EV with hydro static transmission system

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***Abstract*— According to current scenario, automobile industry is undergoing rapid and extensive change, automobile sector is to blame for numerous environmental and fuel-related issues. Consequently, electric vehicles are becoming more prevalent. The electric vehicles are crucial to the automotive sector but one of the major concern with electric vehicle is the high cost. In this paper we focus on the most cost consuming component in EV and comparison of these components with hydro static transmission system. This paper reviews the detailed study of hydro static transmission system and selection of various components in the system with detailed calculation without affecting the efficiency of vehicle as compared to present EV. In order to minimize the cost of electric vehicle, BLDC motor and its controller is replaced by hydro static transmission system.**

Keywords—Hydro static transmission system, BLDC motor, reduce cost, torque.

I. Introduction

The automobile sector is changing fast and wide and onecause of global warming of the earth's atmosphere is the emission of gases and fuel related problems due to automobile, tough emissions targets are being set to reduce the vehicle traffic's contribution of CO2. In order to reduce these effect's, the automotive industry is facing a major change in its drive train, it is moving from combustion to electrical engines. The fact that electric vehicles have zero tailpipe emissions, therefore they are considered as the only solution and as a key enabler to reach the stringent CO2 targets in the country. Due to BS6 Norm, the pollution formed by the vehicle has been reduced.[1] The NOx standard for diesel is reduced to 80 mg/km in BS6 rather than the previous BS4 standard, and the HC + NOx standard is reduced to 170 mg/km. Furthermore, the PM level is reduced by up to 4-5 mg/km. As a result of all of this, people are shifting toward electric vehicle, which cause less pollution than gasoline-powered vehicles but they also face some problems due to the EV's, such as the charging station availability in India for electric vehicles. The most important part is the cost of the electric vehicle. On one hand, the amount of pollution is reduced due to electric vehicles, but on the other side cost of the vehicles increases and a cost issue arises. The parts used in the manufacturing of electric vehicles in India are imported from countries like China, South Korea, and Japan. Mostly, the BLDC motor used in the electric vehicle is imported. The material and parts used for manufacturing the BLDC motor are manufactured in China. As a result the cost of shipments and transportation increases.

In our project we are trying to reduce the cost and increase the efficiency of the EV by making some changes in the transmission system, which replaces the motor with a hydrostatic transmission system. A hydrostatic transmission system in which hydraulic pump for an accumulator will drive hydraulic motor using the fluid passing through flexible hoses.[2-3] In this system gears are not required for converting rotating mechanical energy from one form to another. Because of the displacement of pump and motor arefixed the hydrostatic transmission will itself act as a gearbox.

This transmission system is used for applications which required variable output velocity or Torque.

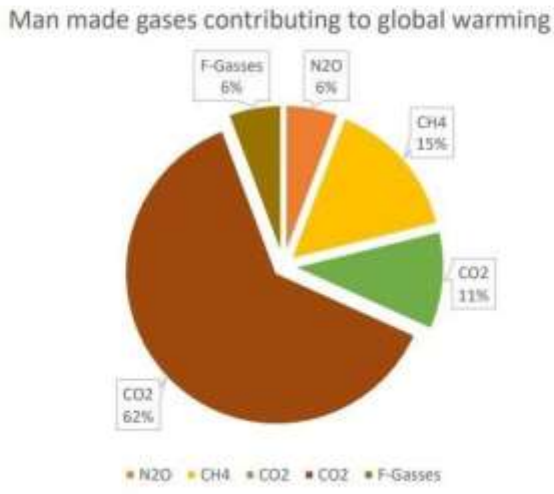

Fig. 1: Man made gases contributing to global warming.

II. Ideation

India is ranked among the top ten polluted countries. One important enabler of keeping the global warming limited is the need of reducing the CO2 emissions from vehicles. This can only happen via the transition from combustion to electric vehicles (EV's). [1]

The enforcement of stringent CO2 emissions regulations worldwide will result in EV's as the primary propulsion system of the future. EVs comprise three critical components: the battery pack, electric motor, and transmission system used in electric vehicles. The battery pack and electric motor are one of the primary reasons for the high cost of BEV. So, in this project we focused on the electric motor. The following diagram shows the basic idea of hydrostatic transmission system.

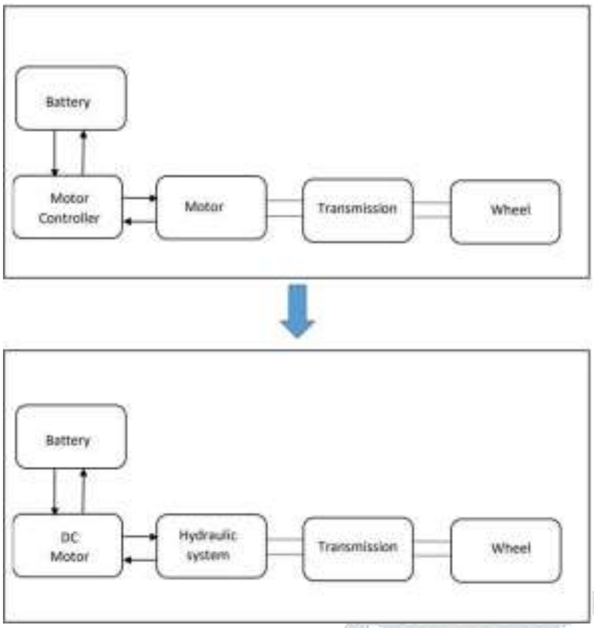

Fig. 2: Block diagram of ideation.

An EV's system begins with a battery, which stores electric power and supplies it to the motor controller. This controller was used to vary the speed according to the acceleration. It gives output signals to the actuator, which is the BLDC motor. [8] This motor runs at varying speeds) according to the input signals received from the controller. This motor shaft is connected to the transmission unit which is a single-speed transmission system. The transmission system connects to the differential, which is used to split the power between both wheels. In brief, here's how an electric vehicle works: Here, first, the battery is used to provide power to the DC motor. This motor is further connected to the pump. The pump is used to pump the fluid towards the hydraulic motor. As the pumping starts, due to fluid flow, pressure is generated and energy is released. [2] Due to the pressure and energy, a hydraulic motor starts running and gives torque at the shaft (RPM).

III. Working And Construction

To reduce the cost of electric vehicle, we replace the BLDC motor and its controller by hydrostatic transmission system which contain, a DC motor, a pump, a hydraulic tank and a hydraulic motor. The working principle of hydrostatic transmission system is very simple: DC motor as a prime mover which will in turn give power to the pump and the fluid will be pumped towards the hydraulic motor. The fluid flow and pressure energy operate the hydraulic motor which generates the required torque at the drive wheel. The hydrostatic transmission system simply acts as a gearbox to transmit power from the prime mover to the driving wheel. The hydrostatic transmission system use a variable-displacement pump, motor, or both so that speed, torque, or power can be regulated.

IV. Design And Calculations

- **Theoretical drive wheel torque for two-wheeler:**

Assumption:

1. The gross vehicle weight (GVW) of the vehicle is taken as 140 kg considering an assumed un-laden weight of 110 kg after hybridization and when loaded with a payload of 30 kg, as per the survey results.
2. The maximum speed of the vehicle is taken as 20 kmph. These all comes under the requirements from the proposed two-wheeler.
3. Radius of the wheel is 0.127 m, taken from the standard manual of vehicle and the service factor is 1.2. [6]

Power rating of the vehicle:

For deciding the power rating of vehicle, the vehicle dynamics like rolling resistance, gradient resistance, aerodynamic drag, etc. has to be considered.

For illustration procedure for selecting motor rating for an electric scooter of gross weight 120 kg is considered.

∴ Force required for driving a vehicle is calculated as:

F total = F rolling + F gradient + F aerodynamic drag + F acceleration [6]

Where,
F total = Total force.
F rolling = Force due to Rolling Resistance.
F gradient = Force due to Gradient Resistance.
F aerodynamic drag = Force due to Aerodynamic Drag.
F acceleration = Required acceleration force. ∴
F total is the total tractive force that the output of the motor must overcome, in order to move vehicle.

Rolling resistance:

Rolling resistance is the resistance offered to the vehicle due to the contact of tire with road. The formula for calculating force due to rolling resistance is given by equation, [6]

F rolling = μ × M × g

Where,
μ = Coefficient of Rolling Resistance,
M = Mass in kg,
g = Acceleration due to gravity = 9.81 m/s

0.001-0.002	Railroad steel wheels on steel rail
0.001	Bicycle tire on wooden track
0.002	Bicycle tire on concrete
0.004	Bicycle tire on asphalt road
0.008	Bicycle tire on rough paved road
0.006-0.01	Truck tire on asphalt
0.01-0.019	Car tire on concrete, new asphalt, cobbles small new
0.02	Car tire on tar or asphalt
0.02	Car tire on gravel-rolled new
0.03	Car tire on cobbles-large worn
0.04-0.08	Car tires on solid sand, gravel loose worn, soil medium hard
0.2-0.4	Car tires on loose sand

Table.1:- Coefficient of rolling resistance. [6]

F rolling = μ × M × g
F rolling = 0.017 × 140 × 9.81

F rolling = 23.34 N

Gradient resistance:

Gradient resistance of the vehicle is the resistance offered to the vehicle while climbing a hill or flyover or while travelling in a downward slope. The angle between the ground and slope of the path is represented as θ which is shown in below figure, [6]

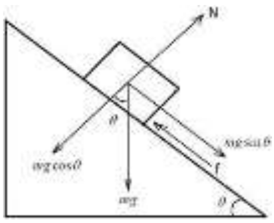

Fig. 3: Free body diagram of a Vehicle moving up an inclined surface. [6]

The formula for calculating the gradient resistance is given by equation below

F gradient resistance = ± M × g × sin θ

Where,
+ (positive) sign for motion up the gradient
- (negative) sign for motion down the gradient

For application consider, in this illustration, let us consider electric scooter run at an angle of θ (inclined angle) = 2.50

F gradient resistance = ± M × g × sin θ
F gradient resistance = 140 × 9.81 × sin (5)
F gradient resistance = 119.69 N

Aerodynamic drag resistance:

Aerodynamic drag is the resistive force offered due to viscous force acting on a vehicle. It is linearly determined by the shape of vehicle. The formula for calculating aerodynamic drag is given by below equation, [6]

F aerodynamic drag = 0.5 × CD × A f × ρ × v2

Where,
CD = Drag coefficient
Af = Frontal area
P = Air density in kg/m3
V = velocity in m/s

For application consider, maximum speed of our scooter is 20 kmph (given) that is 5.55 m/s and air density is 1.1644 kg/m3 at 300 temperature and drag coefficient is 0.5, frontal area is 0.7 as per the table shown below,

Vehicle	C_D	A_f
Motorcycle with rider	0.5-0.7	0.7-0.9
Open convertible	0.5-0.7	1.7-0.9
Limousine	0.22-0.4	1.7-2.0
Coach	0.4-0.8	6-10
Truck without trailer	0.45-0.8	6.0-10.0
Truck with trailer	0.55-1.0	6.0-10.0
Articulated vehicle	0.5-0.9	6.0-10.0

Table.2:- Drag coefficient and frontal area of vehicle. [6]

Then,
F aerodynamic drag = 0.5 × CD × Af × ρ × v2
F aerodynamic drag = 0.5 × 0.5 × 0.7 ×1.1644 × (5.55) 2
F aerodynamic drag = 6.276 N

Acceleration Force:

Acceleration force is the force that helps the vehicle to reach a predefined speed form rest in a specified period of time. The motor torque bears a direct relationship with the acceleration force. Better the torque, lesser the time required by the vehicle to reach a given speed. The acceleration force is a function of the mass of the vehicle. Acceleration force is calculated as: [7]

F acceleration = M × g × a

Where,
a = Required acceleration in rad/s2
M = Mass in kg
g = Acceleration due to gravity = 9.81 m/s2

∴ Now assume we achieve the 20 Kmph in 15 seconds, so the acceleration becomes (a) = 0.370 rad/s2.

F acceleration = M × g × a
F acceleration = 140 × 9.81 × 0.370
F acceleration = 508.158 N

Total Force:

The force required for driving a vehicle is, [6]

F total = F rolling + F gradient + F aerodynamic drag + F acceleration
F total = 23.34 + 119.69 + 6.276 + 508.158
F total = 657.464 N

Then, the power required for driving a vehicle is,

P = F total × V × (1000 ÷ 3600)

Where,
P = Power in watt
V = Velocity in m/s
F total = Total force newton

P = F total × V × (1000 ÷ 3600)
P = 657.464 × 20 × (1000 ÷ 3600)
P = 3648.92 watt.
∴ Power = 3.648 Kw

Torque Calculations:

The torque produced by the drive motor is required for the drive wheels which helps to obtain the desired drive characteristics. The torque is given by: [7]

$$T = R_f \times F_{total} \times r_{wheel}$$

Where,
T = Torque
R_f = Friction factor that account for frictional losses between bearings, axles etc.
r_{wheel} = radius of drive wheel

assume of radius of the wheel is 0.127 m and the service factor 1.2.

$$T = R_f \times F_{total} \times r_{wheel}$$
$$T = 1.2 \times 657.464 \times 0.127$$
$$\therefore\ T = 100.19 \text{ N-m}$$

This torque can be obtained by directly mounting a motor with the torque can be generated by mounting the motor with value of torque on the differential of vehicle of using gearbox or using chain drive to magnify a lesser torque to this value before it drives the wheel. [7]

- **Practical drive wheel torque for two-wheeler:**

Data taken from standard manual of vehicle:

1. Power of the engine of the moped is 5.4 PS or 3.67749 Kw.
2. Radius of rear wheel (r) is 0.127 m.

Assumption:

1. Speed of the vehicle is 20 Kmph i.e. 5.55 m/s.

Torque calculations:

Velocity is given by,

$$V = \Pi \times D \times N/60$$

Where,
V = Velocity in (m/s)
D = Diameter of Wheel in (m)
N = Speed in (RPM)

$$V = \Pi \times D \times N/60$$
$$5.55 = \Pi \times 0.254 \times N/60$$
$$\therefore\ N = 417.31 \text{ rpm}$$

Power can be given by the formula,

$$P = 2 \times \Pi \times N \times T/60$$

Where,
P = Power in watt
N = Speed in (RPM)
T = Torque in (N-m)

$$P = 2 \times \Pi \times N \times T/60$$
$$3.67749 \times 103 = 2 \times \Pi \times 417.31 \times T/60$$
$$\therefore\ T = 84.15 \text{ N-m}$$

∴ as the calculated theoretical and practical torque are approximately near. So, consider the maximum torque i.e. 100 N-m for further calculations.

- **Selection of components for hydro static transmission system:**

Motor calculations:

As it can be perceived, this model is actually a two wheel vehicle with one wheel is driving wheel. The pump will drive a motor by providing flow of oil to the motor unit which will then drive the wheel to propel the vehicle. The accumulator and braking units was added to apply brakes as and when needed.
The torque and speed of motor were set to 100 N-m and 417.31 RPM.
The selection of motor has been done by considering Eagle hydraulic as a motor catalogue standard. It was based on required motor torque [6].

Motor configurations:-

1. Model : EBMP 50
2. Displacement = 51.7 cm3/rev (3.15 in^3/rev)
3. Max Speed = 1150 RPM
4. Max Torque = 100 N-m
5. Max Output = 10 kW
6. Max Pressure = 140 Bar
7. Max Flow = 60 LPM (15.9 GPM)
8. Weight = 5.6 kg

According to above configuration following input parameters are required to drive the hydraulic motor, [8]

1. **Required flow rate :**

$$\text{Required flow rate} = \frac{\left(\text{Motor displacement}\left(\frac{in^3}{rev}\right) \times \text{Motor RPM}\right)}{231}$$

$$\text{Required flow rate} = \frac{(3.15 \times 417.31)}{231}$$

∴ required flow rate = 5.69 GPM or 21.538 LPM

2. **Pressure required :**

$$\text{Torque (inch pound)} = \frac{\text{Pressure (PSI)} \times \text{Motor displacement}\left(\frac{in^3}{rev}\right)}{2 \times \pi}$$

$$885.074 = \frac{\text{Pressure (PSI)} \times 3.15}{2 \times \pi}$$

∴ Pressure required= 1765.42 PSI or 121.72 Bar

3. Power required :

$$\text{Power} = \frac{\text{RPM} \times \text{Torque(Nm)}}{5252}$$

$$\text{Power} = \frac{417.31 \times 100}{5252}$$

$\therefore$ Power= 7.94 Hp or 5.92 kW

Now for required flow rate and pressure, we have to select suitable pump to drive hydraulic motor.
The selection of pump has been done by considering a Polyhydron as a pump catalogue standard. It was based on the flow rate and pressure required by motor.

Pump configurations:-

1. Model = 11RC7
2. Displacement = 17.81 cm^3
3. Flow rate = 24.3 LPM
4. Max. operating pressure = 250 Bar

According to above configuration following input parameters are required to drive the hydraulic pump, [10]

1. **Power required:**

$$\text{Power required} = \frac{\text{Flowrate of pump (LPM)} \times \text{Pressure(Bar)}}{600 \times \text{Pump Efficiency}}$$

$\therefore$ Assume the pump efficiency is 0.98 %,

$$\text{Power required} = \frac{24.3 \times 121.5316}{600 \times 0.98}$$

$\therefore$ Power required=5.02 kW

Now for required power, we have to select suitable electric motor to drive a hydraulic pump.

2. **RPM required :**

$$\text{Flow rate (GPM)} = \frac{\text{RPM} \times \text{Pump displacement}\left(\frac{in^3}{rev}\right)}{231}$$

$$5.69 = \frac{\text{RPM} \times 1.086}{231}$$

$\therefore$ RPM=1210.30

3. **Torque required :**

$$\text{Power (W)} = \frac{2 \times \pi \times N \times T(Nm)}{60}$$

$$5.02 \times 10^3 = \frac{2 \times \pi \times 1210.30 \times T(Nm)}{60}$$

$\therefore$ Torque=39.60 Nm

V. Modelling

Modeling of concept of hydrostatic transmission system is done by using solidworks software. The following figures shows the different views and drafting of hydrostatic transmission system.

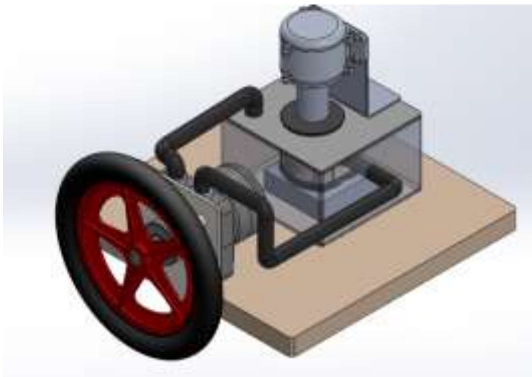

Fig. 4: Isometric view of hydrostatic transmission system.

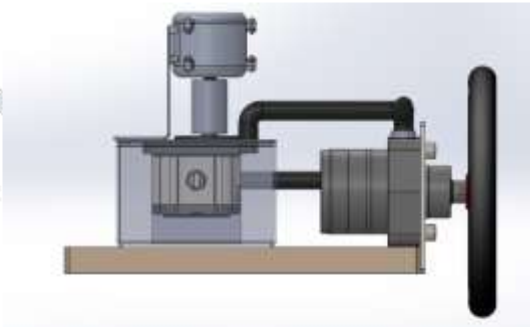

Fig. 5: Side view of hydrostatic transmission system.

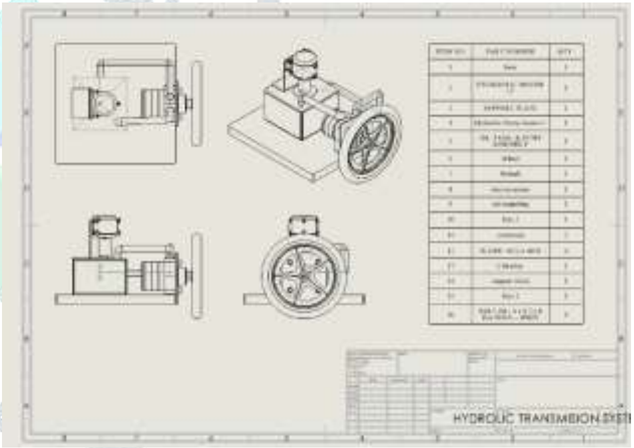

Fig. 6: Drafting sheet of hydrostatic transmission system.

VI. Results

The graphs shown below, are plotted with reference to calculations by using MS Excel software. From Fig. 7. (Speed v/s torque of Hydrostatic System), the graph shows variations of torque with different speeds and it is observed that torque is inversely proportional to speed. Fig. 8. (Speed v/s torque of hydrostatic system and BLDC motor), is a graph of speed v/s torque for comparison of BLDC motor system to hydrostatic transmission system.

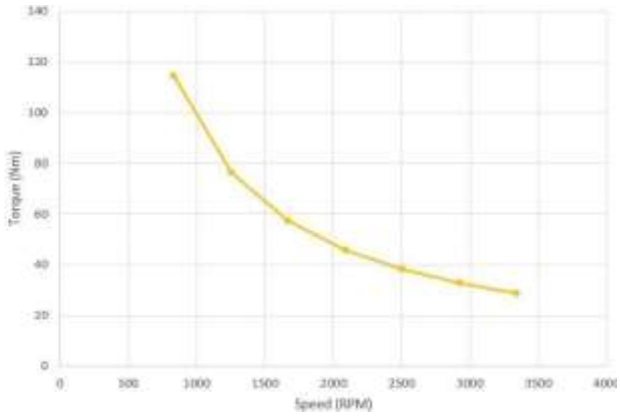

Fig. 7: Speed v/s torque of hydrostatic system.

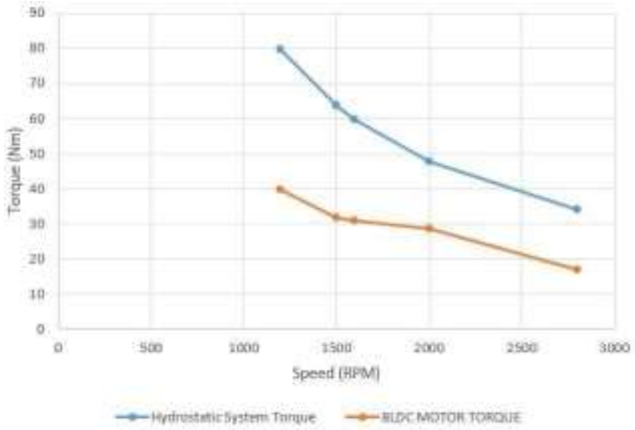

Fig. 8: Speed v/s torque of hydrostatic system and BLDC motor.

Parameters	Hydrostatic System	BLDC
Commutation	No	Electronic commutation based or hall effect sensor
Efficiency	high	high
Life Span	Longer	Longer
Speed/ Torque	Enables operations at all speed with rated load	Enables operations at all speed with rated load
Maintenance	Less	Less
Maintenance Cost	Less	High
Electric Noise generation	Low	Low
Cost of construction	Low	High
Control requirements	Controlled by single lever	High-cost controller
Efficiency at 20% load	93% (Efficiency vary according to load)	90%
Cost Estimation	35k-40k	80k-85k
Inertia to Torque ratio	Nearly 1	Nearly 100

VII. Conclusion

In this project, we researched the current scenario of electric vehicles. The scope of the electric vehicle market is multidimensional, involving a wide array of stakeholders. Over 3,30,000 EV units were sold in 2021, registering a growth of 168 percent over 2020. But the cost of EVs is not economically feasible for the average person.

As our problem statement is to reduce the cost of electric vehicles, we found the BLDC motor has a major contribution to increasing the cost of electric vehicles so we developed the new system which alters the BLDC motor by hydrostatic transmission system. And in this project we have done the analysis on newly designed system and presents the results and effects of hydrostatic system on electric vehicle.

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