Modeling, Simulation and Analysis of Electric Vehicle Driven by Induction Motor

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Abstract. The electric vehicle (EV) was spread around the world due to the environmental considerations. Induction motor (IM) is one type of electric motors used as main drive for EV. The present work uses Matlab/Simulink for modeling and simulation of MITSUBISHI I-MIEV model city car. Three case studies were taken in the simulation of complete (EV+IM) model with different loads and speeds. The simulation tests indicate the ability of IM in driving the EV with high stability in different motion mode.

1-Introduction
The interest in electric vehicles grew out of the environmental concerns, energy problems, the depletion of fossil fuels and high fuel prices [1]. Air pollution and loud noise are caused by the use of internal combustion engines (ICE), which affect human health and leading to air pollution. Therefore, major international companies turned to manufacture EV such as the Chevrolet Volt, Toyota RAV4 EV, Tesla Model S and Renault Twizy [2]. The period 2010-2020 has been described as the 'tipping point' in manufacturing vehicles from ICE to electric propulsion system [3]. Electric vehicles include four systems: the battery, the traction motor, the motor driver and the unit of control. The types of traction motors used in electric vehicles are the brushless permanent magnet motor [2][4] the squirrel cage induction motor [5][6] and the switch reluctance motor [7]. The most popular types of propulsion machines used in commercial electric vehicles are the induction motors (IM) and the permanent magnet (PM) motors. IM's outstanding features make it a favorable option for EV which are higher performance, strong field weakening features, robustness, low cost, and ease of control (PMs don’t have these features) [8]. Many researches search the performance of IM as main drive for electrical vehicle as in [9-10-11-12]. The aim of this work is studying the performance of IM used as main drive for electrical vehicle of MITSUBISHI I-MIEV with different number of passengers and speeds. The loads are: the effected forces upon the vehicle, conditions of the road, and vehicle specifications like vehicle dimensions, tire dimensions, gear ratio are handled by (IM+EV). This work contributed in EV loads calculating based on motion equations with different number of passengers which applied in EV model, and made a connection between the mechanical and electrical sub models of EV to have the results from both IM and EV at the same time.
2-Performance Analysis of Induction Motor Used In EV
IM is used in the drive cycle of EV not operate in maximum torque, it operates at more and less than maximum torque for a moment of total time.

2-1- FOC Control (Vector Control)
Significant development has been happened in electrical drives [13] because of the ability of multiple using of semiconductors in power and signal electronics [14]. These technologies are used very efficient AC drive controls. By using three-phase current and voltage, the electrical drive controllers are become more dependable when Field Oriented Control (FOC) is used. When FOC is applied to an AC machine, the AC machine can be controlled like DC machine. Thus, the AC machine could be suitable when applied in electric vehicle as a main drive. The FOC in the control unit provides IM with an adequate frequency and voltage to achieve the required speed and torque by v/f speed control method. Therefore, the consumption of energy from the battery will be lesser, and that will be increase the distance range of EV.

2-2- Dynamic Model of EV
The proper model of powertrain and vehicle dynamic is required to determine the tractive force as demanded load on the EV in the road conditions. The performance of the vehicle can be determined by the vehicle dynamics, since the speed of EV require a balance between the motive force resulting from an induction motor and the vehicle dynamic forces. The dynamic equations were described in the dynamic model of EV.

3 - Mathematical Analysis of EV
The following steps and equations were used to build the FOC for induction motor speed control and for calculating required torque and loads of EV depending on the theory of motion.

3-1 Steps to implement FOC in MatLab/Simulink.
1. Measurement the currents of the stator phase $i_a, i_b, i_c$.
2. Using Park Transformation to transform $i_a, i_b, i_c$, into id and iq components of the rotor flux rotating field [15].
3. Using Inverse Park Transformation to convert $i^*_d$ and $i^*_q$ of the rotor flux rotating field reference frame into $i^*_a, i^*_b$ and $i^*_c$ variables, where $(i^*)$ means the required calculated current.
4. Calculating the rotor flux with its direction.
5. Calculating the $i^*_q$ from torque reference and $i^*_d$ from flux reference.
6. Calculating the rotor flux phase angle
7. Using the current regulator to get the pulse required for inverter by compare $i^*_a, i^*_b$ and $i^*_c$ with $i_a, i_b$ and $i_c$
8. Calculating the $T^*_e$ from required speed and speed reference.
3-2- Steps of calculating the required load of motor
1. Calculating the speed of vehicle.
2. Calculating the aerodynamic force upon vehicle.
3. Calculating the rolling force upon vehicle.
4. Assuming the slope is zero and the ratio of gear box for vehicle is 4.
5. Assuming the efficiency of gear box is 90% for vehicle.
6. Calculating the tractive force.
7. Calculating the torque required for tractive vehicle.
8. Calculating the mechanical output torque produced by motor.
9. Comparing between the torque produced by motor and required torque.
10. Repeat the steps (2,3) when study the change number of passengers.

3-3- Equations for EV loads
\[ F_t = F_g + F_{ady} + F_{roll} + F_{acc} \] [2]
\[ F_t = M_{veh} \cdot g \cdot \sin \alpha + \frac{1}{2} \cdot \rho \cdot C_d \cdot S_f \cdot v_{veh}^2 + M_{veh} \cdot g \cdot V_f \cdot \cos \alpha + M_{veh} \frac{dv_{veh}}{dt} \] (2)
\[ T_t = \frac{R_w}{K_g \cdot \gamma} F_t \] (3)
\[ v_{veh} = \omega_m \cdot \frac{\pi \cdot R_w}{30 \cdot \gamma} \] (4)
\[ P_m = T_m \cdot \omega_m \] (5)
\[ F_t = F_{ady} + F_{roll} \] (6)

Where:
- \( F_t \) is the front and rear tires traction force (N).
- \( F_{roll} \) is the resistance (rolling friction) (N).
- \( F_g \) is the gravity of force when driving on winding roads or (non-horizontal roads) (N).
- \( F_{acc} \) is the vehicle linear acceleration along the way (m/s^2)
- \( F_{ady} \) is the force of aerodynamic drag (N)
- \( M_{veh} \) is mass vehicle (Kg)
- \( g \) is gravity coefficient
- \( \alpha \) is degree of slope road (degree).
- \( \rho \) is the air density (kg.m^3).
- \( S_f \) is the frontal area of the vehicle (m^2)
- \( C_d \) is the coefficient of aerodynamic drag.
$V$ is the vehicle speed (m/s$^2$).

$V_f$ is rolling resistance of road.

$R_w$ is wheel radius (m).

$T_t$ is total tractive torque on the motor side (N).

### 4- EV modeling by MATLAB/Simulink

Table 1 shows the specifications of the induction motor used as the main drive in EV of this work, and figure 1 illustrates the MATLAB/Simulink model with FOC.

#### Table 1. IM Specifications

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

![Figure 1. IM model with FOC](image)

Table 2 and Figure 2 show the specifications and the MATLAB/Simulink model of EV.
Table 2. Specifications of EV

| Parameter            | Value       | Parameter            | Value       |
|----------------------|-------------|----------------------|-------------|
| Power Rate           | 35000 W     | Max power            | 49000 W     |
| Max. speed           | 130 km/h    | Max torque           | 196 Nm      |
| Type of Battery      | Lithium-ion | Battery voltage      | 330 V       |
| weight of Vehicle    | 1450 Kg     | Wheel diameter       | 762 mm      |
| Battery Energy       | 16000 Wh    | Transmission         | Auto Gear   |

Figure 2. Dynamic Model of EV

The complete simulation model of electric vehicle by MATLAB/Simulink is illustrated in Figure 3.
5- Case Studies
Three case studies were adopted in the complete EV model to assess the performance of IM as follows:
Case (1): in this case study the load of one and four passengers with different motor speeds were adopted on the EV model.
Case (2): in this case study the speed is constant and variable loads were adopted on the EV model.
Case (3): in this case study a sudden change in motor speed with constant load adopted on the EV model.
Table 3 shows the effect of changing the number of passengers on EV rolling force, tractive force, and required torque of the motor.

Table 3. Motor loads

| No. of passenger | Rolling Force | Tractive force | Torque require |
|------------------|---------------|----------------|----------------|
| 1                | 194 (N)       | 1334 (N)       | 141.1 (N.m)    |
| 2                | 205 (N)       | 1345 (N)       | 142.3 (N.m)    |
| 3                | 215 (N)       | 1355 (N)       | 143.4 (N.m)    |
| 4                | 225 (N)       | 1365 (N)       | 144.4 (N.m)    |

6- Results and discussions
Table 4 and Figure 4 show the simulation results of Case 1, in which the induction motor operated for 4 seconds with dynamic vehicle model at different loads (1 and 4 passengers) with four variable speed regions. The simulation results showed the induction motor reached the target speed with different times depending on the EV load value, and do not exceed the maximum mechanical torque and rated current of it, and that gave an indication about the induction motor is operate at constant torque operation.
Table 4. Results of Case study (1)

| Motor Speed region(rpm) | Starting Current(A) | Rated Current(A) | Time Of Reaching Stability(sec) | Speed Vehicle(Km/h) |
|-------------------------|---------------------|------------------|--------------------------------|---------------------|
|                         | One Passenger       | four Passengers  | One Passenger                   | four Passengers     | One Passenger       | four Passengers     |
| 0-1780                  | 108.7               | 110.5            | 598.7                          | 61.4                | 2.015               | 2.05               | 32.9               | 32.7               |
| 0-1350                  | 108.75              | 111.29           | 60.32                          | 63.3                | 1.516               | 1.55               | 29.2               | 28.7               |
| 0-900                   | 111.2               | 111.3            | 61.2                           | 64.4                | 1                   | 1.022              | 26.3               | 25.8               |
| 0-450                   | 111.44              | 117.9            | 63.9                           | 64.8                | 0.504               | 0.509              | 23.4               | 22.9               |

Figure 4. The Behavior of IM in Speed Reaching Time, Torque and Current for One Passenger at Speed Region (0-1780) rpm

Figure 5 showed the simulation results of Case 2, in which the induction motor operated for 4 sec with dynamic vehicle model at constant (900 rpm) with variable loads refer to virtual change in number of passengers. In sec (1,3) the load refers to one passenger in addition to vehicle weight, and in sec (2,4) the load refers to four passengers in addition to vehicle weight. The simulation results showed the induction motor operates with high stability, so it’s can be considered as good option to drive EV.
Figure 6 showed the simulation results of case 2, in which the induction motor operated at sudden change in EV pedal speed with constant load (four passengers) for 4 sec with dynamic vehicle model. In sec (1) pedal speed is 89% of motor speed, in sec (2) the pedal speed is 50% of motor speed, in sec (3) the pedal speed is 100% of motor speed, and in sec (4) the pedal speed is -50% of motor speed. According to this case, the EV acceleration, cruising, deceleration, braking and opposite direction motion will be simulated for EV. At the interval of (3-4) sec the motor shaft speed decreases and the IM will rotate in opposite direction and works in the regenerative braking region with negative torque, and will generate an electrical power which supplied to the EV battery.
Figure 6. The Behavior of IM for Torque, Current and Motor Shaft Speed with Changes in Pedal Speeds

7-Conclusion:
The modeling of electric vehicle (EV) drivers by induction motor (IM) was done successfully using Matlab/Simulink according to the (EV) and IM specifications. The dynamic model of EV includes all vehicle mechanical consideration and IM model includes FOC control. Three cases studies were taken in the complete (EV+IM) model to assess the performance of IM with different EV loads (number of passengers) and speeds. The simulation results show the ability of IM in driving the EV with high stability in cruising, accelerating, deceleration and reverse motion mode.

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