Investigation On Performance Evaluation of Electric Vehicle Batteries on Different Drive Cycles

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Abstract— **The electric vehicle components designing, sizing, rating and selection are influenced by drive cycles. For that reason, it is essential to test an Electric Vehicle (EV) in a simulation environment on different standard drive cycle before testing it real- time to understand its life cycle and hence determine the most suitable design of EV- efficient and economical. Many European countries use New European Driving Cycle (NEDC) as their own emission test procedures but there are also other driving cycles such as FTP75, US06 etc. which can be used globally for "real-world" performance testing of vehicles. Besides its cell chemistry, the range and performance of the EV battery mainly depend on how it looks like. The battery performances of diverse EV batteries have been examined under various standard international & Indian driving cycles in this research paper. This paper has adopted Nissan leaf 2018 EV model data to study the performance of the EV battery through developing an EV drive train test system. This research has presented field-oriented control (FOC) for PMSM traction motor. An SVPWM algorithm is introduced to reduce harmonics and increase quality of switching losses for PWM Inverter operation. Battery energy consumption per charge based on distance travelled by vehicles is calculated to compare different EV batteries for evaluating their performance**.

Index Terms—**Batteries, Electric vehicle, filed oriented control, Field-weakening, Maximum torque per ampere, Permanent magnet synchronous motor, EV drive cycles.**

1. Introduction

As concerns about the environmental impact increase, electric vehicles (EVs) are becoming more popular as a cleaner mode of transportation.

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however, the limited driving range of EVs remains a significant challenge, which is mainly due to the performance of key components such as batteries and motors. it is important to understand how these components work together, especially since driving conditions can vary greatly around the world due to different roads, traffic situations, and driving habits. therefore, it is necessary to evaluate the performance of EVs in specific contexts. when it comes to batteries, there are different types to consider. lead- acid batteries are often used as support batteries due to their affordability and slow power loss. however, nickel-cadmium (NC) batteries, which were once popular for their superior qualities, are now restricted due to environmental concerns and high costs. lithium-ion batteries, particularly those with materials like lithium iron phosphate (LFP) and lithium nickel cobalt Aluminum oxide (LI-NCA), are now the preferred option for EVs. they offer high power, energy density, and longer lifespans.

The lifespan of a battery is influenced by factors such as usage patterns and temperature. in terms of motors, there are different types used in EVs, including brushless dc (BLDC), induction motors (IM), permanent magnet synchronous motors (pmsm), and switched reluctance motors (SRM). PMSM motors, known for their efficiency and power, are commonly used in four-wheelers and heavy vehicles. to improve EV technology, it is crucial to understand how driving conditions affect performance. while existing studies have evaluated battery stability and efficiency under different conditions using global standards like the worldwide harmonized light vehicles test procedure (WLTP) and new European driving cycle (NDEC), there is still a need for a comprehensive assessment that considers both motor and battery performance under various driving conditions, especially in countries like India. this research aims to fill this gap by examining how different types of batteries perform under various driving conditions, taking into account the specific dynamics of Indi roads. the following sections will outline the proposed dynamic modeling of EVs, the mathematical modeling of PMSM, and how driving conditions impact EV battery performance. this comprehensive approach aims to offer practical insights into the performance of electric vehicles in real-world situations, particularly in India, where the performance of EVs on Indian roads can differ significantly from that in other countries. to address these differences, this study investigates the performance of various battery cell chemistries across different driving cycles. in the EV drivetrain system, the speed and torque of the permanent magnet synchronous motor (PMSM) are controlled using field-oriented control (FOC) with field- weakening operation, optimizing for maximum torque per ampere. this approach aims to enhance the overall efficiency and responsiveness of EVS in diverse driving conditions.

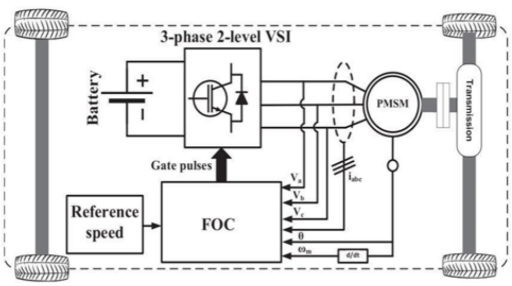

Fig.1. The electric vehicle drive train test system block diagram

2. Literature Survey

[1]Gebisa A, Gebresenbet G, Gopal R, Nallamothu RB. Driving Cycles for Estimating Vehicle Emission Levels and Energy Consumption. Future Transportation. 2021; 1(3):615-638.

Standard driving cycles (DCs) and real driving emissions (RDE) legislation developed by the European Commission contains significant gaps with regard to quantifying local area vehicle emission levels and fuel consumption (FC). The aim of this paper was to review local DCs for estimating emission levels and FC under laboratory and real-world conditions. This review article has three sections. First, the detailed steps and methodologies applied during the development of these DCs are examined to highlight weaknesses. Next, a comparison is presented of various recent local DCs using the Worldwide Harmonized Light- Duty Test Cycle (WLTC) and FTP75 (Federal Test Procedure) in terms of the main characteristic parameters. Finally, the gap between RDE with laboratory-based and real-world emissions is discussed. The use of a large sample of real data to develop a typical DC for the local area could better reflect vehicle driving patterns on actual roads and offer a better estimation of emissions and consumed energy. The main issue found with most of the local DCs reviewed was a small data sample collected from a small number of vehicles during a short period of time, the lack of separate phases for driving conditions, and the shifting strategy adopted with the chassis dynamometer. On-road emissions measured by the portable emissions measurement system (PEMS) were higher than the laboratory-based measurements. Driving situation outside the boundary conditions of RDE shows higher emissions due to cold temperatures, road grade, similar shares of route, drivers' dynamic driving conditions.

3. A Brief Description of The Ev Drive Test System

A real-time simulation of the electric vehicle drive train system is required to evaluate the battery's performance throughout various driving cycles, and one is currently being developed. As shown in Fig.1., the vehicle body, longitudinal driver, VSI, PMSM with FOC control, and PMSM are the key components of the drive system.

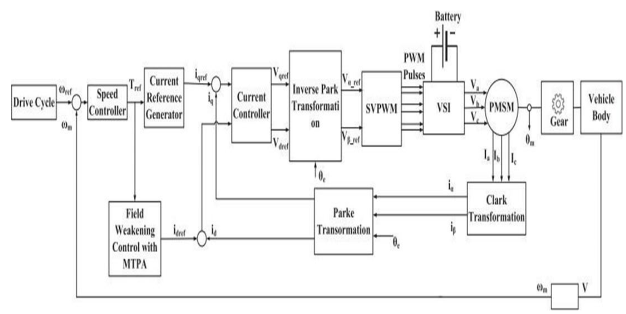

Fig.2. Block diagram of EV drive test system

The road dynamics and a given velocity profile are used to determine the motor torque. The commanded phase voltages are produced by the torque control loop. Ultimately, the PMSM's FOC mechanism generates the regulated PWM pulses. The following chapters provide a description of the system's modeling and control components.

A. Design features of the EV system

Figure 2 depicts the vehicle dynamics and resistive forces operating on the electric vehicle. The forces affecting The vehicle is (i). Resistance force in rolling (ii). force of aerodynamics (iii). Force gradient and (iv). force of acceleration. Equations can be used to quantitatively express them. by (1) through (5) and Equation (5).

$$\boldsymbol{Fr} = \boldsymbol{CrrMgcos}\alpha \tag{1}$$

where Fr= Rolling resistance force (N), Crr= Rolling coefficient, M = Gross vehicle weight, g = Gravitational acceleration (m/s2) and α= Inclination angle (degrees)

$$Fa = \frac{1}{2} Acd\rho v2 \qquad (2)$$

where Fa= Aerodynamic force (N), A= Frontal area, Cd=Coefficient of drag, ρ=Air density (kg/m3), and v = Velocity of vehicle (m/s).

$$Fg = Mgsin\alpha \qquad (3)$$

where Fg= Gradient force (N)

$$Facc = Ma \qquad (4)$$

where Facc= Acceleration force (N) and a = Acceleration (m/s2)

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

where Ft= Total tractive forces (N).

To determine the charging and discharging current of the battery the following Eqs. (6) and (7) are us

$$icharge = \frac{(Fa + Fg + Fr + Facc)v \times \eta totalcharge}{Vn} \qquad (6)$$

where icharge=Battery charging current (A),Vn= Nominal voltage of the battery (V),V = Velocity of vehicle (m/s) and ηtotalcharge= Total charge performance.

$$idischarge = \frac{(Fa + Fg + Fr + Facc)v}{Vn \times \eta total, discharge} \qquad (7)$$

where idischarge= Battery discharging current (A), and ηtotaldischarge= Total discharge performance.

The size of the motor and battery are determined from Eqs. (8) to (20) based on vehicle dimensions and forces acting on it. From the force obtained (5), the torque at the wheel is calculated as

$$Tw = Ft \times wr \qquad (8)$$

where Tw= Wheel torque (Nm), wr= Wheel radius (m)

$$mw = \frac{v \times 60}{2\pi wr} \qquad (9)$$

where ωw= Wheel speed (rad/s)

$$G.R = \frac{mm}{mw} or \frac{Tw}{Tm} \qquad (10)$$

where G.R = Gear ratio, ωm= Motor speed (rad/s), Tm= Motor torque (Nm).

The torque and speed at the motor are calculated by considering the gear ratio and Transmission efficiency as given in eq. (11) and (12).

$$Tm = Tw\ G.R \times Teff \qquad (11)$$

where Teff= Transmission efficiency

$$mm = G.R \times mw \qquad (12)$$

The output power motor, inverter and power required from the battery are calculated from the Eqs. (13) to (15)

$$Pm = Tm \times mm \qquad (13)$$

where Pm= Motor output power (W).

$$Pinv = \frac{Pm}{\eta motor} \qquad (14)$$

where Pinv = Inverter output power (W) and ηmotor= Motor efficiency

$$Pb = \frac{Pinv}{\eta inv} \qquad (15)$$

where Pb= Battery power (kWh), ηinv= Inverter efficiency

$$BAh = \frac{Pb}{Vdc} \qquad (16)$$

where BAh= Battery capacity (Ah) and Vdc= Battery voltage (V)

Average Power Consumption of Vehicle

$$Pava = \frac{2\pi mrTm}{60x1000} \qquad (17)$$

Running range without considering AC & other equipment's

$$(k1) = h1 \times vavg \qquad (18)$$

where **vavg**= Average velocity of the vehicle, and

$$\boldsymbol{h1} = \frac{battery\ capacity}{Pavg}$$

Average energy consumption per km without AC & other equipment's

$$= \boldsymbol{h2} \times \boldsymbol{vavg} \quad (19)$$

where $\boldsymbol{h2} = \frac{Battery\ capacity - 1.5 \times h1}{Pavg}$

Running range with considering AC& other equipment's

$$\boldsymbol{k2} = \frac{Battery\ capacity \times 1000}{k1} \tag{20}$$

Average energy consumption per km without AC & other equipment' s

$$= \frac{Battery\ capacity \times 1000}{k2} \tag{21}$$

Per charge cost based battery capacity $(\boldsymbol{q1}) = \boldsymbol{Battery\ capacity} \times \boldsymbol{Per\ unit\ Electricity\ Cost}$

$$\tag{22}$$

Per km running cost based battery capacity

$$(\boldsymbol{q2}) = \frac{\boldsymbol{q1}}{\boldsymbol{k1}} \tag{23}$$

Acceleration of vehicle

$$(\boldsymbol{u1}) = \frac{\boldsymbol{Tm \times G.R}}{\boldsymbol{wr}} \tag{24}$$

Acceleration from 0 to 100sec

$$= \frac{100 \times 1.35 \times \frac{5}{18}}{u1} \tag{25}$$

Battery capacity required based on distance traveled by EV

$$(bc) = \frac{Pavg \times distance\ in\ km}{vavg} \tag{26}$$

Per charge cost based on distance traveled

$$(\boldsymbol{q3}) = \boldsymbol{bc} \times \boldsymbol{Per\ unit\ electricity\ Cost} \tag{27}$$

Per km running cost based on distance traveled

$$(\boldsymbol{q4}) = \frac{q3}{distance\ in\ km} \tag{28}$$

Per km running cost based on distance traveled

$$(\boldsymbol{q4}) = \frac{q3}{distance\ in\ km} \tag{29}$$

Required battery Ah rating

$$= \frac{\mathbf{BAh \times 1000}}{\mathbf{Vdc}} \tag{30}$$

The number of cells required by the battery is calculated from Eqs. (31) to (33)

$$\mathbf{Ns} = \frac{\mathbf{Vdc}}{\boldsymbol{Vcell}} \tag{31}$$

where Ns= Number of cells connected series, and VCell= Cell voltage (V)

$$\mathbf{Np} = \frac{\mathbf{BAh}}{\mathbf{CellAh}} \tag{32}$$

NP= Number of cells connected parallel and Cell Ah= Cell capacity (Ah)

$$\boldsymbol{Nt} = \boldsymbol{Ns} \times \boldsymbol{NP} \tag{33}$$

where Nt= Total number of cells in the battery pack.

4. An Overview of the PMSM-Based EV Drive System's Control Method

A. Analysis of Permanent magnet synchronous motor Mathematically in the direct-quadrature Coordinate System

PMSMs are the preferred motors. for electric vehicles because of its superior efficiency and power density when in contrast to other motor types such as IMs and BLDC. Eqs. (34) through (41) give a mathematical description of the PMSM in the rotor flux reference frame. The d and q -axis voltage equations are

$$\boldsymbol{vd} = \boldsymbol{idRs} + \frac{d\lambda d}{dt} - \boldsymbol{meLqiq} \tag{34}$$

$$\boldsymbol{vq} = \boldsymbol{iqRs} + \frac{d\lambda q}{dt} - \boldsymbol{meLdid} + \omega e\lambda \mathbf{pm} \tag{35}$$

Stator flux equations are given in Eqs. (36) and (37)

$$\lambda d = Ldid + \lambda pm \tag{36}$$

$$\lambda q = Lqiq \tag{37}$$

By substituting the Eqs. (36) & (37) in (34) & (35) respectively the d, q-axis voltage give as

$$vd = idRs + Ld\frac{did}{dt} - meLqiq \tag{38}$$

$$vq = iqRs + Lq\ diq\ dt + meLdid + me\lambda pm \tag{39}$$

Electromagnetic torque equation, $Te = 3\ 2\ p\ (\ \lambda pmiq + (Ld - Lq)\ idiq)$ (40)

Steady-state torque equation $Te - TL = J\ dmm\ dt + Bmm$

(41)

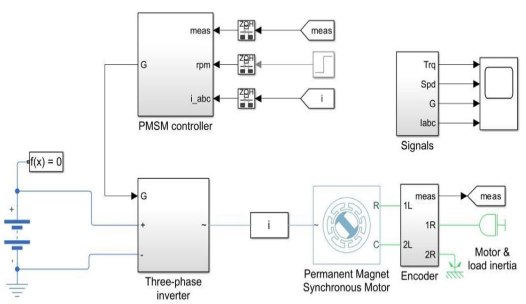

Fig.3. Block diagram PMSM controller

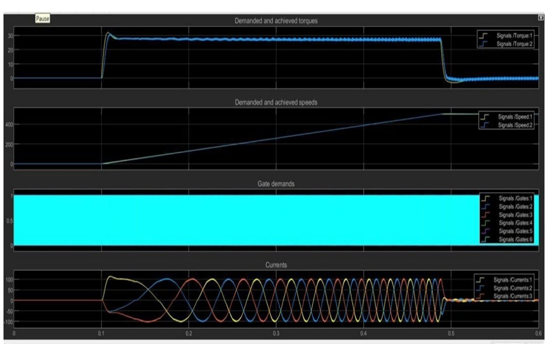

Fig.4. Performance Characteristics of PMSM motor

B. The EV drive test system with PMSM base

Its speed and torque can be controlled by FoC. A block diagram of the proposed drive train system for speed and torque is shown in Fig. 3. At least at minimum speed, the rated current and flux produce the rated torque while output powers and voltages increase linearly until it reaches its rated voltage level. The motor cam reach its rated speed when it reaches its rated voltage level, which is also referred to as base speed of the motor. If we want to increase our speeds above our rated speeds then we will have to reduce or weaken flux while voltage remains constant at rated value.

Beyond the base speed, there is no change in output power because torque varies inversely with velocity over us much as it does under us thus making this region also flat line on graph area according to fig 4b This operational region is known as the flux weakening/ constant power region as shown in Fig. 5(a).In Fig. 5 (b), the trajectory of maximum torque per ampere (MTPA) is given in id and iq axis The PMSM can be controlled using FOC algorithm where the flux rated ID = 0, and by back EMF, stator voltages, and limiting currents of rated with operation over this base speed, resulting in complex motor behavior.

If the id value is made negative, the rotor flux linkage will reduce thereby causing the PMSM to operate above its base speed; this approach is known as field- weakening control algorithm method. However, depending on PMSM and VSI parameters, Id ref computation varies. Nevertheless, in field weakening control algorithm Iq ref and output torque are restricted by machine loading condition and rate current. Therefore, until base speed is reached beyond which it becomes constant power region with a limited torque higher than that at base speed as shown in Fig. 4., the motor runs at a constant torque region. Equations. (41) – (45) provides basis for determining what constitutes a minimum threshold of Equations for PMSMs.

To achieve the highest torque in IPMSM, it is necessary to calculate id ref and Iq ref from the equation of torque.

Id ref is determined by a voltage and current limited maximum torque (VCLMT) control algorithm during the field weakening operation (FWO). The id

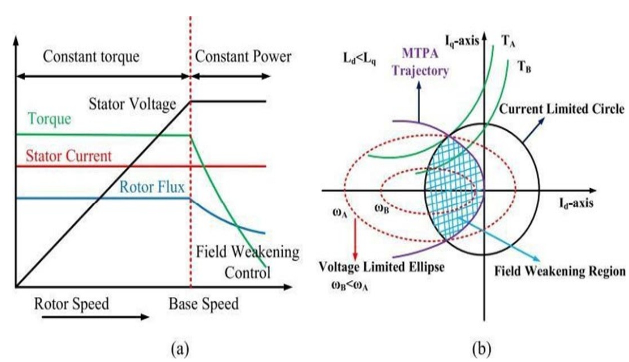

Fig.5. Fig. (a) Ideal field weakening characteristics of PMSM
Fig. (b) The trajectory of MTPA in id and iq axis

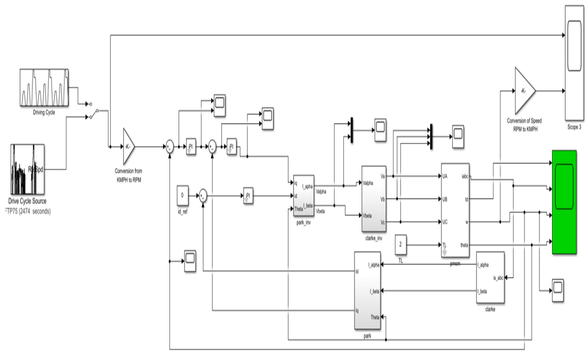

Fig.6. Simulation Block of different driving cycle.

This is why many countries and companies involved in EV manufacturing have come up with various drive cycles to determine EV battery's performance. To check their overall performance before releasing them into the market, manufacturers usually subject their cars through several standard drive cycles both in computer simulations and real-time conditions. Consequently; these drive cycles vary across nations due to differences in local conditions. Henceforth; it is important to choose an appropriate drive cycle for particular weather of a country due to traffic levels present together with other factors like roads' physical attributes and different driving styles among others. In this paper four standard drive cycles are considered for evaluating vehicle battery performance.

Table 1
EV vehicle parameters specifications

Parameter	Value
Curb vehicle weight	1580 kg
Gross vehicle weight	1995 kg
Number of passengers	5
Average massper passenger	83 kg
Air Drag coefficient	0.28
The frontal area of vehicle	2.276 sq.m
The Average velocity of the vehicle	60 kmph
Rolling coefficient	0.02
Transmission efficiency	85%
Gear Ratio	8.1938
Type of Tire	205/22 R16
Gravitational Acceleration(g)	9.8 m/s^2
Grading Angle	5 degrees

Table 2
High voltage Battery Parameters

Parameter	Value
Battery pack Rating	40kwh
Nominal voltage	360V
Rated Voltage	398.4V
Minimum Voltage	240V
Battery Dimensions	1547 * 1188 * 264 mm
Battery Weight	273-296kg

Table 3
Parameters Of the Motor

Parameter	Value
Motor Rating	110kw
Speed	3284-9795 RPM
Maximum Torque (Tmax)	320 N-m
Stator d-axis Inductance (Ld)	0.00024368(H)
Stator q-axis Inductance (Lq)	0.00029758(H)
Stator zero-sequence Inductance(L0)	0.00012184(H)
Stator Resistance/phase (Rs)	0.010087Ω
Permanent Magnet Flux Linkage(λpm)	0.04366 wb
Number of pole pairs(P)	4
Rotor Inertia(J)	0.1234 kg-m^2

Table 4
Various Performance indices of LFP Battery on WLTP CLASS-3 drive cycle

Parameter	LFP(PSL-FP-IFR18650EC)
Battery Voltage (V)	360V
Required Battery Ah rating	103.652294Ah
Average Energy Consumption of vehicle	8.330752KWh
Running Range without considering AC and Other equipment	230.471395km
Average Energy consumption per km without AC and other Equipment	138.845864 Wh/km
Running Range considering AC and other equipment	188.973689 Km
Average consumption per km with AC and other equipment	169.335743 Wh/Km

Per unit electricity cost(approximate)	5rs
Per charge cost-based battery capacity (for 40KWH battery)	214 Rs
Acceleration of vehicle	4.159409m/s^2
Per km running cost based battery capacity (for 40KWh battery)	0.928532 Rs/km
Battery Capacity Required Based on Distance travelled (for 215 km)	37.314826 KWh
Per charge cost based on distance Travelled (for 215 km)	186.4741301 Rs
Per km running cost based on distance travelled (for 215 km)	0.867787 Rs/km

Table 5
Performance Comparison of different EV Batteries

Parameters	WLTP	NEDC
Motor torque (N- m)	91.70	86.92
Average Speed (RPM)	31.11	20.70
G-Force	1.1106e^-2	1.591e^-2
Motor Temperature	22.49 degree centigrade	15.8 degree centigrade
SOC of Li-ion Battery	97.76	98.99
SOC of NC Battery	97.86	99.11
SOC of NMH Battery	97.74	99.06
Current of Li-ion Battery	31.95A	23.04A
Current of NC battery	31.95A	23.02A
Current of NMH Battery	31.95A	23.04A
Voltage of LFP Battery	391.2V	408.5V
Voltage of NC battery	399V	415.V
Voltage of NMH battery	400V	415.2V
Power Of LFP battery	12.57 kW	20.67 kW
Power of NC battery	12.28 kW	21.14 kW
Power of NMH battery	12.89 kW	21.12 kW
Battery Temperature (Centigrade)	22.55 degrees	21.5 degrees
Battery Capacity Required (Power consumed by the battery)	3.30 kWh	0.42 kWh

5. Results And Discussions

A. CASE1: WLTP DRIVE CYCLE

At first the drive system we tested on the CLASS 3 drive cycle with a battery rated at 40kwh for the WLTP CLASS 3 drive cycle for a distance of 225km the battery consumed is 37.31kwh without considering the Air conditioner in the vehicle. The performance of the battery train system with FOC with MPTA on the WLTP drive cycle the results of the drive train system were shown in the table 5. From this case we get an analysis of velocity vs time graph in the fig.7. from the given graph it is observed that the actual velocity vs time graph is similar to the achieved velocity vs time graph.

Similarly, as what we have done in testing the characteristics of Velocity and time graph we have to do it for getting the characteristics of the Torque the average torque of the vehicle of the given WLTP drive cycle is given in the fig 6 as the time and torques are varying with respect to the time for various batteries the ranges are not very much similar so that we can analyze that which battery can be a certainty of the usage.

The temperature of the WLTP driving cycle lies under the ranges of 20degress and while after the vehicle is appraised to a distance of a certain level the temperature of the battery changes from 20 to 24 degree Celsius then the vehicle cooling system will be enabled to drive the system to a safer level of operation the current ,speed ,Torque and the angle variation of the vehicle wheel are seen in the fig 8 the following results are taken from MATLAB these accurate results will justify the performance of the EV drive train system. From the table 5 we can observe the values of various drive train system characteristics are tabulated.

The voltage level of the Lithium Ferrous Phosphate battery is up to 391.7V and the capacity of the battery is given up to 3.3KWh The power rating of the battery is 12.57 KW the average speed of the WLTP drive cycle is up to 31.1 kmph.

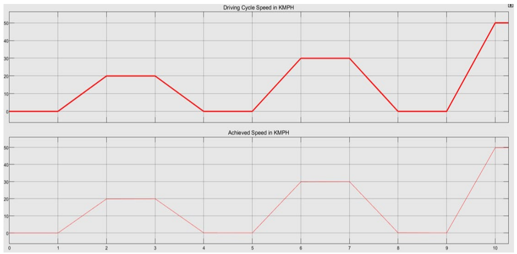

Fig.7.1 Velocity vs time graph

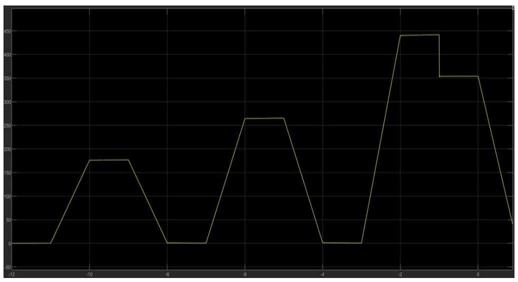

Fig.7.2 Torque vs Time graph

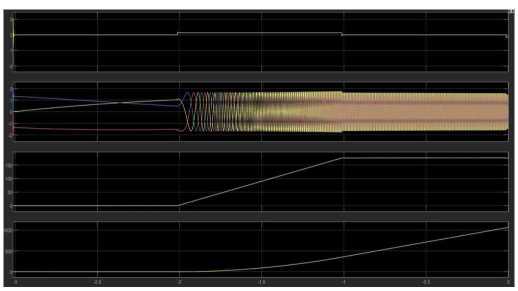

Fig.7.3 Iabc,Torque,Speed ,Rotor angle vs Time

B. CASE 2: NEDC DRIVE CYCLE

The NEDC Drive cycle is been tested unlike the WLTP drive cycle the NEDC cycle shows a slightly different kind of characteristics based on the drive system it is engaged to shows the different characteristic traits the NEDC drive train System is tested up to 230km Driving range without considering the AC in the vehicle system so that the traits found are purely based on the physical performance of the vehicle the battery rating that is 40KWh and the battery consumed while doing this performance test is 37.7KWh the vehicle in the particular drive system is up to speeds.

20.11kmph.from fig 6.4 the graph shows the speed graphs of the reference speed and achievable speeds will be similar to Each of them that states that they are working at a similar manner with respect to the reference speeds.

Similarly, the Torque characteristics of the NEDC system is shown in the fig 6.5 and the currents Iabc, Torque, Rotor angle and speed vs time graphs is been plotted at 6.6.

In the table 5 it is shown that the voltage level of the NEDC with Lithium Ferrous Phosphate (LFP) is taken out to be 408.5V the current rating of NEDC is 23.04A Average speed of 20.70 and the Torque value is 86.7N-m. The gravitational force is 1.591e^-2

Which is higher than the WLTP drive cycle.

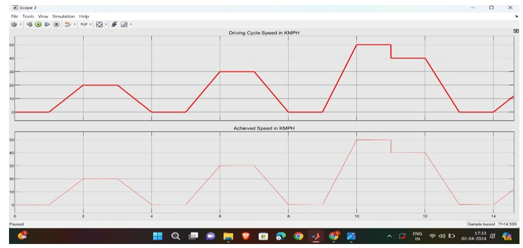

Fig.7.4 Speed vs Time graph

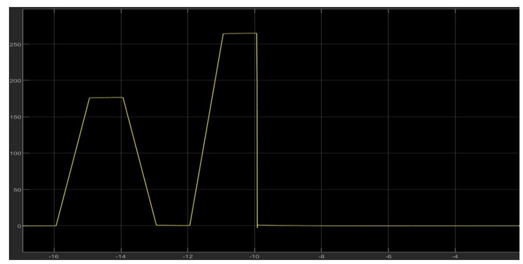

Fig.7.5 Torque vs Time Graph

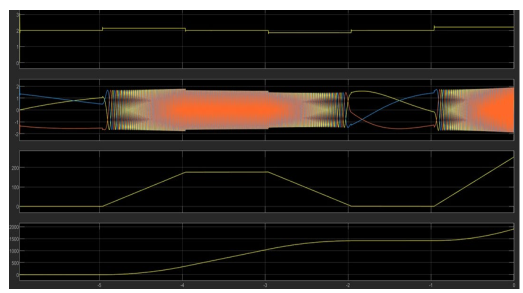

Fig.7.6 Iabc,Torque,Speed,Rotor angle vs time

6. Conclusion

In this regard, the performance of an electric vehicle using alternative battery chemistries was investigated in this paper. Lithium Iron Phosphate (LFP), Nickel Cobalt (NC) and Nickel Metal Hydride (NMH) batteries were used for this study with a focus on Nissan Leaf 2018 EV model. The energy consumption of an electric vehicle depends on driving conditions, road profiles and driver behavior. Numerous features pertaining to battery have been taken into account: state-of- charge, voltage-current-temperature characteristics; thus allowing estimating overall energy consumption during car's operation for given drive modes: WLTP class 3 – urban cycle; WLTP class 2 – aggressive highway cycle; NEDC – general test procedure for passenger cars; Indian urban typical urban cycle with frequent stops and starts; Indian highway – steady speed highway simulation. It must be noted that when selecting a battery type for an electric vehicle or hybrid one has to consider not only such parameters as nominal voltage. Energy consumption of an electric car depends on many factors including but not limited to: driving mode, temperature profile within a day, number of passengers traveling in the car etc. The comparison is based on the vehicle speed, vehicle loading, battery SOC, battery voltage degradation, and battery temperature and energy consumption under different driving cycles. From the comparison table it can be concluded that LFP battery performance is good compared to remaining two batteries. The results also show that drive cycle has an effect on the performance of EV batteries. Cost analysis was also carried out for three batteries whereby it was observed that LFP battery is original cost is high but its operating costs are low as opposed to other two batteries.

References

[1]. Yingnan Wang, W. Zhu, U. Schaefer, Study on the real time driving cycles and its influence on design of the electrical motor of EV, in: 2014 IEEE Conference and Expo Transportation Electrification Asia-Pacific (ITEC Asia Pacific), IEEE, 2014, pp. 1–6. S. Chopra and P. Bauer, "Driving Range Extension of EV With On-Road Contactless Power Transfer—A Case Study," in IEEE Transactions on Industrial Electronics, vol. 60, no. 1, pp. 329-338, Jan. 2013, doi:10.1109/TIE.2011.2182015.

[2]. Gebisa A, Gebresenbet G, Gopal R, Nallamothu RB. Driving Cycles for Estimating Vehicle Emission Levels and Energy Consumption. Future Transportation. 2021; 1(3):615-638.

[3]. E. Chemali, M. Preindl, P. Malysz and A. Emadi, "Electrochemical and Electrostatic Energy Storage and Management Systems for Electric Drive Vehicles: State-of-the-Art Review and Future Trends," in IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 4, no. 3, pp. 1117- 1134, Sept.2016.

[4]. A.A. Kebede, T. Coosemans, M. Messagie, T. Jemal, H.A. Behabtu, J. van Mierlo, M. Berecibar, Technoeconomic analysis of lithium-ion and lead- acid batteries in stationary energy storage application, J. Energy Storage. 40 (2021), 102748.

[5]. W.A. Lynch, Z.M. Salameh, Realistic electric vehicle battery evaluation, IEEE Trans. Energy Convers. 12 (1997) 407–412. [6] V. Kulkarni, G. Ghaisas, S. Krishnan, Performance analysis of an integrated battery electric vehicle thermal management, J. Energy Storage. 55 (2022), 105334.

[6]. V. Kulkarni, G. Ghaisas, S. Krishnan, Performance analysis of an integrated battery electric vehicle thermal management, J. Energy Storage. 55 (2022), 105334.

[7]. S. Singirikonda, Y.P. Obulesu, Battery modelling and state of charge estimation methods for energy Management in Electric Vehicle-a review, IOP Conf. Ser.: Mater. Sci. Eng. 937 (2020), 012046.

[8]. S. Singirikonda, Y.P. Obulesu, Advanced SOC and SOH estimation methods for EV batteries—a review, in: Lecture Notes in Electrical Engineering, Springer Science and Business Media Deutschland GmbH, 2021, pp. 1963–1977.

[9]. E. Samadani, M. Mastali, S. Farhad, R.A. Fraser, M. Fowler, Li-ion battery performance and degradation in electric vehicles under different usage scenarios, Int. J. Energy Res. 40 (2016) 379–392.

[10]. S. Singirikonda, Y.P. Obulesu, Battery modelling and state of charge estimation methods for energy Management in Electric Vehicle-a review, IOP Conf. Ser.: Mater. Sci. Eng. 937 (2020), 012046.

[11]. E. Samadani, M. Mastali, S. Farhad, R.A. Fraser, M. Fowler, Li-ion battery performance and degradation in electric vehicles under different usage scenarios, Int. J. Energy Res. 40 (2016) 379– 392.

[12]. J. de Santiago, H. Bernhoff, B. Ekergård, S. Eriksson, S. Ferhatovic, R. Waters, M. Leijon, Electrical motor drivelines in commercial all- electric vehicles: a review, IEEE Trans. Veh. Technol. 61 (2012) 475–484.

[13]. S.P. Nikam, V. Rallabandi, B.G. Fernandes, A high-torque-density permanent magnet free motor for in-wheel electric vehicle application, IEEE Trans. Ind. Appl. 48 (2012) 2287–2295.

[14]. Z. Gao, T. LaClair, S. Ou, S. Huff, G. Wu, P. Hao, K. Boriboonsomsin, M. Barth, Evaluation of electric vehicle component performance over eco- driving cycles, Energy 172 (2019) 823–839.