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Comparative Performance Assessment of Sizing of Electric Motor through Analytical Approach for Electric Vehicle Application

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Abstract

For battery electric vehicle (BEV), electric motor is the only power source. The motor drive system in electric vehicle has many challenges like cost, weight, efficiency, detail torque speed characteristics, motor power rating. Accurate motor power rating prediction is very much necessary to fulfil the performance requirement of electric vehicle. Selection of oversized motor for Electric vehicle application results into overprice motor, more energy consumption and decline in vehicle range. Due to this there will expansion of battery size and increases the overall cost of vehicle. On the other hand, selection of undersized motor leads to poor vehicle performance that limits the drivability of vehicle. This paper gives detailed calculations of motor rating of electric motor. New approach is developed to predict the correct power rating of motor without affecting the desired vehicle performance. According to the requirement, accurate prediction of power rating of motor has been taken for cost efficient and upgradation the performance of motor. The work presented in this paper adopts a method of vehicle performance assessment on the basis of comparison with four different methods with new developed method. Traction motor is major & most expensive component of EV. Selection of motor play's crucial role in the development of electric vehicle. Undersized and oversized motor results in rise in cost of motor which ultimately increases the cost of vehicle. But by using appropriate motor this cost been reduced up to 50-60% with performance enhancement.

Introduction

Global warming has become a vital issue worldwide. Most of the past years have seen its impact. [1]. One of the primary causes of global warming is air pollution. Air pollution is mainly caused by vehicle emissions, which account for 21% of greenhouse emissions [3]. New I.C.E. technologies are being developed to reduce vehicle emissions, but it is not sufficient to reduce air pollution to a satisfactory level. The popularity of electric and hybrid electric vehicles is increasing [3].

Electric vehicles are becoming more popular due to their 42-72% wheel efficiency when powered by solar or wind systems. An electric vehicle has a greater efficiency than an internal combustion engine vehicle, which has an efficiency of 12 % to 30 % [4].

As global warming has become a crucial problem throughout the world. Its impact is seen in most of past years [1]. Air pollution is the one of the main causes of global warming. Vehicle emission is main source of air pollution which produces the 21 % of greenhouse emission [3]. The world is moving towards reducing the vehicular emission by developing the new I.C.E. technologies, but it's not enough to reduce the air pollution at satisfactory level [2]. Electric vehicle and Hybrid electric vehicle are becoming more popular [3].

The demand of electric vehicle is increasing due to its 42 to 72 % well to wheel efficiency when electricity is generated through solar or wind system. Efficiency of electric vehicle is high as compared to internal combustion engine vehicle whose efficiency is 12 % -30 % [4].

Electric vehicles offer several benefits including zero emissions, increased efficiency, better torque speed capabilities, ability to operate without complex transmission, less maintenance, and quiet operation [5]. An effort is being made to develop electric vehicles as a reliable, quiet, and affordable form of transportation.

An electric vehicle system contains three main subsystems: the electric motor propulsion unit, the energy source-battery, and auxiliary

Nomenclature: Fd: Aerodynamic resistance force; Cd: Coefficient of drag; Cr: Ccoefficient of Rolling resistance; Fr: Rolling Resistance; Af: Frontal area of vehicle; Fg: Gradient force; Fa: Inertia Force; Ft: Tractive resistance force; Mv: Vehicle gross weight

Abbreviations: TM: Traction motor; PMSM: Permanent magnet synchronous motor; EV: Electric Vehicle; BEV: battery electric vehicle; HVAC: Heating, ventilation and air conditioning systems such as power steering, brake booster, and HVAC unit [1]. Direct current motor, Induction motor, Permanent magnet DC Motor, Permanent magnet AC motor, and switched reluctance motor are the usual motors used in EV. [5,8,9,10]. The main consideration for ensuring vehicle performance in an electric vehicle's propulsion system design is an accurate motor power rating.

The electric motor is a crucial part of the EV. From in-depth literature [1,5,8,9,10,12,17,18] and market surveys, it has been observed that many EV manufacturers are using different motors with different power ratings. The power required for the electric motor is mostly determined by the vehicle performance parameters, which include maximum vehicle speed, maximum gradeability, and maximum acceleration [1,2,6,7, 20].

The consolidated vehicle performance results indicate that a higher powered motor may be needed, which could affect the vehicle's range, energy consumption, and cost. Current research has shown progress in the design of propulsion systems for electric vehicles [6,7]. Vehicle dynamics and parametric design of electric drivetrains have been discussed. Motor power determination methods and drive cycle-based power sizing of motors were discussed. The size of electric vehicle drive train components is proposed to be based on vehicle performance characteristics such as maximum speed, maximum acceleration, and maximum gradeability. The focus was on sizing the powertrain and energy source in the various design aspects of EV development. Researcher [5] presented a method for sizing the motor and battery for a specific route that has minimum and maximum road slope.

The author revealed the method for determining the necessary power based on acceleration time [6]. The effect of the base speed of the motor on the acceleration properties of the vehicle was investigated. The choice of motor for EVs is influenced by efficiency, power density, torque density, and the environmental conditions, such as highway driving and intercity driving. The range of an electric vehicle is impacted by the size of the motor. The main aim was to determine the factors that impact the range of electric vehicles. The impact of vehicle acceleration on motor power rating was also discussed [11]. The author focused on the effect of powertrain and component sizing on the performance of pure electric vehicles. The conventional methodlogy for component sizing has been highlighted [12].

The method of estimating the power of an electric motor [14] was explained by the investigator. The electric motor power is sized by taking into account the car's dynamic response and maximum speed [20]. A procedure for calculating the power needed by an electric motor has been presented [21].

From the extensive literature review above, it has been observed that very few researchers have addressed the detailed calculations of the power rating of electric motors for EVs. The majority of researchers have used the combined vehicle performance parameters to evaluate motor power, which has an impact on the vehicle's performance (range, cost, efficiency). This inspires us to carry out a thorough analysis of the required motor power before selecting the appropriate motor for an EV application. An accurate power rating of the motor will lead to a more cost-effective solution for EVs based on the requirement.

In EV powertrain design, the correct power rating of the motor is key deliberation to meet the vehicle's performance without bulky power rating of the motor. Vehicle performance parameters will not assure the correct power rating of the motor because most of the investigators assumed the combined vehicle performance while rating the motor but with the real condition vehicle performance parameter varies according to driving condition. This inspires us to investigate these parameters and contemplate the power rating of the traction motor for various vehicle performance combinations in various conditions. Analysis has been done to finalize the procedure for estimating the motor's power rating.

The main aim of the present work is to develop a simple procedure for power sizing of electric motor based on ramping acceleration performance with a speed limit of 60 km/h. The development of a methodology for power sizing motors addresses the challenges mentioned above. The longitudinal vehicle dynamics procedure has been approached for defining the demanded power for powertrain system. This approach uses the methodology of variable acceleration rate to size the motor power, which is not endorsed by other investigators.

Through a literature survey, it was identified that there was a gap in the detailed analysis of motor power rating calculations.

Vehicle Dynamics:

The principle of vehicle dynamics presented in [21] states that resistance attempts to stop a vehicle when it moves. The resistance encompasses rolling resistance, aerodynamic resistance, and uphill resistance. The forces exerted on a vehicle as depicted in Fig. 1.

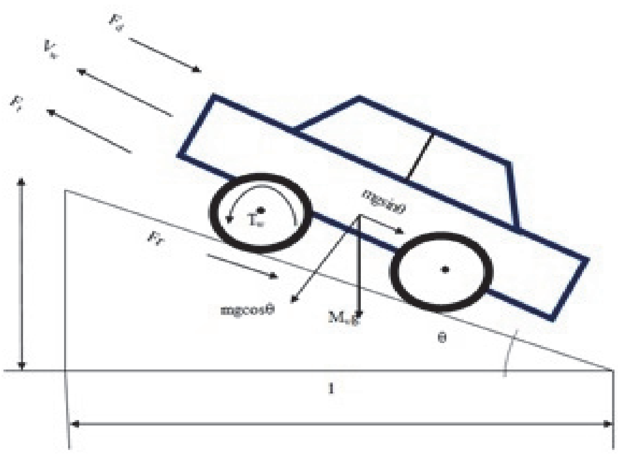

Figure 1 Forces acting on vehicle [21].

Rolling Resistance:

Force that resists vehicle motion on a road surface. In equation (1), Cr is the coefficient of rolling resistance between wheel and road surface. The rolling resistance coefficient Cr, depends on the tire material, tire structure, tire temperature, tire inflation pressure, tread geometry, road roughness, road material, and the presence or absence of liquids on the road. In this case it is assumed that vehicle is running on concreate road surface and Cr of 0.013 is taken into account, θ is the road angle. [21]

$$Fr = Cr \times M\nu \times g \times \cos\theta \qquad \text{…..(1)}$$

Mν is the gross weight of vehicle including the curb weight & payload (weight of passenger & driver, weight of luggage, weight of accessories)

Aerodynamic Resistance:

When the vehicle is running on air at a certain speed, it experiences a force that resists its motion. This force is called the aerodynamic drag force. The aerodynamic drag is influenced by the vehicle's speed (V), frontal area (A_f), shape, and air density (ρ).

$$Fd = \frac{1}{2} \times \text{pair} \times Af \times Cd \times (V + VW)^2 \qquad \text{…..(2)}$$

In equation (2), Cd is coefficient of drag that characterizes the shape of the vehicle, Vw is wind velocity component of wind speed on the vehicle's moving direction, which has a positive sign when this component is opposite to the vehicle speed and a negative sign when it is in the same direction as vehicle speed. Drag coefficient value is between 0.25 to 0.7 based on shape of the vehicle [21]. In this study, the vehicle body is assumed as wedge shaped so Cd is selected as 0.3 and ρair is the density of air in Kg/m^3 depending on humidity, temperature, pressure and altitude at sea level at temperature 25^o and standard atmosphere pressure of 1013.25 Pascal, ρair is 1.225 Kg/m^3 [20].

A_f is the frontal/ effective cross-sectional area of the vehicle in m^2, depending on the vehicle size & shape. V is the speed of the vehicle in m/s.

Gradient Resistance:

Gravitational force is necessary to propel a vehicle uphill. It depends on the mass of the vehicle and the grade angle. The term gradeability describes a vehicle's ability to run on slopes. [3]. Interstate highways commonly have a grade of 4% (2°). [22] Road grades can range from 1% to 30% [5,22].

$$Fg = M\nu \times g \times \sin\theta \qquad .....(3)$$

$$\theta = \tan^{-1}\left(\frac{h}{l}\right)$$

Where, θ is the angle between the level road & horizontal plane of the vehicle. h is the vertical distance and l is the horizontal distance as shown in Fig. 1.

Inertia Force:

Inertia force needs to be taken into account if the vehicle's velocity fluctuates. Linear and angular acceleration of the vehicle is caused by this force.

$$Fa = M\nu \times a \qquad .....(4)$$

Where, a is the acceleration due to gravity in m/s^2

Tractive resistance:

The force needed to overcome the resistance force and propel the vehicle forward. Its a summation of all the tractive forces listed above [3].

$$Ft = Fr + Fd + Fg + Fa \qquad .....(5)$$

Wheel Power:

The wheel power can be calculated by the product of tractive force Ft acting on the wheel and speed of the vehicle V. The desired power rating of electric motor can be determined from above equation (5) based on initial acceleration, maximum of vehicle & credibility. Demanded power of the vehicle is determined by

$$Pwheel = Ft \times Vmax \qquad .....(6)$$

Where Ft is the total tractive force in N, V is the maximum velocity of the vehicle in m/s, τ is the tractive torque in N-m, ω is the angular velocity of wheel in rad/sec.

Torque & Power Calculations:

$$\tau wheel = Ft \times rwheel \qquad .....(7)$$

r_{wheel} is the radius of the wheel in meter.

For motor power calculations, motor efficiency must be considered,

$$Pm = \frac{P\ wheel}{\eta\ motor} \times 100 \qquad .....(8)$$

EV performance requirement:

In order to determine the required power to propel the electric vehicle, it is important to consider the acceptable vehicle performance. For this study, Maruti 800 AC model is considered whose specifications are given in Table I. The top speed of the vehicle is 60 Km/h, the acceleration time for 0 to 60 km/h is 20 sec and road slope is assumed as 2 to 18° [5].

Table 1

Technical Specifications of Maruti 800 AC, BSII.

Parameters	Specifications
Length	3335mm
Width	1440 mm
Height	1405 mm
Curb (Vehicle) Weight	665 Kg
Passenger weight	335 Kg
Vehicle Gross weight	1000 Kg
Ground clearance	170 mm
Wheel base	2175 mm
Engine & Transmission	
Engine type	3 Cylinder, Petrol
Displacement	796 cc
Maximum Torque	59 Nm @2500 rpm
Maximum Power	37BHP @ 5000 rpm
Transmission	Manual

Table 2

Vehicle Parameters considered for power ratings.

Parameters	Symbol	Value
Vehicle Gross weight	M_v	1000 (kg)
Frontal Area	A_f	1.6934 (m^2)
Wind velocity	V_w	5 (m/s)
Rolling Resistance coefficient	C_r	0.013
Coefficient of drag	C_d	0.3
Air Density	ρ_{air}	1.225 (kg/m^3)
Wheel Radius	r	0.253 m
Road inclination	θ	2-18

Motor power determination methods:

In this section, the complete power ratings of electric motor of EV have been analyzed. Initially standard methods described by most of investigator are analyzed to investigate the power rating of motor at specified vehicle speed. The methodologies adopted for determination of power rating of electric motor are described as follows:

i. Condition I- At maximum vehicle speed with minimum road grade
ii. Condition II- At maximum gradeability
iii. Condition III- At maximum acceleration rate
iv. Condition IV- Extreme Condition (maximum speed, gradeability, acceleration)
v. Condition V- New approach- for motor power calculation

The variation of tractive force versus vehicle speed is shown in Figure 2. It shows three power determination methods like maximum speed (Point ‘b’), maximum grade (point ‘c’) & acceleration performance (point ‘a’). Point ‘b’ & ‘c’ illustrate the maximum velocity with null acceleration & point ‘a’ indicates the maximum acceleration [1]. Above said are typical methods adopted by most of investigator to predict the power rating of the electric motor.

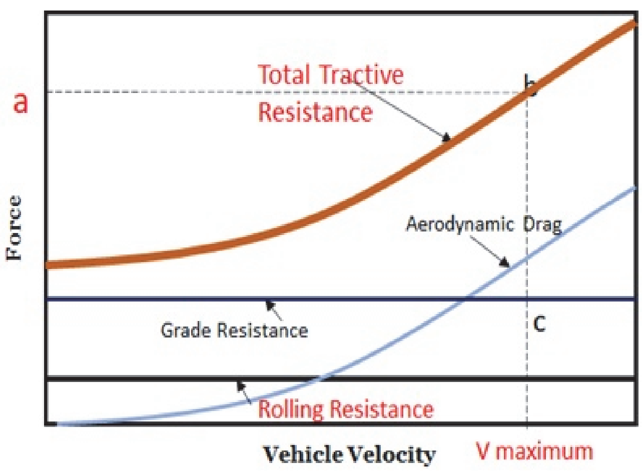

Figure 2 Tractive force Vs Vehicle speed.

Condition I: At maximum speed:

In this methodology, power required by traction motor is calculated when vehicle runs at maximum speed. (Point ‘b’ in Fig. 2). In this case resistive force acting on the vehicle are aerodynamic, rolling and minimum gradient force at 2^o & 4^o road slope. When vehicle is running at maximum speed its acceleration will be zero & maximum speed is achievable only when its running on straight road means road inclination angle should be minimum.

For this study, when acceleration is given to vehicle when its normally at no slope road has been assumed. So, Due to this acceleration force as well as high gradient force is not considered in condition II. In most of the common situations grade angle is assumed as 2^o & 4^o [5]. So, analysis has been done for both 2^o and 4^o road angle. At this condition acceleration force in equation (5) could be zero. Then total tractive force becomes

$$Ft = Fr + Fd + Fg \quad .....(9)$$

$$Ft = Cr \times M\nu \times g + 0.5 \times pair \times Af \times Cd \times (V + Vw)^2 + M\nu \times g \times \sin\theta$$

$$Ft = 0.013 \times 1000 \times 9.81 + 0.5 \times 1.225 \times 1.6954 \times 0.3 \times (16.66 + 5)^2 + 1000 \times 9.81 \times \sin^2.$$

Table 3

Power at maximum speed.

Sr. No.	Speed (km/h)	Road slope in degree	Power (KW)
1	10	2	8.13
2	20	2	8.40
3	30	2	8.74
4	40	2	9.16
5	50	2	9.66
6	60	2	10.24
7	10	4	13.82
8	20	4	14.08
9	30	4	14.43
10	40	4	14.85
11	50	4	15.35
12	60	4	15.93

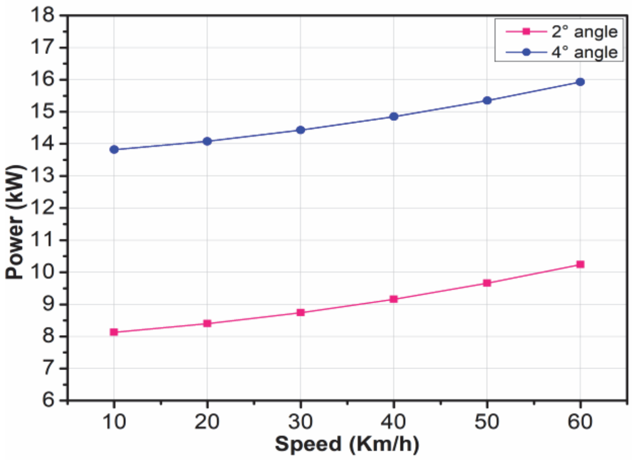

Figure 3 Power of motor at maximum speed.

Above calculation reveals that as the vehicle speed increases the power need of electric motor increases. The motor demanded power at given speed is 10.24 KW at 2˚and 15.93 KW at 4˚. The same results are shown in Fig. 3. By increasing vehicle speed the demanded power increases because vehicle requires more power to overcome the aerodynamic resistance force.

Considering above tractive force requirement of the vehicle, to propel the vehicle with specified performance parameters traction motor with 15.93 KW is required.

Condition II: At maximum Gradeability

The resistance offered to the vehicle while started climbing a hill or flyover. The angle between the ground and slope of the path is represented by θ. When vehicle is running at maximum speed and suddenly road inclination of 18˚arise. In that situation only two forces can be considered like Fr and Fg. In this case only two resistive forces will act on the vehicle. Aerodynamics resistance is neglected for the study as the vehicle will not achieve maximum speed (Point 'a' in Fig.2) when vehicle is climbing a hill. The inclination of road varies from 0˚ to 18˚ [3,5]. The power required to propel the vehicle on maximum inclination angle is more but the speed achieved by the vehicle is low. Vehicle runs on hill so inertia force becomes an insignificant. Total tractive force equation (5) becomes

$$Ft = Fr + Fg \quad \text{.....(10)}$$

$$Fd = 0$$

$$Ft = M\nu \times Cr \times g \times \cos\theta + M\nu \times g \times \sin\theta$$

$$Ft = 1000 \times 0.013 \times 9.81 \times \cos 18 + 1000 \times 9.81 \times \sin 18$$

Table 4

Power at maximum grade results.

Sr. No.	Speed (km/h)	Road slope in degree	Power (KW)
1	10	18	8.7
2	20	18	17.51
3	30	18	26.27
4	40	18	35.08
5	50	18	43.78
6.	60	18	52.54

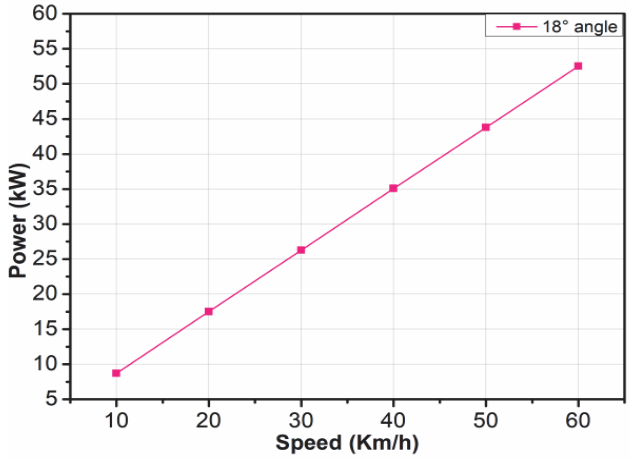

Figure 4 Power of motor at maximum grade.

Fig. 4 demonstrate the effect of road slope on demanded power of electric motor. It shows that road slope effects on the demanded power of electric motor. At 18° road inclination power needed to propel the vehicle is 52.54 KW which is very high as compared to road slope at 2° as shown in Fig. 3. When vehicle travels on upward gradient or hilly region it requires more power to overcome the gradient resistance. Increase of road slope angle reveals to increase in energy consumption requirement of the vehicle.

To fulfil the performance requirement of vehicle at specified speed with highest road grade angle 52.54 KW traction motor is required.

Condition III: At maximum acceleration performance:

Acceleration performance is evaluated by time required to accelerate the vehicle from zero speed to maximum speed. Acceleration performance is solely depend on torque speed characteristics of the traction motor [7] In this methodology, determination of demanded power to accelerate the vehicle from zero to maximum speed is considered. The vehicle will run with maximum acceleration at flat road (i.e. $\theta=0^\circ$)).

Total resistive force on vehicle in acceleration mode on straight & horizontal road are rolling resistance, aerodynamic resistance & acceleration resistance. Therefore, total tractive force of (5) becomes

$$Ft = Fr + Fd + Fa \quad \text{.....(11)}$$

$$Ft = Mv \times Cr \times g \times \cos\theta + 0.5 \times pair \times Af \times Cd \times (V + Vw)^2 + Mv \times a$$

$$Ft = 1000 \times 0.013 \times 9.81 \times \cos 0 + 0.5 \times 1.225 \times 1.69 \times 0.3 \times (16.66 + 5)^2 + 1000 \times 0.833$$

Table 5

Power at maximum acceleration.

Sr. No	Speed (km/h)	Acceleration time (sec)	Power (KW)
1	60	20	18.34
2	60	18	19.97
1	60	15	23.06

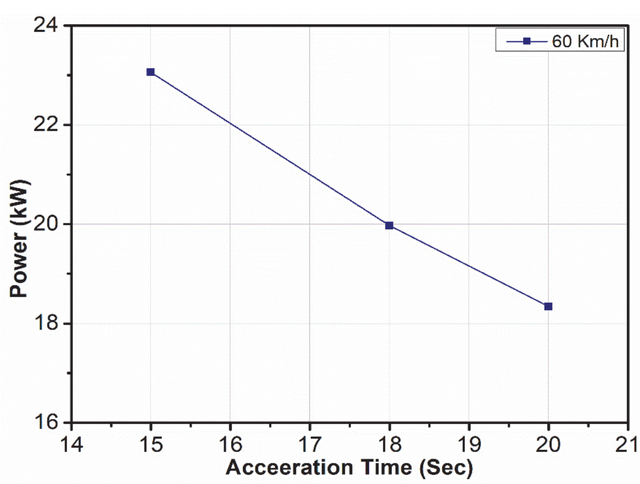

Figure 5 Power of motor at maximum acceleration.

Above analysis Fig.5 indicates that more motor power is required to achieve the maximum acceleration (maximum speed with less time). As acceleration time reduces more acceleration force is required to achieve the specified performance. The Power required for maximum acceleration is 23.06 KW. Fig. 7 shows the effect of acceleration time on vehicle power.

To propel the vehicle at 60kmph within 15 sec requires 23.06 KW traction motor. Traction motor with power rating less than this will not achieve the specified performance of the vehicle.

Condition IV: At extreme condition:

Extreme condition faced by the vehicle is maximum speed with maximum grade angle & maximum acceleration shown in Fig. 2 (point b). Motor should deliver peak power to overcome such critical cases. The demanded power to propel the vehicle is so high. In real condition vehicle never face such type of situation but most of the manufacture as well as investigators considered this condition for estimation of power rating of electric motor in electric vehicle [5,6,7,8]. By considering this case, for estimation of power then demanded power will be very high which affects the size of motor, energy consumption & cost of electric vehicle. To fulfil this motor power requirement, large battery pack is needed. Thus, from economical point of view this method is not feasible.

$$Ft = Fr + Fd + Fg + Fa$$

$$Ft = Mv \times Cr \times g \times \cos\theta + 0.5 \times pair \times Af \times Cd \times (V + Vw)^2 + Mv \times g \times \sin\theta + Mv \times a$$

$$Ft = 0.013 \times 1000 \times 9.81 \times \cos 20 + 0.5 \times 1.225 \times 1.69 \times 0.3 \times (16.66 + 5)^2 + 1000 \times 9.81 \times \sin 20 + 1000 \times 0.833$$

$$Pwheel = Ft \times rwheel$$

$$Pwheel = Ft \times 0.253$$

Table 6

Power at extreme situation.

Sr. No	Speed (km/h)	Road Slop in degree	Acceleration time in (sec)	Power (KW)
1	60	0	20	18.44
2	60	2	20	24.13
3	60	8	20	41.17
4	60	10	20	46.8
5	60	18	20	68.86

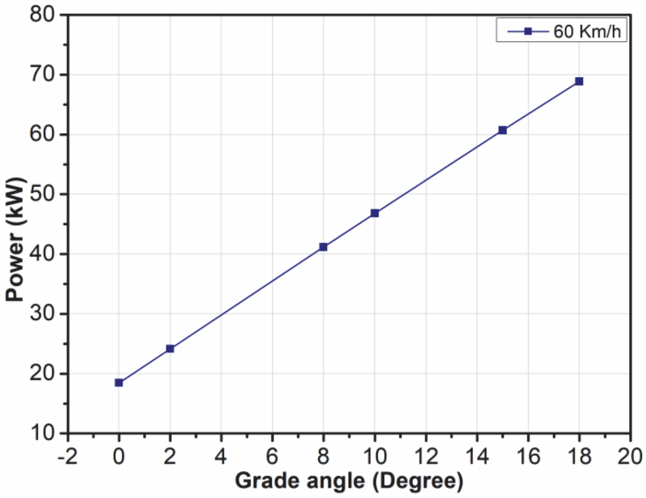

Figure 6 Needed power of motor at critical condition.

The power calculation was made for the different vehicle performance parameters as shown in table 3,4,5,6. From above analysis it is observed that power rating is not consistent for selection of motor sizing. These results are not furnishing the accurate motor sizing for EV's application. The Power rating is varying from 15.93 KW to 68.86 KW due to which it is challenging to select the power rating from above specified methods.

Table 7

Detail demanded power analysis for different critical conditions.

Sr. No	Conditions	Parameter	Values	Power (KW)
1	Condition I	Maximum speed (V)	60 km/h	15.93
2	Condition II	Maximum gradeability (θ)	18°	52.54
3	Condition III	Maximum Acceleration (t)	15 sec	23.06
4	Condition IV	Extreme Condition $(V, \theta, t)_{max}$	Peak	68.86

Above said parameter in section 3.1 is applicable only when vehicle runs at maximum speed, power needed to propel the vehicle is 15.93 KW. Section 3.2 is feasible only when vehicle travelling in hilly region & demanded power to fulfil the vehicle requirement is 52.54 KW, Section 3.3 for maximum acceleration power required to meet the vehicle demand is 23.06 KW and in Section 3.4 determined power rating has found to be 68.86 KW when all parameters are at peak. These preceding methods cannot estimate the accurate power rating of the motor.

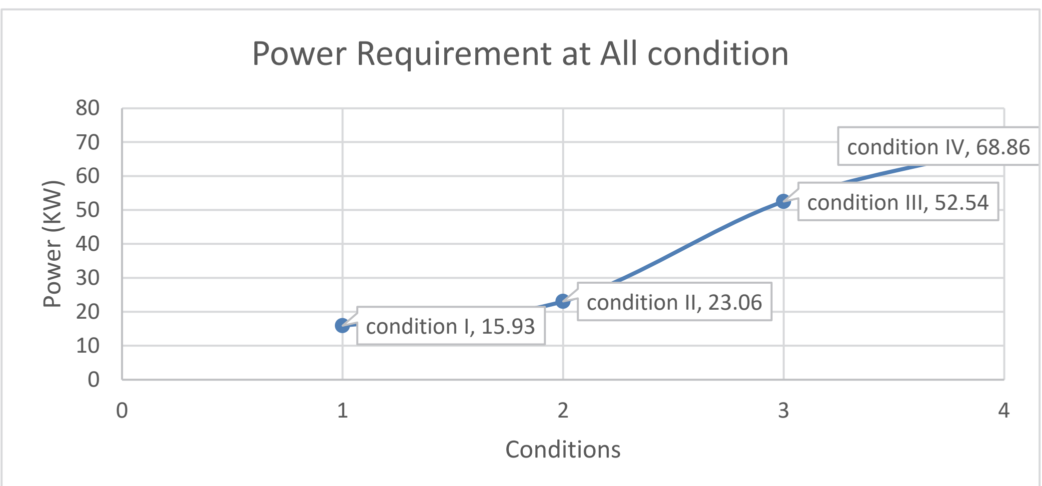

Figure 7 Power Requirement at different conditions.

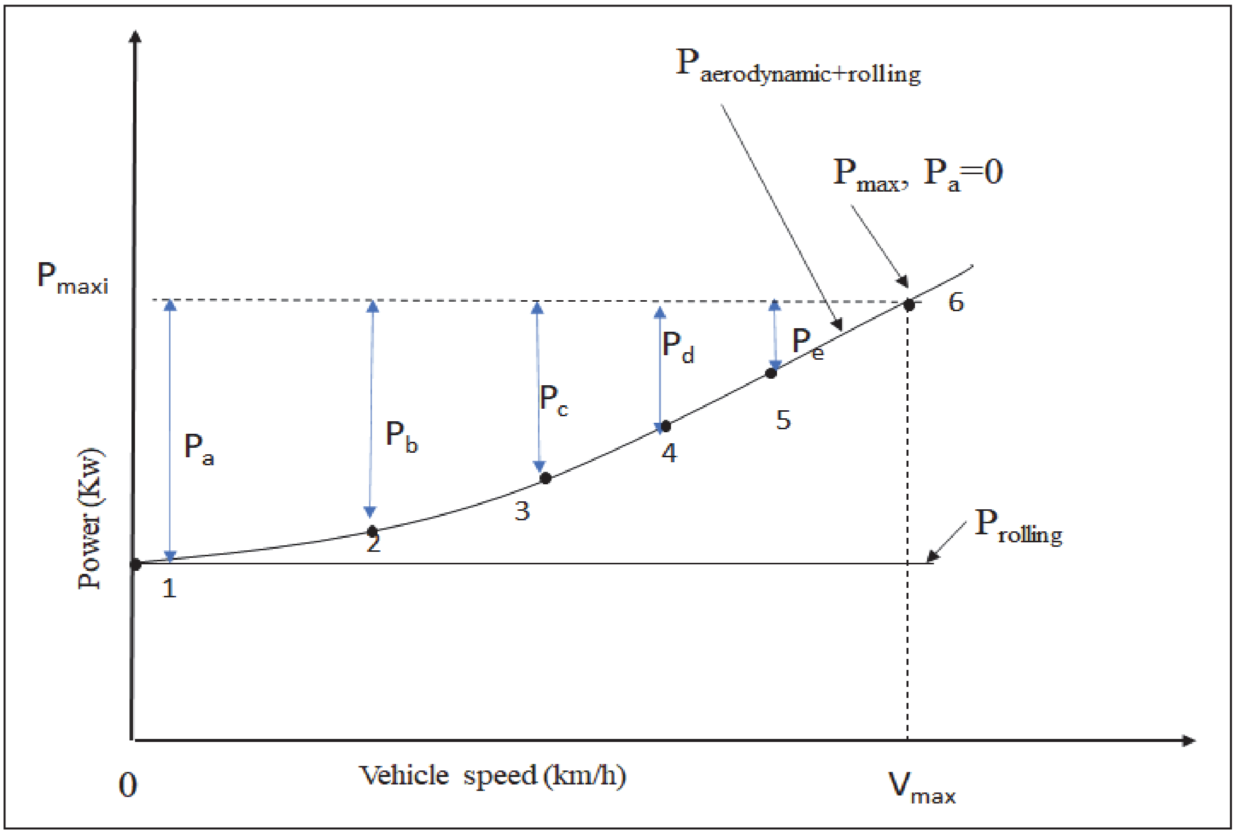

Figure 8 Demanded Power Vs Vehicle speed.

New approach- for motor power calculation

The aforesaid methodologies cannot predict the accurate estimation of demanded power rating for traction motor. It is difficult to apply same technique for all running condition of the vehicle as vehicle performance is not consistent at all time. However, the new approach is developed to determine the required power which will fulfil the performance requirement of vehicle. Power rating is determined by considering the ramp up acceleration performance from initial to maximum speed of the vehicle and normally acceleration is avoided at slope road.

Fig. 8 show the demanded power versus vehicle speed. Rolling resistance power is constant and it is independent of vehicle speed but aerodynamic power is proportional to vehicle speed given in equation (2). So total tractive power graph nature is parabolic in nature. Pmax indicates the maximum power when vehicle is running at maximum speed. In this analysis gradient force is neglected as vehicle is running on flat road. Pmax is required power including the aerodynamic, rolling resistance and acceleration. At previous speed of point Vmax (60 km/h), aerodynamic power reduces, rolling power remains same, acceleration power exists and it is Pe at point '5'. Similarly, Pd, Pc, Pb, Pa are the acceleration power for speed of 40, 30, 20, 10 km/h. Point '1' shows the maximum acceleration with negligible aerodynamic power. This depicts that maximum acceleration power is needed at initial period for acceleration and as vehicle speed increases acceleration power starts decreasing and it becomes zero at maximum speed.

In this approach, Pmax is calculated at maximum speed by considering aerodynamic, rolling resistance & acceleration. However, the vehicle is running at maximum speed thus acceleration is zero at point '6'. At point '6' only rolling and aerodynamic power exists. At earlier speed point '5', total tractive power is reduced from P6 to P5 and vehicle gets additional acceleration power Pe, this is a difference between P 6 to P5. This additional acceleration will help in reducing the acceleration time. Further speed has been analyzed speed at 40km/h, results into additional acceleration power of Pd which is greater than Pe. However, the tractive power remains same (i.e., Pmax). This will further reduce the acceleration time for decrease speed of 10km/h from 50 to 40 km/h. Same trend was observed for speed of 30, 20, 10, 0 km/h. Considering this additional acceleration power total time required to achieve speed of 60 km/h is 17.5 sec and Pmax is 18.16 KW. However, our design parameter acceleration time is 20 sec. Hence, we can reduce the Pmax and optimize it for 20 sec as acceleration time by back calculations.

Above power rating it is depicts that power revision is needed to achieve the specified acceleration performance. By performing numerous iteration optimal power rating of the vehicle is determined which fulfills the specified acceleration performance.

Table 8

Power requirement by new approach.

Sr. No	Speed (km/h)	Acceleration time in (sec)	Power (KW)
1	60	17.5	18.16
2	60	19.06	17.5
3	60	19.33	17.3
4	60	19.74	17
5	60	19.95	16.80
6	60	19.97	16.84
7	60	19.98	16.83
8	60	20	16.81

Table 8 & Fig 9 shows that the accurate power rating of the motor at specified acceleration performance at 20 second. At speed of 60 km/h, demanded power to propel the vehicle is 16.81 KW. By using new approach, power rating is reduced from 18.16 KW to 16.81 KW. Motor power rating determined by using this novel approach fulfill the vehicle performance.

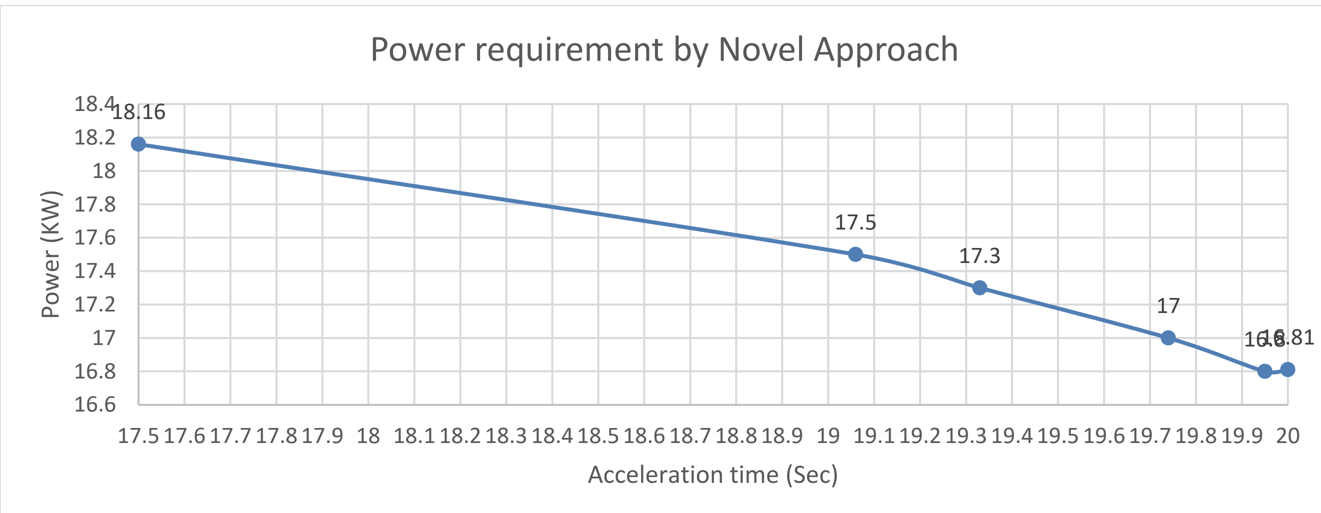

Figure 9 Power rating with novel approach.

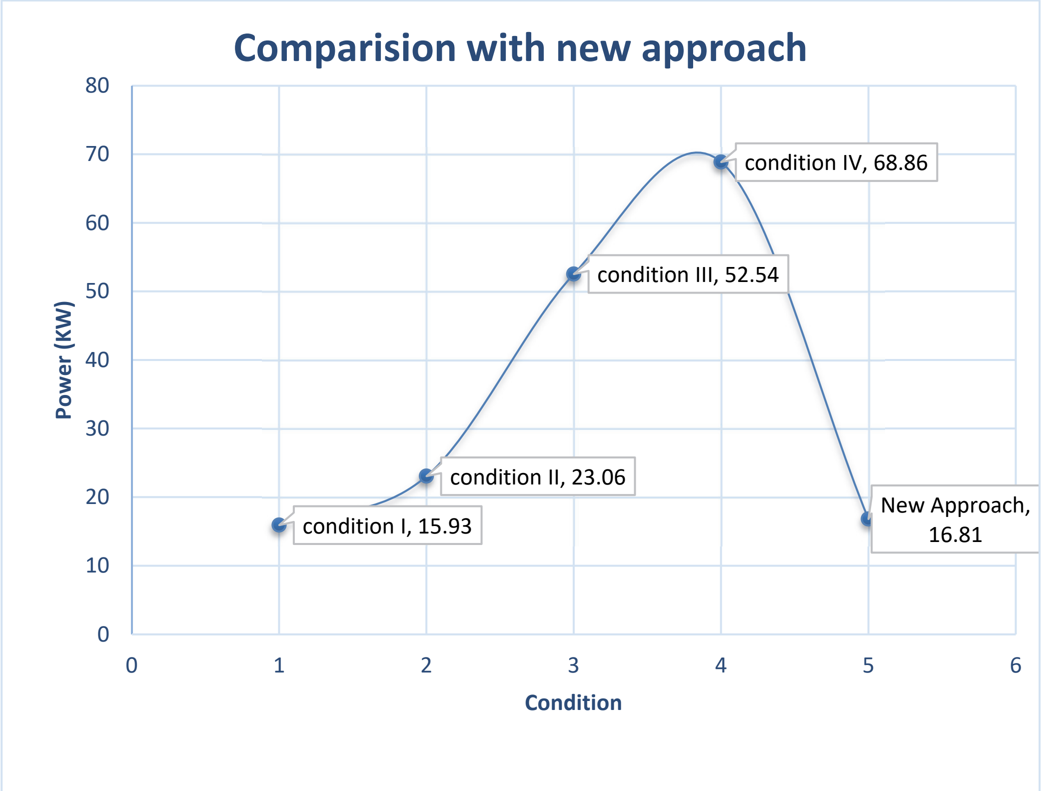

Figure 10 Comparative Analysis.

Results and Discussion

Currently motors used in electric vehicles are Induction motor, PMSM, SRM for four-wheeler electric vehicle application [5,8,9,10]. By using conventional approach discussed in section 3.1,3.2,3.3,3.4 &3.5motor power rating varies from 15.93 KW to 68.80 KW. Considering cost analysis by using induction motor through conventional approach motor cost increases up to 50-60%. Conventional approach also impacts on cost of battery, motor controller. High power rated motor requires high-capacity battery pack which will indirectly enhance the battery cost. As the battery cost increases, overall cost of electric vehicle will be more. Motor power rating selected through conventional method at maximum speed is 15.93 KW, with maximum gradeability is 52.54 KW, at maximum acceleration is 23.06 KW and at critical condition is 63.86 KW. The costs of selected induction motor vary from 1.60 lakhs (15.93KW) to 4 lakhs(63.86KW) which is very high. If motor selected by novel approach discussed in section 3.5 cost of motor will be approximately 1.85 lakhs which reduces the motor cost up to 50% without hampering the vehicle performance. Novel approach discussed above estimates the decreased motor power rating which requires lower size battery pack. So, by using this approach overall cost of electric vehicle can be reduced. This approach provides cost effective solution to car manufacturer.

Table 9

Motor selected for specified vehicle.

Parameter	Rated Unit
Traction Motor Type	Induction Motor
Rated power (KW)	21.74
Rated Torque (Nm)	60.4
Rated Speed (Rpm)	3500

Table 9 show the final ratings of traction motor selected for the specified vehicle. Above selected motor fulfills the performance requirement of vehicle specified in the section 2.8.

Conclusions

For this assessment one reference vehicle (Maruti 800, BSII, petrol car) has been considered An in-depth analysis of power rating of electric motor for electric vehicle is presented in this paper. An analytical method for determination of accurate power rating of motor is presented. A typical method for sizing the motor power on the basis of vehicle maximum speed, maximum gradeability and acceleration is analyzed and it gives the high motor power rating.

Motor power has been decided based on rolling resistance power, aerodynamic power and acceleration power at maximum speed. Motor power can be optimized by considering the variations of aerodynamic power to get additional acceleration power at speed less than the maximum speed. Calculated power obtained by new approach investigated through this approach is less than power obtained by typical approach. This optimized power can be used for selection of motor power rating of electric vehicle. Power estimation of electric motor through this new approach affects the size of battery, range of electric vehicle and cost of electric vehicle. This approach provides the cost-effective solution for electric motor sizing.

The methodology discussed in the paper will be useful in the sizing of electric motors for battery electric vehicle where acceleration performance is the major selection criteria. By adopting this novel approach cost of traction motor cab be reduced by 50%. So overall cost of electric vehicle can be reduced by using this approach because traction motor is major component in electric vehicle. This paper provides methods and reference for manufacturers and investigators for motor sizing of electric vehicle applications.

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