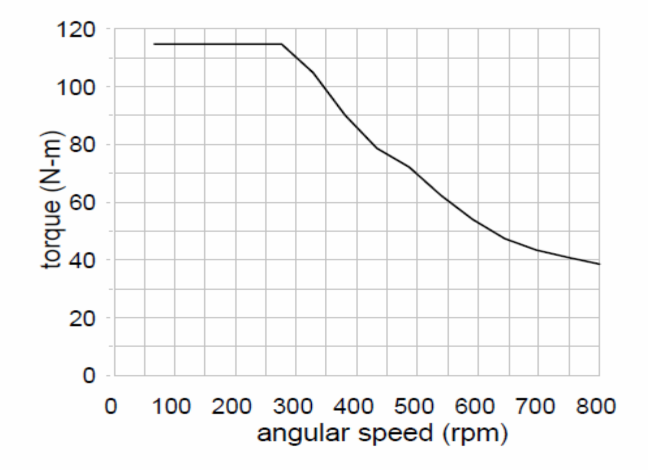

Figure 9. Experimental Speed-Torque characteristics

B. Battery Performance

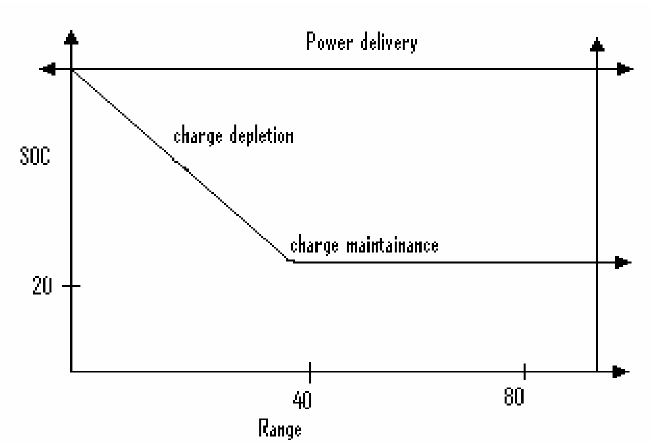

Figure 10. Range/State of Charge characteristics

C. Speed characteristics of vehicle

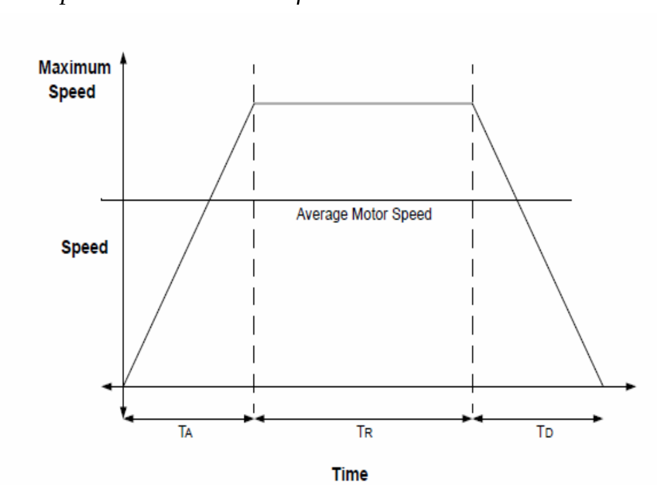

Figure 11. Speed-Time characteristics of BLDC motor

D. Motor Efficiency

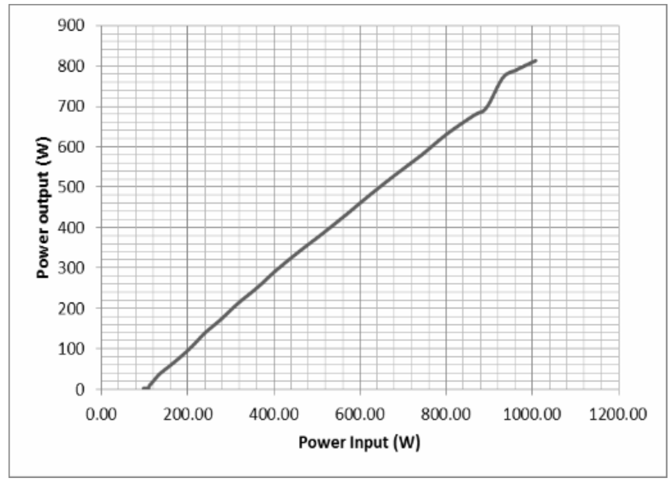

Figure 12. Power output/ Power input

E. Charging Characteristics

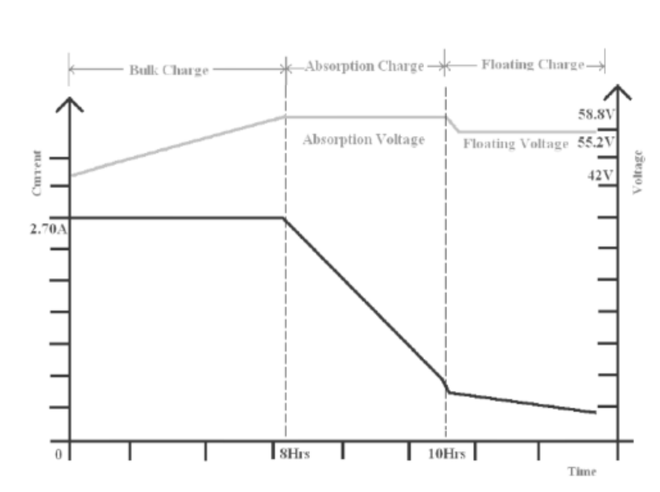

Figure 13. Charging characteristics of battery

X. ADVANTAGES & DISADVANTAGES

A. Advantages

i. The range of an electric bike is increased.
ii. The city traffic air and noise pollution is decreased to a greater extent.
iii. One third of energy is captured by regenerative braking, which would otherwise go waste.
iv. Decreased the dependency of fossil fuels.

B. Disadvantages

i. The initial cost of the vehicle is marginally increased, compared to the conventionally available.
ii. The disposal of battery is to be properly handled to avoid pollution.

XI. CONCLUSION

With the wide range of advantages electric hybrid scooter is a potential solution to replace the conventional fossil fuel powered vehicle. About half of the total range can be regenerated through the back EMF that is produced. On line recharging of electric vehicles by this design would capture the automobile industry soon.

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He has organized more than 60 programmes in the past three years, which includes three International conferences. He is an approved Ph.D Research guide under Anna University, Tiruchirappalli, Anna University Chennai and Anna University Coimbatore and also at Karpagam University, Coimbatore. He has been invited as chairperson and has delivered special lectures in many National and International conferences and symposiums. He is a life member in Indian Society for Technical Education, Indian Institute of Industrial Engineering, Indian Institute of Metals, Indian Society for Advancement of Materials and Process Engineering, Tribology society of India, Indian Institute of Production Engineers, Indian Welding Society, Association of Machines and Mechanisms and Materials Research Society of India. He is also a member of International Association of Engineers, Institution of Engineers and Society of Automotive Engineers. At present, he is guiding 9 Ph.D. Research Scholars, also serving the institute in the capacity of Professor - Research & Development.