Comparative Study of Electric Tractor and Diesel Tractor.

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Abstract. The increase in population day-by-day causes a direct and indirect effect on country’s pollution and resources. These have adverse effects on the environment and contributes directly to climate change. A transition from an internal combustion engine to an electric vehicle is vital, since with a lot of motor and battery technology available globally. This paper focuses on different types of motors and batteries that can be sourced in India, for the conversion of a diesel tractor to an electric tractor and the running costs related to the same is compared.

1. Introduction

To desperately fight against all the factors that hamper the environment, various methods were adopted by many countries, pacts and treaties were signed to abate the effect of this global cause: pollution, which is a major factor leading to climate change cannot be ignored at all. Some important agreements include The Kyoto Agreement of 1997 and The Paris Agreement of 2015. Focusing on mobility, it is one important aspect with which a country’s GDP might increase considerably, but it also responsible for approximately 40% of pollution caused in India. The major pollutants released by burning fuels are Nitrogen oxides (NOx), Ozone (O3), Carbon Monoxide (CO) [1]. Thus, the transition from moving from conventional energy sources to clean energy sources directly effects on the country’s growth and development, and the environment. We can observe the transition in 2-wheelers and small passenger vehicles. These modes of transports are very frugal and have a running cost of approximately Rs.2/km which is drastically less when compared to IC engine vehicles. Climate change is the most concerning factor and is one of the reasons to move towards electric mobility. India has also promised to reduce harmful greenhouse gases by approximately 35% to that in 2005 by 2030.

The reason why the transition towards EV is expanding day by day is due to:

- Advancements and Rapid growth in renewable energy technology have also facilitated in the growth of EV, making it parsimonious and highly efficient wind turbines and solar cells are less expensive, cleaner and have less load on the grid when compared to the technology used a few years back, these systems are getting smarter and more efficient day-by-day. This is also possible because of data analysis and digital revolution by using GPS to reduce the cost and achieve high efficiency. Due to the abundance of skilled manpower and technology in manufacturing and the IT sector is also responsible for this growth.

- Betterment in battery technology has improved battery efficiency, high energy density, quick recharge and improved better battery health. The improvement in motor-technology makes the complete system economical and improves in performance.

- Energy security is higher in electricity when compared to diesel and petrol, the system requires extensive labor and supply chain cost and also prone to frequent fluctuation in cost. The cost of this is also affected by weather, geopolitical factors and other miscellaneous expenses.
This concept is in development for commercial vehicles which will reduce carbon emissions hence resulting in pollution reduction. It is observed that commercial vehicles (light) are majorly bound in the city limits and have higher run time when compared to private vehicles, electrifying commercial vehicles will help in reducing pollution drastically. The tractor is the most used and essential part of the agriculture sector, usage of electric vehicles in the farming sector is an untouched domain, expanding usage and innovations in this sector will help in reducing the overall development cost for farmers and in an agricultural country like India where the agriculture sector contributes 17.7% of the GDP and reduction in working capital will be profitable for the farmers and consumers as the probability of fluctuation cost of the commodity is reduces [2]. Based on available tractor models, motors and batteries, the suitable battery pack capacity is calculated and by combining different types of batteries and motors, the basic cost for the battery pack along with the running cost of the diesel and electric tractor is compared to prove the usage of electric tractor is more frugal. This study aims to compare an internal combustion engine tractor with a lithium-ion based electric tractor.

2. Literature Review
According to Anil Khurana, V. V. Ravi Kumar and Manish Sidhpuria, to control the increasing amount of CO2 emissions the urgency and need to shift to EV is inevitable. The transport sector is the highest emitter of this greenhouse gas. The author has approached using two parts in a questionnaire, first part focuses on the demographics and the second part on model variables. The author has used his own sample and variable to do the modelling. For the survey the author has considered attributes like environmental concern, economic benefits, social influence, self-image, attitude and behavioural intention. [3].

The research done by I. H. Ryu, D. C. Kim and K. U. Kim, formulates all the necessary data required for power transmission and efficiency of a four-wheel-drive diesel tractor. The research also points out necessary details regarding international standards for power transmission creating a foundation to support the research. The research relies on intensive parameters, like axle torque, engine speed, velocity, etc., for calculation of efficiency. The values obtained had a range of 56% to 86%, and an estimate mean of 72.5%. These values were also referred in our case to calculate the battery pack size considering 80% efficiency.[4]

An exploratory study by Mr. Bajrang Lal & Dr. Ajmer Singh stated that in a diesel tractor, CO2 emissions are causing maximum environmental effects. Over 68.86% of the rural population was influenced by agriculture giving 54% of tractor sales in India which is highest in the world. This lead to an increase in the demand for high fuel efficiency with less maintenance [5].

Study on the Development of the Electric Tractor by Yuko UEKA, Jun YAMASHITA, Kazunobu Sato, Yoshinori DOI the study here resulted in remodeling the tractor that using and adding the weight have very less effect on the performance of the tractor. Thus, electric equipment for travelling and tillage reduced 70% of energy consumption. Further, CO2 emissions were reduced to 70% from internal combustion to Electric vehicles with a 10KW tractor. The main advantage was that electrification eliminated the direct emission of exhaust gases [6].

An overview of lithium-ion batteries for electric vehicles by Xiaopeng Chen, Weixiang Shen, Thanh Tu Vo, Zhenwei Cao, Ajay Kapoor reviewed the most commonly used lithium-ion batteries by specifying how well it will perform on an electric vehicle. This provided a brief idea about the characteristics of LiFePO4 (LPO), LiCoO2 (LCO), LiMn2O4 (LMO) and LiNiMnCoO2 (NMC) depending upon cost, safety, operating temperature, thermal stability, etc. Further analysis resulted that LCO is the best option.
for an EV but manufacturers generally use NMC, LFP and LMO as they are cheap and safe for the environment [7].

Mr. A. Rakesh Kumar and Dr. Sanjeevikumar Padmanaban stated various concepts and technology related to electric vehicles and sub-systems which support the electric vehicle ecosystem. This includes charging infrastructure, battery chemical research and usability, battery management system (BMS) and converters, and electric motors. These have helped us selecting our motor and battery technology. Real-life comparison between diesel and electric car energy consumptions [8].

Sreeram k, Preetha PK and Prabaharan Poornachandran have given deeper insights on the real condition of electric vehicles in India as well as on a global level, including power production, plans, dependency on fossil fuels, and minimizing the dependency on fossil fuels. The paper also highlights different types of motors available and their merits and demerits. Motors like Brushless DC Motor (BLDC), Permanent Magnet Synchronous Motor (PMSM), Induction Motor (IM), Switched Reluctance Motor (SRM) and Reluctance Motor (SYNRM) are included. Also, real-world cases of electric vehicles are used and compared which includes a comparison between Mahindra e-verito and Mahindra e2o. A brief idea of hybrid systems that can be used in the transition phase from IC engine vehicles to electric vehicles as no complete dependency will be there on either of the two technologies. Hybrid technology uses a motor to assist which is powered by either a Lithium-ion cell or a supercapacitor depending on the application. Considering the shortcomings and future capabilities improvement in battery technology, reduction in charging time and better infrastructure of charging can be expected [9].

In a recent case study by Diego Troncon and Luigi Alberti, focuses on non-road vehicles and machinery and electrification of it. The system here in focus was a tractor of 100HP. The idea was the conversion from the standard internal combustion engine to a hybrid powertrain. With experiments carried out in real operating conditions on a traditional tractor, the performance requirements for the hybrid powertrain is analyzed with an electric motor in focus. The author also highlights the point where complete electric tractors would be suitable for light tasks. The study also supports the use of Permanent Magnet motors and analyzing the system considering the thermal-equivalent torques. Further design and analysis were carried out using Finite Element Analysis and the system was validated through thermal analysis of the electric motor. The main purpose for conversion to the hybrid system was to downsize the internal combustion engine and the choice for permanent magnet motor was selected to make the tractor cost-effective in terms of production and ownership [10].

A study on electric vehicles in India by Mohamed M, G Tamil Arasan and G Sivakumar highlights Battery Electric Vehicles (BEV) and Hybrid Electric Vehicle (HEV), the two systems are briefly explained along with the advantages of using EVs. The timeline of all EVs is also included right from 1832-2040. Most importantly the scope and opportunities for EVs in India are explained which includes government initiatives, battery technology, commercial/industrial sector implementation.[11]
3. Methodology

3.1. Diesel Tractor

The process of designing began with selecting and comparing the IC engine tractors available on sale. Some of the top-selling utility tractors in India are from prominent manufacturers which includes Mahindra&Mahindra, Escort, Sonalika, John Deer, etc.

Utility tractors are compact low-cost tractors ranging from 35HP to 70HP. Despite the low cost, these tractors are used for small to medium-sized farms and farmers increasingly adopt them. Utility tractors are capable of carrying out almost all modern farming machinery such as plough, cultivator, thresher, water pump, etc. The diesel tractor which we used for comparison: **Mahindra 575DI (year 2020)**.

Specifications:

| Name                     | Values   | Symbol |
|--------------------------|----------|--------|
| Vehicle Weight           | 1860kg   |        |
| Lifting capacity         | 1600kg   |        |
| Total Weight (W)         | 3460kg   | W      |
| Height (h)               | 2.1m     | h      |
| Length (L)               | 3.51m    | L      |
| Width (w)                | 1.95m    | w      |
| Frontal Area (Af) = (h * L) | 7.37mm²  | Af     |
| Coefficient of Drag (Cd) | 0.9      | Cd     |
| Air Density              | 1.2 kg/m³|        |
| Front Tyre               | 0.08m    |        |
| Rear Tyre                | 0.17m    |        |
| Rolling Resistance       | 0.1      | Rr     |
| Rolling Resistance (field) | 0.02    | Rrf    |
| Top Speed                | 40kmph   |        |

*Linear wheel Travel* = 2π*(Rear tyre) = 1.08m

To calculate the power consumed by the tractor depends on parameters of resistance, drag and gradient. The rolling resistance is the resistance offered by the surface of the road to the vehicle. The drag is the resistive force offered by the air to the vehicle and gradient force is the resistance offered by gravity due to the inclination of the surface of the road.
To calculate the power required [Table 2]:

\[ P_r = F_r + F_{Cd} + F_{gcr} \]

\( P_r \) is the power required, \( F_r \) is the rolling resistance force, \( F_{Cd} \) is the Drag force, \( F_{gcr} \) is the gradient force.

\[ F_r = m * g * v * R_r \] 
(rolling resistance = 0.1) [12]

\[ F_r = m * g * v * R_{rt} \] 
(rolling resistance = 0.02)

Where \( m \) is the mass of the vehicle with attachments, \( g \) is the gravitational force, \( v \) is the velocity of the vehicle, \( R_r \) is the rolling resistance and \( R_{rt} \) is the rolling resistance for the tar road

\[ F_{Cd} = 0.5 * (\text{Air density} * C_d * A_f * v^2) \]

Where \( C_d \) is the coefficient of drag, \( A_f \) is the frontal area.

\[ F_{gcr} = m * g * \sin \Theta \]

Considering inclination of 10° (\( \Theta \)).

Where \( F_{gcr} \) is the force acting on an inclined plane and \( \Theta \) is the angle of inclination.

\[ RPM = \frac{(\text{Speed} \times 60)}{\text{(linear distance travelled)}} \]

The tractor efficiency is considered as 80% including all the loses.

\[ Pr = Pr * 1.2 \]

\[ Torque = \frac{(P_r \times 60)}{(2 \times \pi \times RPM)} \]

| Speed (kmph) | Speed (m/s) | Fr    | Fcd   | Fgcr  | Pr (Watts) | Torque |
|--------------|-------------|-------|-------|-------|------------|--------|
| 10           | 2.78        | 9418.89 | 80.99 | 5764.36 | 18317.1    | 1134.19|
| 15           | 4.17        | 14128.33 | 273.33 | 5764.36 | 24199.2    | 998.94 |
| 20           | 5.56        | 18837.78 | 647.89 | 5764.36 | 30300      | 938.09 |
| 25°          | 6.94        | 3767.56  | 1265.41 | 5764.36 | 12956.8    | 320.91 |
| 35°          | 9.72        | 5651.33  | 3472.28 | 5764.36 | 17865.6    | 316.07 |
3.2. Electric Tractor

The drivetrain of an electric tractor consists of [Fig. 1] [8]:

- Motor
- Battery
- Battery Management System
- Power Converters (Drive signal control)

![Figure 1. EV Block Diagram](image)

The theoretical power calculations provided above will require an appropriate electric motor as well as several batteries. The motor selection was based on availability as well, some motors selected based on the motor technology are:

- Induction motor
- PMDC motor
- PMAC motor

The motor’s choices are PMAC ME1302, PMDC ME1909, PMDC ME1002, Induction Motor 1LE7 IE2. The PMAC ME1302 is a motor with a peak power output of 38kW and continuous power output of 15kW, the voltage and current ratings are 120V and 220A respectively. The motor has a weight of 16kgs. The second choice is using two PMDC ME1909 motor, each motor has a peak power output of 20kW and continuous power of 11.5kW. The motor has a voltage rating of 72V and a current rating of 200A. The weight of the motor is 17kgs. The PMDC ME1002 is the motor with the highest power output, the peak power and continuous power of this motor is 63kW and 26kW respectively. The motor requires a voltage of 144V and 170A of 3-phase current. [Fig. 4]

In the single motor setup, the motor replaces the IC engine keeping the gearbox, the four-wheel-drive (4WD) system and power take-off (PTO) intact. In the dual motor setup, the motors are placed on each axle, i.e. front axle and rear axle. This system eliminates the 4WD gearbox/differential and the motor placed on the rear axle is also responsible for the functioning of the PTO.

For EV based on the comparison between different types of battery chemical technologies and the availability of batteries in India from the local vendors the three types of battery technologies selected are:
- LiFePO₄ (Lithium-Iron-Phosphate)
- Li₄Ti₅O₁₂ (Lithium-titanate)
- NMC (Lithium Mixed Nickel-Manganese-Cobalt Oxide)

**Battery:**

| Battery | Voltage | Current | Grade (C) | Life Cycle | Weight (kg) |
|---------|---------|---------|-----------|------------|-------------|
| NMC     | 3.7V    | 2.5Ah   | 3C        | 1100       | 0.045       |
| LPO     | 3.2V    | 6Ah     | 3C        | 1500       | 0.14        |
| LTO     | 2.3V    | 30Ah    | 10C       | 25000      | 1.23        |

Calculations for the number of cells:

1. \( N_{cs} = \frac{V_{bp}}{V_{bc}} \)
2. \( N_{cp} = \frac{I_{bp}}{I_{bc}} \)

\( N_{cs} \) is the number of cells in series, \( V_{bp} \) is motor voltage, \( V_{bc} \) is the voltage of each battery cell, \( N_{cp} \) is the number of cells in parallel, \( I_{bp} \) is the current of the motor, \( I_{bc} \) is the current of each battery cell.

Required data of one cell:

- Voltage (V), Rated capacity if one battery (Ah), Grade (C).

**Power(Wh)= (Ah)*(V)**

**Discharge rate(Current) = (C)* (Ah)**

**Run time= 1/(C) ..... in hours**

Calculation of energy stored, current and voltage for a set of batteries in series and parallel

**Capacity of battery pack= (Current of pack) *(Run time)**

**Power of the battery pack= (Voltage of battery pack) *(Capacity of battery pack)**

In the table given below, the cost shows the amount required for charging a battery once. Since, the cost of electricity varies in different regions in India and also varies on the units consumed, the range of cost is calculated by considering the cost of 1 unit or 1kWh as Rs.6 and Rs.9 for lower and upper limit respectively.
The cost of LTO cells is the highest but the life cycle of these cells is 3 times the life cycle of NMC/LPO.

The calculation of the cells in the battery pack is made based on the 100% efficiency of the motor. The efficiency of the motor, transmissions along with the electronic components is considered to be a minimum of 80%. [13]

NMC cells:

| Motor          | Cells  | Capacity(kWh) | Cost per Charge (INR) |
|----------------|--------|---------------|-----------------------|
|                | Series | Parallel | Total |                         |
| PMAC           | 40     | 88       | 3520  | 32.560                  | 195.36-293.04 |
| PMDC           | 40     | 94       | 3760  | 34.780                  | 206.68-313.02 |
| PMDC(M1002)    | 36     | 89       | 3204  | 29.637                  | 177.82-266.73 |
| Induction Motor| 113    | 31       | 3503  | 32.402                  | 194.41-291.62 |

LPO cells:

| Motor          | Cells  | Capacity(kWh) | Cost per Charge (INR) |
|----------------|--------|---------------|-----------------------|
|                | Series | Parallel | Total |                         |
| PMAC           | 42     | 40       | 1680  | 32.256                  | 193.54-290.30 |
| PMDC           | 47     | 38       | 1786  | 34.291                  | 205.75-308.62 |
| PMDC(M1002)    | 46     | 34       | 1564  | 30.028                  | 180.17-270.25 |
| Induction Motor| 132    | 13       | 1716  | 32.947                  | 197.68-296.52 |

LTO cells:

| Motor          | Cells  | Capacity(kWh) | Cost per Charge (INR) |
|----------------|--------|---------------|-----------------------|
|                | Series | Parallel | Total |                         |
| PMAC           | 55     | 8        | 440   | 30.360                  | 182.16-273.24 |
| PMDC           | 66     | 8        | 528   | 36.432                  | 218.59-327.88 |
| PMDC(M1002)    | 65     | 7        | 455   | 31.395                  | 188.37-282.55 |
| Induction Motor| 216    | 2        | 432   | 29.808                  | 178.84-268.27 |
The running cost of a diesel tractor is calculated to compare it with the running cost of an electric tractor. Here the major focus is the Haryana and Punjab region where the average farm size is approx. 5 acres which is roughly 22,500 m$^2$. Therefore, the length and breadth of the field are 150m X 150m. Here the widest accessory used for farming is considered, which is offset 22 disc harrow. The width of the accessory is 2.5m. So to use the disc harrow throughout the field, the tractor needs to cover a distance of 9km is to be covered. Therefore, the average speed of the tractor is considered to be 6kmph, and using this information average time is calculated and considering the average fuel consumption of the tractor, the total fuel of approximately 10 litres is required. The cost of diesel as per August 2020, the running cost for the diesel tractor was calculated to be Rs.93.5/km.

The electric tractor’s running cost can be calculated by considering the travel factor as 13.335 and with calculated battery pack capacity as 24.199 KW. The range and average speed calculated is 200kms and 15 kmph respectively. The power consumption is calculated by dividing power and speed, the cost for units consumed per km is calculated as 1.613 units/km. The cost per unit in India as per August 2020 is considered and the cost per km for the electric tractor is Rs.14.15/km. [Fig. 3.]

From the above calculations, it can be deduced that the electric tractor is 84.86% efficient in terms of cost.
4. Conclusion
The paper presented shows an analytical comparison between an electric vehicle and a diesel tractor by studying the vehicle, battery and motor specifications. The tractors with 40-50HP are dominating the tractor market and it is necessary to bring a change by considering the pollution and the increase in the fuel cost. The electric tractor will have fewer environmental effects than the diesel tractor. Furthermore, the running cost of the electric tractor and the diesel tractor is being calculated and the result shows that electric tractors are less expensive in the long-term use which is 84% cheaper than the diesel tractor.

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