A Wide Component Sizing and Performance Assessment of Electric Drivetrains for Electric Vehicles

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***Abstract*—The main purpose of this paper is to provide a wide parametric design procedure for drivetrain system of electric vehicles (EVs). This method, for a given vehicle's specifications, can determine both the ratings and maximum capabilities of the powertrain. The ratings include motor power, torque, speed, and battery capacity. In the proposed methodology, the ratings consider the maximum velocity and maximum acceleration rate of the vehicle to achieve the heaviest road conditions. The validation of the proposed methodology is discussed with case study: Nissan-Leaf2015 E-Car. The performance of the vehicles is simulated and assessed with two different driving cycles (Urban Dynamometer Driving Schedule (UDDS) and high way ARTEMIS MW_130 and is validated through extensive simulations at 100% ratings and up to 140% of power ratings.**

Keywords—Electric vehicle, tractive motor ratings, battery capacity, practical driving cycles.

I. Introduction

In recent years, more and more electric drives have been involved in vehicle traction, such as electric vehicles (EVs), hybrid electric vehicles (HEVs), and fuel cell powered vehicles (FCVs). The drivetrain technologies are the most promising vehicle solutions for the foreseeable future [1]. A modern electric drivetrain consists of three major subsystems: electric motor propulsion, energy source, and auxiliaries. The electric propulsion subsystem comprises the vehicle controller, power electronic converter, electric motor, mechanical transmission, and driving wheels. The energy source subsystem involves the energy source, the energy management unit, and the energy refueling unit. The auxiliary subsystem consists of the power steering unit, the hotel climate control unit, and the auxiliary supply unit [2]. A vehicle’s driving performance is usually evaluated by its acceleration time, maximum velocity, and road gradeability. In EV's drivetrain design, proper motor power rating and transmission parameters are the primary considerations to meet the performance specification without oversized ratings. The design of all these parameters depends mostly on the speed-power (torque) characteristics of the traction motor and predicted road circumstances. Some representative driving cycles (driving schedules) have been developed to emulate typical traffic environments. These driving cycles are represented by the vehicle speeds versus the operating time while driving on a flat road [1].

Some recent studies have reported progress towards the parametric design of the drivetrain of the EVs [3]. Performance of two of the clean powertrain cars is evaluated in Lab condition and on road in [4]. Description of a complete EV system is introduced; and the performance of its powertrain has been evaluated in [5], in which a test bench is designed for modelling purposes of small EVs. The performance of a complete EV powertrain was presented in [6] with experimental evaluation and assessment of each plant. However, this work considered the possible performance of the EV based on theoretical calculations using its specifications. Moreover, it lacked to the battery pack calculations. There exist only rare reports in the literature addressing the detail calculations of the power ratings of the drivetrain plants of the EVs/HEVs. The researchers in [7] covered various design aspects of EV development with main focus on powertrain system. Reference [8] proposed a methodology for pre-sizing the electric motor propulsion power of an EV. However, the main objective here was to find the minimum motor weight, volume and cost that will meet the design constraints with minimum power under the European ECE and EUDC driving cycles. The vehicle level targets were used for developing a novel approach to optimally size the traction motors using the scalable electric machine model [9]. However, the approach was demonstrated on the in-wheel motor electric powertrain.

This paper develops a wide parametric design methodology for the electric propulsion system and its energy storage device of the EVs that addresses these challenges. It adopts a methodology of assessment of vehicle's performance with simulation results for maximum exploitation of the powertrain of EVs. The electric motor optimal power is therefore calculated regarding the EV desired performances and given driving cycles. The power of the drive system can be designed by two methods i.e. at maximum speed and at base speed. At base speed, the power depends on the selected speed ratio which guarantees the designed acceleration rate; whereas the other power is found to achieve the maximum velocity at minimum acceleration rate. The chosen power rating has to satisfy the two requirements. The proposed power sizing methodology is illustrated under modified Urban Dynamometer Driving Schedule (UDDS) and high way ARTEMIS MW_130 driving cycles [10]. The proposed design methodology is applied to the commercial Nissan-leaf 2015 E-car.

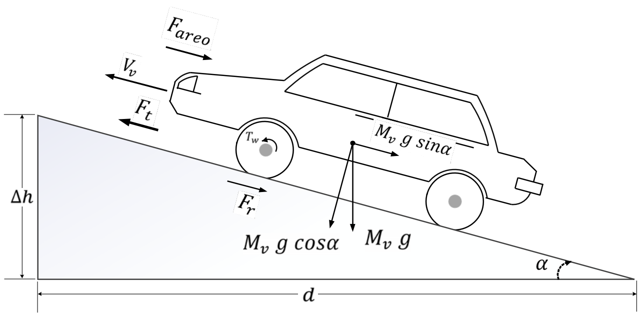

Fig. 1 Forces acting on a vehicle moving up a grade

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II. VEHICLE DYNAMICS

Based on principles of the vehicle dynamics presented in [3] and [11], the forces acting on a vehicle moving up a grade are gravity F_g, aerodynamic F_d, rolling resistance F_r, and acceleration F_a forces, as shown in Fig. 1. The total tractive force which is required from the electric powertrain of the vehicle F_t could be calculated by

$$F_t = F_g + F_r + F_d + F_a \tag{1}$$

$$F_t = M_v\, g\, sin\alpha + M_v\, g\, C_r\, cos\alpha + \frac{1}{2}\rho_a C_d\, A_v (V_v + V_{air})^2 + \delta\, M_v \frac{d}{dt} V_v \tag{2}$$

where; M_v, g and α are the vehicle mass, gravity coefficient and the slop of the road, respectively. The vertical rise of the road Δh represents the gradeability of the road G when the EV is traveled a horizontal distance d of $100m$. Then, the slop could be found as [12]

$$\alpha = tan^{-1} \frac{G}{100} \tag{3}$$

Rolling force F_r is the combination of all frictional load forces due to the deformation of the tire on the road surface and the friction within the drivetrain depend on the rolling coefficient C_r. This coefficient is a function of the tire material, tire structure, tire temperature and typical values of rolling resistance coefficients could be found in [1]. The resistance of air to the movement of the vehicle is called aerodynamic force F_d. It depends on air density ρ_a, frontal area of the vehicle A_v, air velocity V_{air}, vehicle velocity V_v and drag coefficient C_d. This coefficient depends on the shape of the vehicle. The acceleration force F_a due to the gross mass and vehicle inertia is usually stated as the minimum time to accelerate from 0 to 100 km/h on level ground. The effective mass coefficient δ accounts for rotating parts and axle inertia J_{axle} in addition to vehicle mass $\delta\, M_v = \left(M_v + \frac{J_{axle}}{R_w{}^2}\right)$, the value of δ is around 1.08-1.1% [1]. The integration of the rolling, gravity, and aerodynamic forces are known as road load force F_{road}.

$$F_{road} = F_g + F_r + F_d \tag{4}$$

III. PARAMETRIC DESIGN OF ELECTRIC DRIVETRAIN

In this section, the whole ratings of the electric drivetrain of EVs are calculated. The pseudo-code of the proposed methodology is presented as (1) specification of the requested vehicle i.e. maximum velocity, type of vehicle, passengers, acceleration rate, etc. (2) calculation of the rated power according to the maximum velocity, maximum acceleration rate, driving cycles, (3) determination of the speed factor, (4) choosing of the transmission gear ratio, i.e. single-stage or multi-stage, (5) calculation of the base speed of the traction motor (TM), (6) calculation of the rated torque, (7) determination of the maximum torque, and (8) determination of the battery capacity and energy consumption.

The variation of motor power, traction force and road force on a grade road versus the vehicle velocity are shown in Fig. 2. In the figure, determination of the rated power of the TM by two methods is depicted from three concentrated points. Points 1 and 2 demonstrate the maximum velocity with zero acceleration rate while point 3 demonstrates the base velocity with maximum acceleration rate.

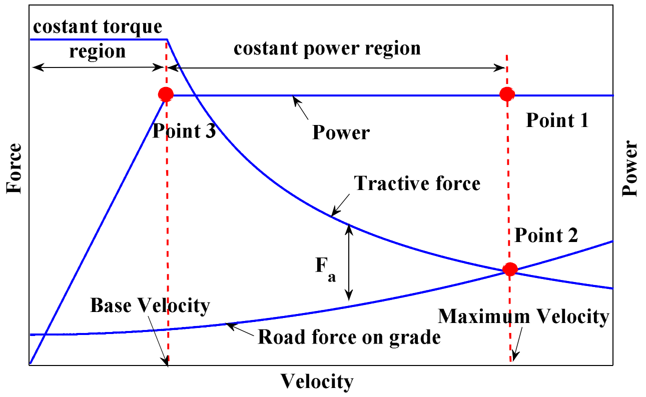

Fig. 2. Motor power, traction force and road force versus vehicle's velocity

A. Power Rating Design of the Traction Motor Based on Maximum Vehicle's Velocity

In this methodology, the rated power of the traction motor is calculated when the EV runs at the maximum velocity V_{vm} (point 1 in Fig. 2). At point 2 in Fig. 2, the total tractive force almost equals to the road force on gradeability as (4). At this condition, the acceleration force term in (2) could be canceled i.e. $\frac{d\,V_v}{dt} = 0$ and minimum road slop α_{min} is considered. Then, the total tractive force of (2) becomes

$$F_t = \frac{1}{2}\rho_a C_d\, A_v (V_{vm} + V_{air})^2 + M_v\, g\, (C_r \cos\alpha_{min} + \sin\alpha_{min}). \tag{5}$$

Then, the rated power of the traction motor P_m depends on the maximum velocity V_{vm}, the total tractive force F_t and the efficiency of transmission gear box η_{tr} and it is expressed as

$$P_m = \frac{1}{\eta_{tr}}\, V_{vm} F_t \tag{6}$$

B. Power Rating Design of the Traction Motor Based on Maximum Acceleration Rate

In the second methodology, the rated power is calculated at the base velocity and the maximum acceleration rate $\left(\frac{d\,V_v}{dt}\right)_{max}$ of the vehicle (point 3 in Fig. 2). When the vehicle is run with its maximum acceleration, it is sense to consider a flat road ($\alpha = 0$). Therefore, the total tractive force of (2) becomes

$$F_t = \frac{1}{2}\rho_a C_d\, A_v\, (V_v + V_{air})^2 + M_v\, g\, C_r + \delta\, M_v \left(\frac{d\,V_v}{dt}\right)_{max}. \tag{7}$$

Below base velocity, the torque can be maintained constant to achieve the maximum acceleration value. Whereas, when the vehicle runs above base velocity, a constant power operation mode is applied with sacrificing in the acceleration capability up to the final velocity. Hence, the time interval from start to final velocity (100km/h) is divided into two parts. In constant torque region, the torque of the TM is maintained constant at the rated value T_m or at a time-dependent oversized value. In this region, the tractive force is considered constant according to the rated power and base speed and equals to $F_t = \frac{P_m}{V_b}$ (point 3 in Fig. 2). So, from (7), the acceleration rate dV_v/dt is maintained constant from zero speed to base speed V_b in time t_b as (8)

$$\int_o^{t_b} dt = \int_0^{V_b} \frac{\delta\, M_v}{\frac{P_m}{V_b} - \frac{1}{2}\rho_a C_d\, A_v\, V_v{}^2 - M_v\, g\, C_r} dV_v \tag{8}$$

In constant power region, the tractive force will be decreased when the vehicle velocity is increased above the base value. This force equals to $\frac{P_m}{V_v}$ from base velocity V_b to final velocity V_f in time from t_b and t_f as (9).

$$\int_{t_b}^{t_f} dt = \int_{V_b}^{V_f} \frac{\delta M_v}{\frac{P_m}{V_v} - \frac{1}{2}\rho_a C_d A_v (V_v)^2 - M_v g C_r} dV_v \quad (9)$$

According to specifications, the vehicle can be accelerated from zero velocity to final velocity V_f of 100km/h in an acceleration time of t_f. After intensive abbreviation of (8) and (9) [1], the rated power of the TM in both regions can be expressed as (10).

$$P_m = \frac{1}{\eta_{tr}}\left[\frac{\delta M_v}{2 t_f}\left({V_f}^2 + {V_b}^2\right) + \frac{1}{5}\rho_a C_d A_v {V_f}^3 + \frac{2}{3} M_v g C_r V_f\right] \quad (10)$$

In this methodology, the base speed is crucial for calculating the rated power in acceleration and gradeability periods. The ratio between maximum speed to the base speed is called speed ratio $x = \frac{V_{vm}}{V_b}$. The speed ratio could be equals to unity when base speed is set at maximum speed and it could be 2-4 times for induction motor [11], [13], i.e. the boundary of the speed ratio is $1 \leq x \leq 4$. Considering the speed ratio, the rated power (10) becomes

$$P_m = \frac{1}{\eta_{tr}}\left[\frac{\delta M_v}{2 t_f}\left({V_f}^2 + \left(\frac{V_{vm}}{x}\right)^2\right) + \frac{1}{5}\rho_a C_d A_v {V_f}^3 + \frac{2}{3} M_v g C_r V_f\right]. \quad (11)$$

For increasing the speed ratio x, the rated power is decreased and the constant power region is widely increased. Finally, the rated power of the TM can be calculated from (5) and (6) to achieve the maximum velocity at minimum gradeability. Moreover, (11) can be used to determine the rated power at the base speed by finding the suitable speed ratio. The selected power should guarantee both maximum acceleration and maximum velocity performance.

C. *Driving Cycles-Based Power Sizing*

In this methodology, the average power of the tractive motor could be estimated with the expected driving cycles according to nature of the vehicle's environment. The cycles could be modified to match the design calculations i.e. maximum velocity, acceleration, deceleration, consumed and regenerative power, and therefore travelled distance. Then, these cycles are used to estimate the capacity and energy consumption of the used battery. This methodology is used in this work for determining the battery capacity and the consumed power.

D. *Calculation of Maximum/Base Speed and Rated Torque*

For a given maximum cruise velocity V_{vm} and vehicle specification, the maximum motor speed N_{max} is found as:

$$N_{max} = \frac{30\ n_g}{\pi\ \mathrm{R}_w} V_{vm} \quad (12)$$

where R_w and n_g are wheel radius and gear transmission ratio, respectively. Then, the base speed can be calculated as

$$N_b = \frac{N_{max}}{x} \quad (13)$$

Thus, the base speed depends mainly on the selected speed ratio. The motor rated torque T_m could be found as

$$T_m = \frac{P_m}{\omega_b} = \frac{30}{\pi}\frac{P_m}{N_b} \quad (14)$$

The developed torque could be oversized to extend the vehicle's capabilities i.e. acceleration, gradeability, weight, and/or maximum velocity.

E. *Battery Pack Sizing*

The capacity of the energy storage battery C_{batt} is estimated according to the average consumed power P_c. This power is calculated along practical driving cycles when the vehicle runs at an average velocity V_{av} for an on-power distance D_{on}. The average regenerative braking power P_{reg} is also considered along the same practical driving cycles. This negative power is estimated for an average velocity V_{av} on the off-power distance D_{off}. Summation of the distances during on- and off-power equals to the total travelled distance D. Considering both tractive and regenerative powers, the total required capacity kWh of the battery pack C_{batt} is found as:

$$C_{batt} = \frac{1}{\eta_m}\frac{1}{\eta_{inv}}\frac{1}{DoD}\frac{P_c}{V_{av}} D_{on} - \eta_{reg}\frac{P_{reg}}{V_{av}} D_{off} \quad (15)$$

where η_{inv}, η_m, η_{reg}, DoD are inverter efficiency, motor efficiency, regenerative efficiency and depth of discharge of the battery, respectively. The specific energy consumption E_c to the distance D is

$$Ec = \frac{C_{batt}}{D}. \quad (16)$$

The voltage of battery could be calculated from the required RMS value of motor line voltage V_{rms} as

$$V_{batt} = \sqrt{2}\, V_{rms} \quad (17)$$

Battery pack Ampere hour (Ah) is calculated from the battery capacity C_{batt} and the battery pack voltage V_{batt} as

$$Ah = \frac{C_{batt}}{V_{batt}} \quad (18)$$

IV. PRACTICAL CASE STUDY OF ELECTRIC VEHICLES NISSAN-LEAF 2015 ELECTRIC CAR

In this section, the ratings of the tractive motor and battery pack for Nissan-leaf 2015 electric car are calculated and then examined to the published ratings in [3], [15]. All the calculations are done according to the commercial vehicle. Table I shows the specifications and coefficients of Nissan-leaf 2015 electric car.

i. *Calculation of ratings of TM at maximum velocity*

First, the rated power is calculated according to (5) and (6) at the maximum velocity. For the maximum velocity of 144 km/h, the required power is 32kW at flat level. When the gradeability is increased, the tractive power is accordingly increased. Figure 3 shows the motor power versus vehicle velocity at different gradeability for Nissan-Leaf 2015 e-car. At 7% gradeability and maximum velocity of 144km/h, the tractive power is found 80 kW. The selected rated power depends on the vehicle capability to moving up the grade road at its maximum velocity. Referring to Table I, the power of 80 kW is set as the commercial power rating of Nissan-Leaf 2015 e-car. When the TM is sized at 80 kW, the vehicle can run at 200 km/h on a flat road; while it could climb up with 25% grade with velocity of 65 km/h.

TABLE I. SPECIFICATIONS AND COEFFICIENT OF NISSAN-LEAF 2015 ELECTRIC CAR [3], [15]

Vehicle's specifications		
Parameter [unit]	**Symbol**	**Value**
Gross mass [kg]	M_v	1645
Maximum velocity [km/h]	V_{vm}	144
Maximum acceleration [km/h/sec]	$d\ V_v$ /dt	100/11.5
Distance for one charging cycle [km]	D	160
Wheel radius [m]	r	0.315
Transmission ratio	n_g	8.19
Frontal area [m2]	A_v	2
Axle moment of inertia [kg/m^2]	J_{axle}	3
Vehicle's coefficients		
Rolling resistance	C_r	0.0083
Air density [kg/m2]	ρ_a	1.2
Aerodynamic coefficient	C_d	0.28
Transmission efficiency	η_{tr}	0.96
Air velocity [km/h]	V_{air}	12
Inverter efficiency	η_{inv}	0.95
Motor efficiency	η_m	0.95

ii. Calculation of ratings of TM at maximum acceleration

To accelerate the vehicle up to $V_f = 100km/h$ in time $t_f = 11.5\ s$ considering the maximum velocity of $V_m = 144\ km/h$, according to (11), the rated power is calculated at different speed ratios as

$$P_m = \frac{1.1 * 1645}{2 * 11.5}\left(27.7^2 + \left(\frac{40}{x}\right)^2\right) + \frac{1}{5} * 1.2 * 0.28 * 2 * 27.7^3 + \frac{2}{3}1645 * 9.81 * 0.0083 * 27.7.$$

At speed ratio of $x = 4$, the rated power equals to 76 kW. This value is lower than the calculated power from (5) and (6). Once the speed ratio is decreased to $x = 2.5$, the rate power equals to 89 kW. However, the later represents oversized power compared to the calculated power of 80kW. For power of 80kW, the speed ratio is selected as $x = 3.3$ to guarantee the maximum velocity of the car (point 1 in Fig. 2) and the final velocity of 100km/h in the time of 11.5s (see Table I).

iii. Maximum/base speed and torque calculations of EM

The maximum motor speed is related to the maximum velocity as (12), $N_{max} = \frac{30*8.19}{\pi*0.315} * \frac{144}{3.6} = 9932\ rpm$. At $x = 3.3$, the base speed from (13) is $N_b = \frac{9932}{3.3} \cong 3000\ rpm$. This speed equals to base vehicle velocity of 44km/h. From (14), the rated motor torque is $T_m = \frac{80000}{\frac{\pi}{30}*3000} = 254N.m$.

Figures 4 and 5 show the tractive force and acceleration performance for different speed ratios x of 2.5, 3.3 and 4 times. At speed ratio $x = 4$, the rated power is 76 kW at the highest tractive force and then highest initial acceleration. This power is suitable for acceleration performance however it is insufficient for maximum velocity of 144km/h with 7% grade road. This option is not accepted. In contrast when the speed ratio is chosen as $x = 2.5$, the rated power is increased to 89 kW. This power overflows the power required for maximum velocity and grade road conditions. For speed ratio $x = 3.3$ and Referring to (8), below base velocity, the acceleration rate is fixed at12 km/h/s with tractive force of 6.2 KN. This rate guarantees to reach at the base velocity of

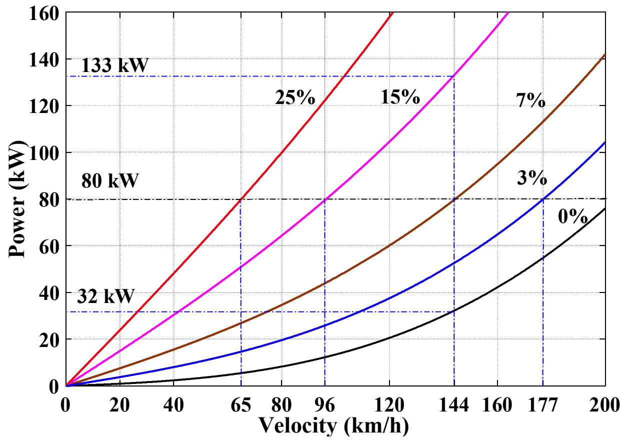

Fig. 3. Gradeability-based road load power at maximum velocity

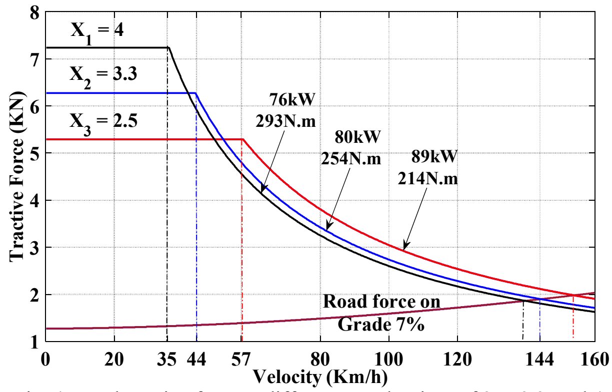

Fig. 4. Total tractive force at different speed ratio x of 2.5, 3.3, and 4

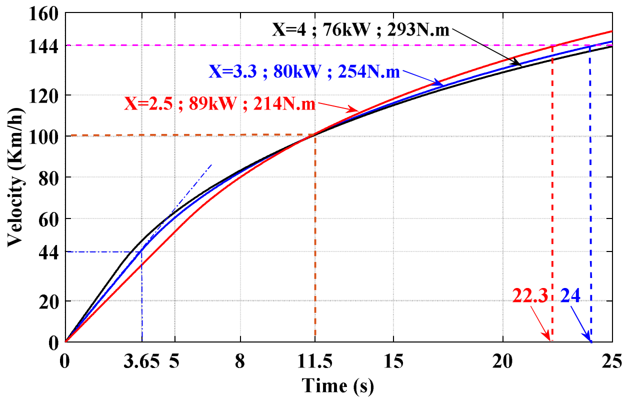

Fig. 5. Acceleration performance at different speed ratio x of 2.5, 3.3, and 4

44km/h in 3.65 s as shown in Fig. 5. Whereas, above the base velocity, the acceleration rate is decreased according to decreasing of the acceleration force referring to (9). This acceleration rate guarantees to reach at the final velocity of 100 km/h in 7.85 s as shown in Fig. 4.

iv. Battery pack sizing using Urban drive cycle

The energy sizing of the required battery pack depends on the driving conditions i.e. maximum velocity and consumed power. First, a typical drive cycle, modulated Urban Dynamometer Driving Schedule (UDDS) [6], [10], is used to found out the capacity of the battery, as depicted in Fig 6(a). For this cycle, the maximum velocity is 144km/h, the average velocity is found as 44.75km/h and then the total distance is 17 km during a time of 1230s. If 0% gradeability is considered, the average consumed power becomes 10.51 kW and the average velocity is 44.75 km/h. At these conditions,

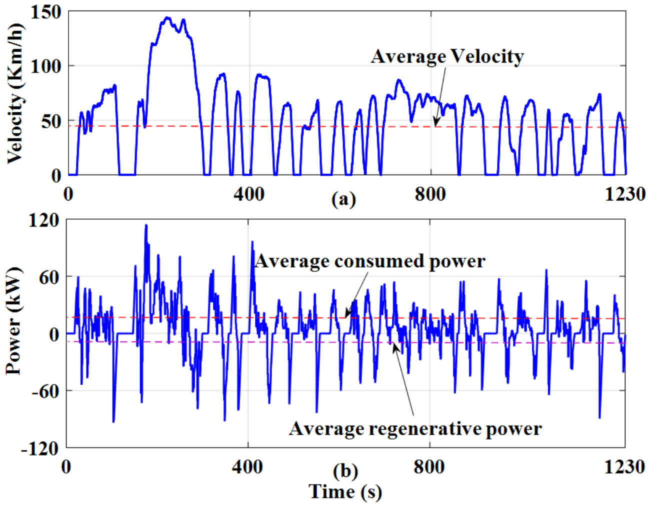

Fig. 6. Typical Urban drive cycle, UDDS: (a) vehicle velocity (b) power.

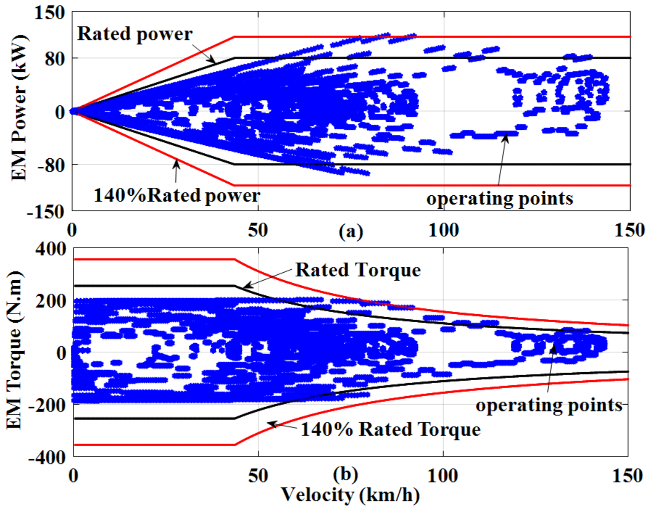

Fig. 7 TM operating points in torque and power boundary for UDDS cycle.

the on-power distance equals 12.1km in the modified UDDS cycle. Moreover, the average braking power that could be regenerated is 5.58 kW. When the vehicle runs at an average velocity of 44.75km/h, the off-power distance is 4.9 km. Referring to Table I, the total travel distance is 160km in one battery-pack charging capacity. Therefore, this driving cycle is repeated to 160kW/17kW= 9.41 times. For the average velocity of 44.75km/h, the on-power distance is found as 114 km whereas the off-power distance is found 46 km. According to (15), the DOD is considered 100% and the regenerative efficiency is 90%. Therefore, the battery pack capacity could be calculated as

$$C_{batt} = \frac{1}{0.95}\frac{1}{0.95}\frac{10.51}{44.75}114 - 0.9\frac{5.58}{44.75}46 \cong 24kWh.$$

Figure 7(b) shows the operating points of the TM power and torque for UDDS cycle. It shows the rated and maximum boundaries for power and torque. The maximum capability is considered 140% of the rated [14]. The majority of the operating points inside rated boundary, whereas some points are located between the rated and maximum boundaries.

v. Battery pack sizing using highway drive cycle

Another type of drive cycle, a modified Artemis MW_130 [10], is tested to find out the battery pack capabilities.

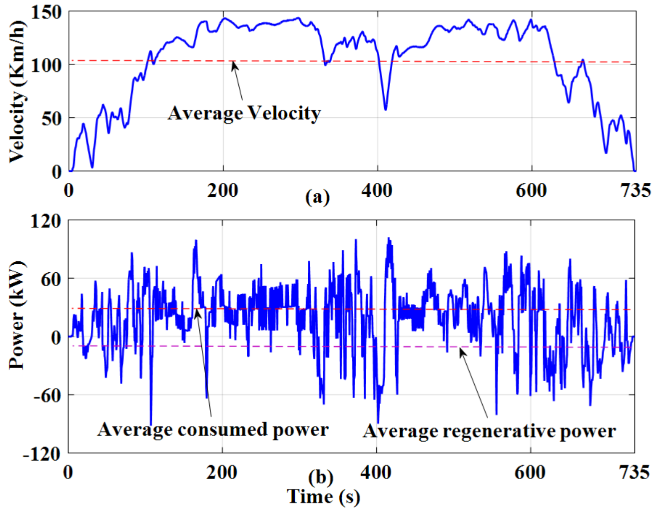

Fig. 8. Typical highway drive cycle, ArtMW: (a) vehicle velocity (b) power

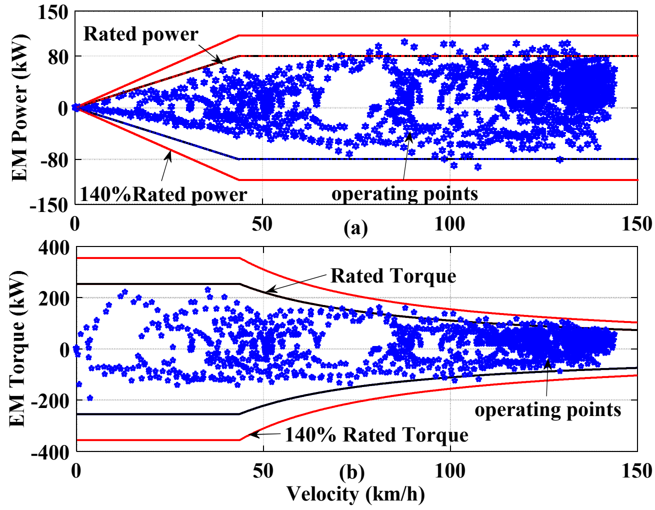

Fig. 9. TM operating points in torque and power boundary for Artemis MW_130 cycle.

In this cycle, the maximum velocity is 144km/h and the average velocity is 104 km/h. At these conditions, the vehicle can travel total distance of 21.7 km during 735 s, as shown in Fig.8(a). If 0% gradeability is considered, the average consumed power becomes 24.47 kW and the average velocity is 104 km/h. Under these conditions, the on-power distance equals to 17.61 km. Moreover, the average braking power that could be regenerated is 6.03 kW. When the vehicle runs at an average velocity of 104 km/h, off-power distance is 4.1 km. Referring to Table I, the total distance of 160km on one battery pack charging capacity, the drive cycle is repeated 160kW/21.7kW = 7.37 times. For the average velocity of 103 km/h, the on-power distance is found as 129.7km whereas the off-power distance is found 30.3 km. According to (15), the DOD is considered 100% and the regenerative efficiency is 90%. Therefore, the battery pack capacity could be

$$C_{batt} = \frac{1}{0.95}\frac{1}{0.95}\frac{24.47}{104}129.7 - 0.9\frac{6.03}{104}30.3 \cong 32.2kWh.$$

Figure 9 shows the operating points of the EM power and torque for the modified Artemis MW_130 cycle. The capacity of the battery back is 32.3kWh to provide 160 km distance. It is noticed that if the operation conditions are changed, the size of the battery-pack is changed. The required capacity is affected by the type of the vehicle (i.e. city car, highway car and sport car) and driving cycle i.e. maximum velocity, average velocity, acceleration, deceleration and numbers of start stop. These factors are reflected on the average consumed power and average negative power. Therefore, the required battery capacity is different for UDDS and Artemis MW_130 cycles as shown in Table II. Table III shows the final ratings of the EM and battery pack, this rating matching to [3].

TABLE II. COMPARISON OF DRIVE CYCLES FOR NISSAN-LEAF E-CAR

Specifications [unit]	**UDDS**	Artemis MW_130
Maximum velocity [km/h]	144	144
Average velocity [km/h]	44.75	104
Maximum acceleration [km/h/s]	9.26	10.94
Maximum deceleration [km/h/s]	-9.26	-12.84
No. of start/stop	18	1
Average positive power [kW]	10.51	24.47
Average negative power [kW]	5.58	6.03
Battery pack capacity [kWh]	24	32.2

TABLE III. RATINGS OF TM AND BATTERY PACK OF NISSAN-LEAF E-CAR

Rated [unit]	**symbol**	**Value**
Rated power [kW]	P_m	80
Rated torque [Nm]	T_m	254
Rated speed [rpm]	N_b	3009
Maximum speed [rpm]	N_m	9932
Battery capacity [kWh]	C_{batt}	24

V. CONCLUSION

In this paper, the vehicle's dynamics and the parametric design of an electric drivetrain for EVs have been presented, as well as battery capacity considering regenerative braking. The objective was to assess typical vehicle usage on different road types and implication on vehicle energy consumption due to the drive cycles' characteristics. For this evaluation one reference vehicle (Nissan-leaf 2015 E-car) is designed after set the performance requirements. For Nissan E-car, when considering the maximum velocity for determining of the power ratings, it was found that the vehicle can run at 144 km/h in a 7% grade road by 80 kW TM; while, when considering maximum acceleration rate, it was found that the same performance is got with speed factor of x=3.3. Furthermore, the battery capacity considering regenerative braking is found as 24 kWh and 32 kwh for the modified UDDC and Artemis MW-130 drive cycles, respectively. The vehicle performance dictates these vehicle capabilities, thus dictating the power capacity of the powertrain. However, in normal driving conditions these maximum capabilities are rarely used. During most of the operation time, the powertrain operates with partial load.

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