Journal of Engineering and Sustainable Development
http://jeasd.uomustansiriyah.edu.iq/index.php
https://doi.org/10.31272/jeasd.25.6.2

Vol. 25, No. 06, November 2021
ISSN 2520-0917

PERFORMANCE EVALUATION OF THREE-PHASE INDUCTION MOTOR DRIVING AN ELECTRIC VEHICLE UNDER DIFFERENT ROAD CONDITIONS

***Raad M. Hadboul[1]** **Amer M. Ali[1]**

1) Electrical Engineering Department, College of Engineering, Mustansiriyah University, Baghdad, Iraq

Received 22/2/2021 ***Accepted in revised form 3/6/2021*** ***Published 1/11/2021***

Abstract: Electric vehicles (EV) has been introduced as an alternative to the conventional vehicle as a mid-range vehicle to the world due to environmental considerations and technology development. Many electric motors can be used as the main driver of electric vehicles. Induction Motor (IM) is one of these types. This search uses MatLab/Simulink program for modeling and simulating MITSUBISHI I-MIEV type vehicle as a model of city vehicle based on an IM as the main engine. Four cases were studied by simulating a complete (EV + IM) model with different slopes of road, wind speeds, different road types, and different speeds of vehicle. Simulation tests indicate the IM's ability to drive the electric vehicle in high stability. Thus the specifications of EV depend upon the specifications of IM used as the main drive for EV and mechanical components for EV

Keywords: *Three-phase induction motor, Electric vehicles, Mat lab/Simulink, Road Conditions.*

1. Introduction

The rapid development in electric power, control technology, and micro electricity led to rapid development in the electric vehicle. Hence, the interest in electric vehicles increases as an alternative to the traditional vehicle. Undoubtedly, these vehicles will be part of the main means of transport in the future. The mini electric vehicle has a compact size, no pollution, strength, comfort, and noise. The promotion of small EVs is still difficult because of their high price compared with a conventional vehicles. EV performance can not be compared with conventional vehicles due to its technical restrictions in the industry for comparison long-distance trips and an instance[1]. Many types of research cover the performance of IM as the main drive for the electrical vehicle as in[2-3-4-5]. This work aims to study the performance of IM used as the main drive for electrical vehicles of MITSUBISHI I-MIEV under the influence loads represented like different slopes of road, different vehicle speeds, wind speeds, and different types of roads that upon. Vehicle specifications like dimensions of the vehicle, tire dimensions, gearbox ratio are considered in the model (IM+EV). This work contributed to EV loads calculating based on motion equations applied in EV and effected on IM as the main motor in EV to determine the vehicle's specifications and safe driving in the city.

2. Mathematical Background

The dynamic of the vehicle is necessary to identify the tractive force as the required load on

**Corresponding Author*: raadsama1973@gmail.com

the EV in different road conditions .To determine the vehicle's performance, vehicle dynamics must be considered because the speed of EV depends upon the balance between the motive forces generated by the electric motor and running resistive forces [5]. Figure(1) shows the dynamic equation of a vehicle moving along the longitudinal direction on the road, which is used for modeling the motion of the vehicle's body as all forces on the vehicle are considered [6].

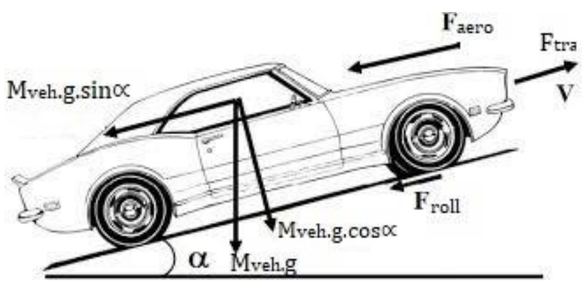

Figure 1. Acting Force on Vehicle

2.1. Dynamic Equation of Load on EV

There are several forces of resistance during the driving of vehicles. These forces are described in the equations below. The equations consider the characteristics of the vehicle. This paper uses MITSUBISHI I-MIEV as a model to calculate the forces acting on the vehicle. The model is shown in Table (1). [6].

$$F_{tra} = F_{gra} + F_{aero} + F_{roll} + F_{acc}, [2] \quad (1)$$

$$F_{gra} = M_{veh} \cdot g \cdot \sin\alpha \quad (2)$$

$$F_{aero} = 0.5\, \rho\, C_d\, S_f\, v_{veh}^2 \quad (3)$$

$$F_{rolling} = M_{veh}\, g\, V_f\, \cos\alpha \quad (4)$$

$$F_{acc} = M_{veh} \times \frac{dv}{dt} \quad (5)$$

At steady state (reach to required speed)for EV. F_{acc} is zero thus F_{tra} will be

$$F_{tra} = F_{aero} + F_{roll} + F_{gra} \quad (6)$$

Faero – gravity force which depends on the angle of the road at uphill driving

Froll – rolling force, which depends on a rolling resistance between wheels and type of roads.as shown in table (2) [7]

Faero – aerodynamic force which depends on an air resistance of the car

F_{acc} – acceleration force

The relation between gear ratio (G), wheel angular

speed (ωw) and angular motor seed (ωm) is given as:

$$\omega m = G \times \omega_W [8] \quad (8)$$

And the torque (Tm) at the motor shaft is given as:

$$T_m = T_w / G [9] \quad (7)$$

Table 1. The Specifications of EV[8]

Parameter	Value	Parameter	Value
Power Rate	35k W	Max power	49kw
Max. speed	130 km/hr	Max torque	196 Nm
Type of Battery	Lithium-ion	Battery voltage	330 V
weight of Vehicle	1450 Kg	Wheel diameter	762 mm
Battery Energy	16 kWh	Transmission	Auto Gear

Table 2. The Road Resistance for different types of road[14]

Tire type	Concrete	Medium-hard soil	Sand
Passenger car	0.015	0.08	0.30
Truck	0.010	0.06	0.25
Tractor	0.020	0.04	0.20

2.2. Mathematical Formals for IM and FOC

The use of the IM as the main mover in the electric vehicle should give high speeds at low torque while giving high torque only at low speeds. The vector field can obtain this requirement using the IM, as the main mover in the electric vehicle by applying an effective field-oriented control (FOC) algorithm to control the speed of an induction motor; thus, IM and FOC are essential in the EV applications. The vector control can obtain this requirement to meet the requirements of urban driving. The equations below describe how FOC is used in the modeling by Mat lab/Simulink based on the specifications of the inductive motor used in the electric vehicle, as shown in table no(3)and Park and Clark transformation [10].

$$\theta = \int W_m + W_r \quad (6)$$

$$W_r = \frac{L_m \times I_q}{T_r \times \Psi^*} \quad (7)$$

$$L_r = \grave{L}_{lr} + L_m \quad (8)$$

$$T_r = \frac{L_r}{R_r} \quad (9)$$

$$I_q = \frac{2}{3} \times \frac{2}{p} \times \frac{L_r}{L_m} \times \frac{T_e}{\Psi^*} \quad (10)$$

$$\Psi^* = \frac{L_m \times I_d}{(1 + T_r \times s)} \quad (11)$$

$$V_s = V_a + V_b \times e^{j\frac{2\pi}{3}} + V_c \times e^{j\frac{2\pi}{3}} \quad (12)$$

Or can be represented as

$$V_s = V_d + jV_q \quad (13)$$

$$\Theta = \tan^{-1}\left(\frac{V_q}{V_d}\right) \quad (15)$$

Where

V_s is space vector filed

3. Modeling of EV

Figure (2) shows the modeling of dynamic loads in MAT LAP/Simulating.

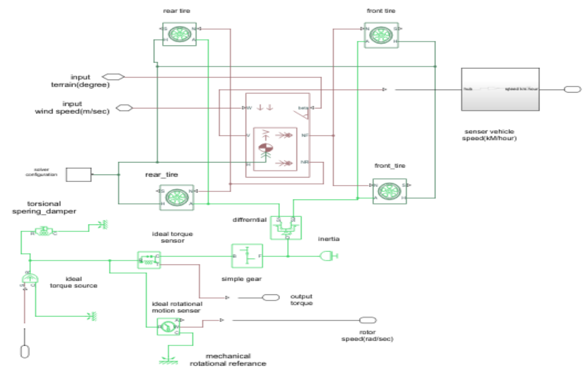

Figure 2. Dynamic Loads in Matlab/Simulink for EV

4. Modeling of Gearbox

We select a single-stage transmission with a fixed gear ratio to fulfill all requests with low cost, low speed, and simplicity for the entire driving system in EV, as shown in figure (3). It is an adequate solution for this kind of city electric car [11].

Table 3. The IM Specifications[8]

Parameter	Value	Parameter	Value
Power Rate	35×10^3 Watt	Inductance of Rotor	0.8×10^{-3} Henry
Voltage	460 Voltage	Mutual inductance	34.7×10^{-3}Henry
Frequency	60 Harts	Moment of inertia	1.662 kg. m^2
Resistance of Stator	87×10^{-3} Ohm	Pair Poles Number	2
Resistance of Rotor	228×10^{-3}Ohm	Type of motor	Squirrel cage
Inductance of Stator	0.8×10^{-3} Henry	Coefficient of Friction	10×10^{-3}

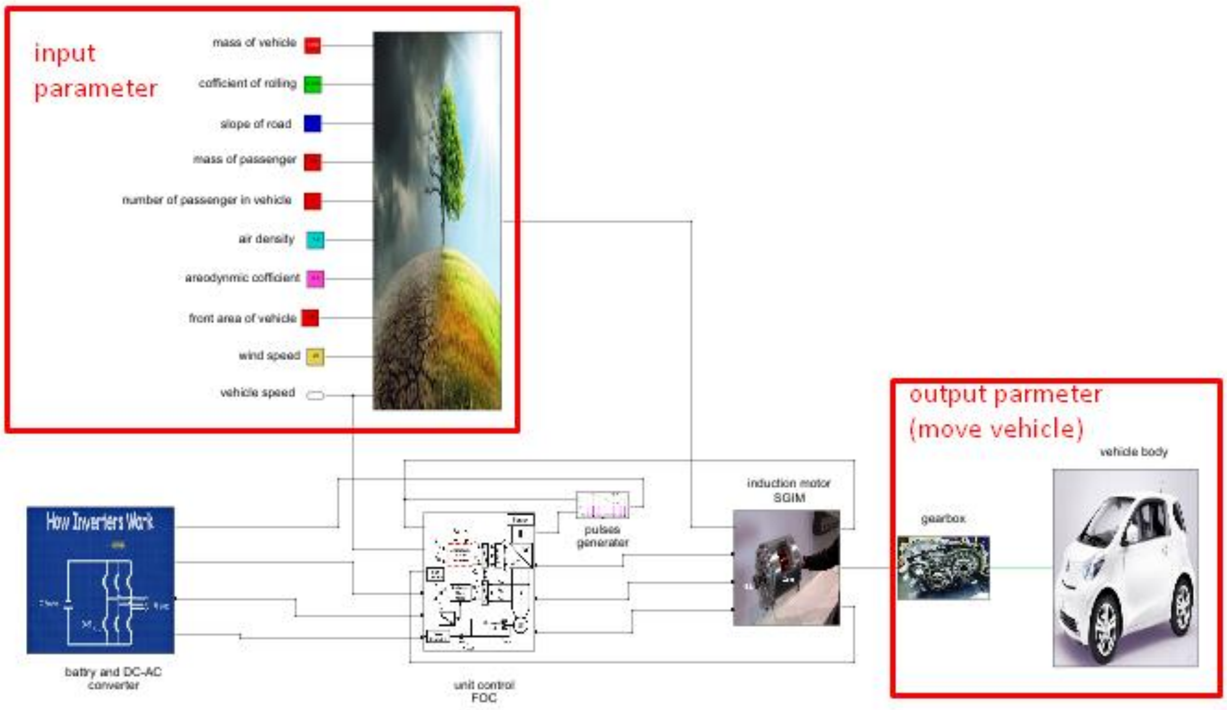

Figure 3. Complete EV Model with gearbox

5. Modeling DC/AC Inverter and FOC

EV uses the battery as the input voltage to the inverter, and the output AC voltage of the inverter is given to IM. The FOC technique generates the signals to lead the inverter switches using the Space Vector Pulse Width Modulation (SVPWM) technique, as shown in figure (4)[12]. In the FOC motor drive system, the rotor flux and torque are separated to get the high dynamic performance of the torque and speed for both transient and steady-state conditions in driving IM.

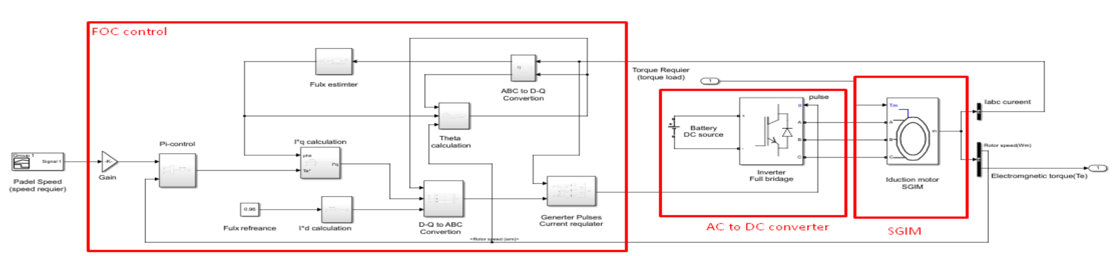

Figure 4. DC/AC Converter and FOC Control

6. The Case Studies:

Four cases were adopted in the complete EV model with the gearbox to assess the performance of IM used as the main drive in EV as blow:

6.1. Case (1)

In this case, the induction motor operating in the EV for 15 seconds with different loads represented by changing the slope of the road from 5 degrees to 30 degrees with(1)passenger, wind speed=0, vehicle speed =80 km/h, and type of road is concrete.

6.2. Case (2)

In this case, the IM operated in the EV for 15 seconds with different loads represented by changing vehicle speed with one passenger that's mean we change the speed for EV from 10 km/h to 110 km/h, wind speed =0, the slope of road =0 and type of road is concrete.

6.3. Case (3)

In this case, the IM operates in EV for 15 seconds at different loads represented by changing wind speed from 0 to 25 m/s, road slope=0, vehicle speed =80 km/h for one passenger, and road type is concrete.

6.4. Case (4)

In this case, the IM operates in an electric vehicle for 15 seconds with different loads represented by changing the type of road with one passenger, vehicle speed = 80 km/hr, wind speed = 0, and slope of road=0.

7. Results and discussion:

Depending on the table(8) that show the rated current and rated torque allowed for the motor to work in EV and comparing them with results of studied cases, in this way we can determine the boundaries for safe driving in the model of EV studied in this research applied the city as shown below[7]:-

7.1. Case (1)

Table 4 shows the simulation results for case 1. The IM draws a current that depends on the change of road slope until EV reaches the maximum slope for road represented by the highest current value of the rated current or rated torque of the IM. We can determine the maximum slope of the road which EV can climb is(15degree).

Table 4. **Results of Case 1**

Slope of Road	$F_{tractiv}$ (N)	EV_{Torque} (N.M)	IM_{Torque} (N.M)	IM_{speed} (RPM)	$\boldsymbol{IM_{current}}$ (A)
5	3260	1369.76	97.84	3819	38.66
10	4556	1919.4	137.1	3439	48.86
15	5830	6.2459.8	186.4	3083	56.88
20	7073	2987.6	214.8	2775	64.0
25	8275	3497.2	253.6	2529	69.83
30	9428	3985.8	287.3	2346	76.18

7.2. Case (2)

Table (5) shows the simulation results for the second Case. We saw the induction motor draws different currents according to the change in the vehicle speed until EV reaches the maximum speed represented by the highest value of the rated current of the IM.

Table 5. Result of Case (2)

Vehicle speed (km/h)	$F_{tractav}$ **(N)**	EV_{Torque} **(N.M)**	IM_{Torque} **(N.M)**	IM_{speed} **(RPM)**	$IM_{current}$ **(A)**
10	252.1	93.49	6.71	976	19.637
20	33.1	128.1	9.15	1962	20.598
30	468.1	185.36	13.24	2930	25.4961
40	657.1	265.3	18.95	3974	28.1428
50	900.1	3682	26.285	4643	34.195
60	1197	493.99	35.285	4400	36.083
70	1548	642.46	45.89	4303	37.823
80	1953	814.03	58.145	4192	41.79
90	2412	1008.336	72.024	4045	49.27
100	2925	1225	87.5	3950	63.639
110	3492	1465.52	104.68	3525	65.05

7.3. Case (3)

Table (6) shows the simulation results for case (3), in which the results of simulation showed that the induction motor used in the EV draws a current that depending on the change in wind speed until IM reaches the rated value of the current or rated value of torque that's refer to the highest value of wind speed can EV afford it thus we can determine the maximum speed of wind for driving which EV can afford is (15-20) m/sec.

Table 6. Result of Case (3)

Speed Wind (m/sec)	$F_{tractive}$ (N)	EV_{Torque} (N.M)	IM_{Torque} (N.M)	IM_{speed} (RPM)	$IM_{current}$ (A)
0	1953	815.4	58.24	4212	33.63
5	2818	1182	84.44	3946	44.44
10	3858	1623	115.9	3642	45.56
15	5073	2138	152.7	3291	54.55
20	6463	2728	194.8	2920	58.01
25	8028	3391	242.2	2575	70.71

7.4. Case (4)

Table (7) shows the simulation results for case(4) in which the IM draws different current values depending on the type of road users; thus, we can drive EV on any type of road without any problem.

Table 7. Results of Case (4)

Type of road	$F_{tractive}$ (N)	EV_{Torque} (N.M)	IM_{Torque} (N.M)	IM_{speed} (RPM)	$IM_{current}$ (A)
0.015	1953	828.1	59.15	4201	26.91
0.08	2929	1242	88.7	3913	47.43
0.3	6231	2642	188.7	2972	68.66

Table 8.The maximum and rated power, torque and the current of IM[7]

Max power (kW)	Rated power (kW)	Max Torque (N.M)	Rated Torque (N.M)	Max current (A)	Rated current (A)
49	35	196	187.7	77	55

8. Conclusion

The simulation results and the studied cases show that road conditions (road inclination), wind speed, and vehicle speed specified by the driver are loads that the vehicle's propulsion engine (IM) must overcome until the vehicle moves as it generates forces and torque greater than the maximum torque of the propulsion engine without the gearbox. The gearbox in the electric vehicle is necessary to overcome these loads with the size of the propulsion engine to be suitable for placing inside the vehicle. The type of roads have no effect on the performance of the induction motor as shown in the fourth case for driving EV in city.

Acknowledgment

The authors would like to acknowledge the Department of Electrical Engineering, College of Engineering, Mustansiriyah University for their encouragement and support.

Conflict of Interest

The authors confirm that the publication of this article causes no conflict of interest.

Abbreviations

List of symbols used in the equations above.

α	road slope angle
ρ	density of air
S_f	the effective frontal area of the vehicle
C_d	coefficient of aerodynamic drag
M_{veh}	total mass for vehicle and passengers
v_{veh}	speed of vehicle
V_f	rolling resistance for road
Ө	electrical angle
Ψ^*	rotor flux motor
L_m	mutual inductance for motor
L_r	The sum of the rotor and mutual inductance.
L_{lr}	rotor inductance
R_r	Resistance of Rotor
W_r	mechanical speed for rotor

W_m mechanical speed for motor
T_e produced torque in motor
P number of poles in the motor
V_a voltage in phase a
V_b voltage in phase b
V_c voltage in phase c
V_q voltage in quadric-axis
V_d voltage in direct-axis
T_r time response
I_d current in direct-axis
I_q current in quadric- axis
EV_{torque} required torque to move the EV
IM_{torque} produced torque by motor
IM_{speed} speed induction motor
$IM_{current}$ current induction motor

9. References

1. Prochazka, P., Pazdera, I., Cipin, R., & Hadas, Z. (2015). "*Optimal Design Techniques for Small Electric Car Operating in Common Urban Traffic*". Przegląd Elektrotechniczny, 91(05). ..
2. Tabbache, B., Kheloui, A., & Benbouzid, M. E. H. (2010, September). "*Design and control of the induction motor propulsion of an electric vehicle*." In 2010 IEEE Vehicle Power and Propulsion Conference (pp. 1-6). IEEE
3. Maher, R. A., Emar, W., & Awad, M. (2012*)." Indirect field-oriented control of an induction motor sensing DC-link current with PI controller*." International Journal of Control Science and Engineering, 2(3), 19-25.
4. Cossar, C., & Rezaei, N. (2017, September)." *The application of average voltage estimation models in simulation of permanent magnet AC electric motor and generator drive systems*." In 2017 New Generation of CAS (NGCAS) (pp. 237-240). IEEE
5. Benbouzid, M. E. H., Diallo, D., & Zeraoulia, M. (2007*)." Advanced fault-tolerant control of induction-motor drives for EV/HEV traction applications: From conventional to modern and intelligent control techniques*". IEEE transactions on vehicular technology, 56(2), 519-528
6. Nise, N. S. (2011). "*Control system engineering*," John Wiley & Sons. Inc, New York.
7. Melnik, R. V., Song, N., & Sandholdt, P. (2002). Dynamics of torque-speed profiles for electric vehicles and nonlinear models based on differential-algebraic equations.
8. Rezaei, N., & Mehran, K. (2019, June). "*Dynamic Modelling and Performance Assessment of a Single Battery Electric Vehicle Powertrain System Employing an Induction Motor*." In 2019 20th Workshop on Control and Modeling for Power Electronics (COMPEL) (pp. 1-8). IEEE.
9. Lulhe, A. M., & Date, T. N. (2015, December). A design & MATLAB simulation of motor drive used for electric vehicle. In 2015 International Conference on Control, Instrumentation, Communication and Computational Technologies (ICCICCT) (pp. 739-743). IEEE.
10. Wong, J. Y. (1997). "*Dynamics of tracked vehicles. Vehicle system dynamics*", 28(2-3), 197-219.
11. Goyat, S., & Ahuja, R. K. (2012). "*Speed control of induction motor using vector or field-oriented control*." International Journal of Advances in Engineering & Technology, 4(1), 475.
12. Rahman, K. M., & Ehsani, M. (1996, October). Performance analysis of electric motor drives for electric and hybrid electric vehicle applications. In Power Electronics in Transportation

13. Ulu, C., Korman, O., & Kömürgöz, G. (2017, July). Electromagnetic and thermal analysis/design of an induction motor for electric vehicles. In 2017 8th International Conference on Mechanical and Aerospace Engineering (ICMAE) (pp. 6-10). IEEE. (pp. 49-56). IEEE.
14. WICAKSANA, Y., & HERMAWAN, F. ROLLING RESISTANCE STUDY OF GRAVELLY SAND MATERIAL ON LABORATORY SCALE.