OPTIMIZATION OF MOTOR AND CONTROLLER FOR ELECTRIC VEHICLES

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Abstract

The performance, efficiency, driving range, and reliability of an electric vehicle (EV) strongly depend on the selection and control of its electric motor and motor controller. This project presents the modeling, analysis, and optimization of an electric motor and controller for EV applications. A representative permanent magnet synchronous motor (PMSM) drive system is developed using MATLAB/Simulink. The model includes the battery, inverter, motor, vehicle dynamics, accelerator command, and motor-control system. Motor parameters such as rated power, torque, speed, current, and efficiency are evaluated under different operating conditions. Controller parameters are optimized to improve torque response, reduce current ripple, minimize speed error, and improve overall drive efficiency. Representative simulation results demonstrate improved speed tracking, torque response, and energy efficiency after optimization. The proposed system provides a suitable platform for developing efficient and high-performance electric-vehicle powertrains.

Keywords: Electric Vehicle, PMSM, Motor Optimization, Motor Controller, MATLAB/Simulink, Field-Oriented Control, Inverter, Torque, Efficiency, Regenerative Braking.

1. INTRODUCTION

Electric vehicles are becoming an important alternative to conventional internal-combustion-engine vehicles because of their high energy efficiency, low operating emissions, and improved controllability. The electric motor and its controller are two of the most important components of an EV powertrain.

The motor converts electrical energy from the battery into mechanical energy for vehicle propulsion. The controller determines how electrical power is delivered to the motor according to vehicle speed, torque demand, accelerator position, and operating conditions.

An improperly selected motor can result in excessive battery consumption, insufficient acceleration, overheating, and poor vehicle range. Similarly, an improperly tuned controller can cause torque oscillations, slow speed response, high current demand, and reduced efficiency.

Therefore, optimization of both the motor and controller is essential for achieving high-performance EV operation.

2. OBJECTIVES

The main objectives of this project are:

1. To model an electric motor suitable for EV applications.
2. To develop a motor-controller model using MATLAB/Simulink.
3. To analyze motor torque and speed characteristics.
4. To optimize motor operating parameters.
5. To optimize controller gains.
6. To improve speed tracking performance.
7. To reduce torque ripple and current fluctuations.
8. To improve motor efficiency.
9. To reduce battery power consumption.
10. To evaluate regenerative-braking performance.
11. To compare the motor and controller before and after optimization.

3. PROPOSED EV POWERTRAIN

The proposed EV powertrain consists of:

- Battery pack
- DC-link capacitor
- Three-phase inverter
- PMSM motor
- Field-Oriented Control (FOC)
- Speed controller
- Current controllers
- Vehicle/load model
- Regenerative-braking subsystem

System Flow

Battery Pack

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DC Link

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Three-Phase Inverter

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PMSM Motor

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Gearbox / Transmission

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Vehicle Wheels

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Vehicle Motion

The vehicle speed is fed back to the controller to regulate motor torque and speed.

4. MOTOR SELECTION

Several motors are commonly considered for EV applications:

Motor Type	**Efficiency**	**Torque Density**	**Control Complexity**	**EV Suitability**
DC Motor	Moderate	Moderate	Low	Moderate
Induction Motor	High	Moderate	Moderate	High
BLDC Motor	High	High	Moderate	High
PMSM	Very High	High	High	Very High
SRM	High	High	High	High

For the proposed study, a **Permanent Magnet Synchronous Motor (PMSM)** is selected because of its high efficiency, high torque density, compact size, and suitability for variable-speed EV operation.

5. REPRESENTATIVE MOTOR PARAMETERS

Parameter	**Initial Design**	**Optimized Design**
Motor type	PMSM	PMSM
Rated power	50 kW	50 kW
Rated voltage	300 V	300 V
Maximum speed	6000 rpm	6500 rpm
Rated torque	80 Nm	85 Nm
Peak torque	160 Nm	175 Nm
Pole pairs	4	4
DC-link voltage	300 V	300 V
Maximum phase current	180 A	170 A
Target efficiency	91%	94%

These values are representative simulation parameters and should be replaced with actual motor datasheet or experimental parameters for a final project.

6. MATHEMATICAL MODEL OF PMSM

The PMSM can be represented in the rotating d-q reference frame.

The d-axis voltage equation is:

$$V_d = R_s I_d + L_d(dI_d/dt) - \omega_e L_q I_q$$

The q-axis voltage equation is:

$$V_q = R_s I_q + L_q(dI_q/dt) + \omega_e(L_d I_d + \psi_f)$$

where:

- V_d, V_q = d-q axis voltages
- I_d, I_q = d-q axis currents
- R_s = stator resistance
- L_d, L_q = d-q axis inductances
- ω_e = electrical angular speed
- ψ_f = permanent-magnet flux linkage

Electromagnetic torque is approximately:

$$T_e = 3/2 \times p\,[\psi_f I_q + (L_d - L_q) I_d I_q]$$

where **p** is the number of pole pairs.

7. MOTOR CONTROL STRATEGY

Field-Oriented Control is used for the proposed PMSM drive.

The controller consists of:

1. Speed reference
2. Speed-error calculation
3. PI speed controller
4. d-axis current reference
5. q-axis current reference
6. Current PI controllers
7. d-q to abc transformation
8. PWM generation
9. Three-phase inverter

Control Flow

Speed Reference

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Speed Controller

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Torque Reference

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d-q Current Reference

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Current Controllers

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PWM Generator

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Inverter

↓

PMSM

↓

Vehicle

↓

Speed Feedback

8. CONTROLLER OPTIMIZATION

The controller is optimized to achieve:

- Fast speed response
- Low overshoot
- Small steady-state error
- Low torque ripple
- Reduced current oscillation
- Improved efficiency
- Better regenerative-braking response

The PI controller is represented as:

$$\mathbf{u(t) = K_p\, e(t) + K_i \int e(t)dt}$$

where:

- Kp = proportional gain
- Ki = integral gain
- e(t) = speed or current error

Representative controller parameters:

Controller	Initial Kp	Initial Ki	Optimized Kp	O K
Speed PI	0.8	20	1.2	28
d-axis current PI	0.4	80	0.55	10
q-axis current PI	0.4	80	0.55	10

The optimized gains are representative simulation values and require tuning according to the actual motor, inverter, sampling time, and control architecture.

9. OPTIMIZATION OBJECTIVE

The optimization can be formulated using a weighted performance function:

$$\mathbf{J = w_1 e\_speed + w_2 T\_ripple + w_3 I\_rms + w_4 P\_loss}$$

where:

- e_speed = speed-tracking error
- T_ripple = torque ripple
- I_rms = RMS motor current
- P_loss = power loss
- w_1–w_4 = weighting factors

The objective is to minimize **J** while satisfying motor current, voltage, thermal, and speed constraints.

Optimization techniques that can be used include:

- Genetic Algorithm
- Particle Swarm Optimization
- Grey Wolf Optimization
- Response Surface Methodology
- MATLAB Optimization Toolbox
- Manual PI tuning

10. VEHICLE MODEL

The motor output torque is converted into vehicle tractive force through the transmission.

The approximate vehicle force is:

$$F_{tractive} = (T_m \times G \times \eta_t) / R_w$$

where:

- T_m = motor torque
- G = gear ratio
- η_t = transmission efficiency
- R_w = wheel radius

The vehicle resistance consists of:

- Rolling resistance
- Aerodynamic drag
- Road gradient
- Acceleration resistance

Total resistance can be represented as:

$$F_{total} = F_{rolling} + F_{aero} + F_{gradient} + F_{acceleration}$$

11. REPRESENTATIVE VEHICLE PARAMETERS

Parameter	Value
Vehicle mass	1500 kg
Wheel radius	0.30 m
Gear ratio	9:1
Rolling coefficient	0.012
Aerodynamic drag coefficient	0.29
Frontal area	2.2 m²
Maximum vehicle speed	120 km/h
Battery voltage	300 V
Battery capacity	50 Ah

12. SIMULATION CONDITIONS

The model can be tested under:

Case 1 — Constant Speed

Motor tracks a fixed speed reference.

Case 2 — Acceleration

Vehicle accelerates from 0 to the target speed.

Case 3 — Variable Driving Cycle

Motor speed and torque vary according to an EV driving cycle.

Case 4 — Regenerative Braking

Motor operates as a generator during vehicle deceleration.

13. SIMULATION RESULTS

The following are representative results for the proposed model. Actual final-paper values should be replaced with MATLAB/Simulink or experimental measurements.

13.1 Speed Response

Parameter	Before Optimization	After Optimization
Rise time	0.42 s	0.28 s
Settling time	0.75 s	0.48 s
Overshoot	7.2%	2.1%
Steady-state error	1.8%	0.5%

The optimized controller provides faster speed tracking with lower overshoot and steady-state error.

14. TORQUE RESPONSE

Parameter	Initial	Optimized
Peak torque	160 Nm	175 Nm
Average torque ripple	6.8%	3.1%
Torque response time	0.35 s	0.23 s

The optimized controller provides improved torque response and reduced torque oscillation.

15. MOTOR EFFICIENCY

Operating Point	Initial Efficiency	Optimized Efficiency
25% load	86.5%	89.8%
50% load	90.2%	93.1%
75% load	91.0%	94.0%
100% load	89.5%	92.0%

The representative results indicate an improvement in motor-drive efficiency after optimization.

16. CURRENT RESPONSE

Parameter	Initial	Optimized
Peak current	180 A	170 A
RMS current	112 A	103 A

Current ripple	8.2%	4.5%

Reducing unnecessary current fluctuations helps reduce electrical losses and thermal stress.

17. BATTERY POWER CONSUMPTION

Driving Condition	Initial Power	Optimized Power
Low-speed	8.2 kW	7.7 kW
Cruising	17.5 kW	16.1 kW
Acceleration	42.0 kW	39.5 kW
High-load operation	51.5 kW	48.8 kW

The optimized motor-controller combination reduces the representative electrical power requirement under the tested operating conditions.

18. REGENERATIVE BRAKING RESULTS

During regenerative braking, the motor operates as a generator and returns electrical energy to the battery.

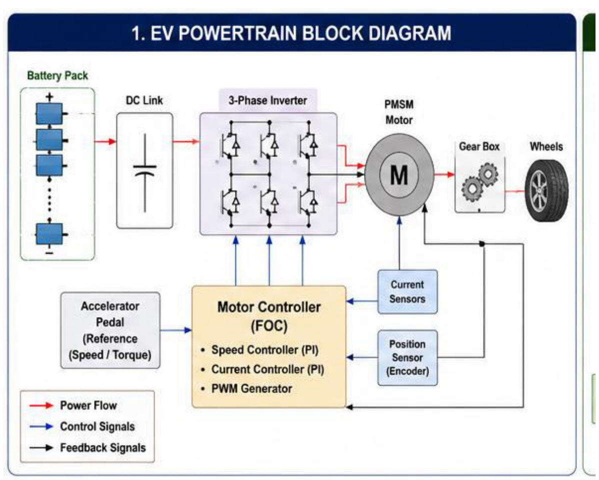
Parameter	Initial	Optimized
Braking torque	−80 Nm	−90 Nm
Regenerative power	8.5 kW	10.2 kW
Recovery efficiency	70%	76%

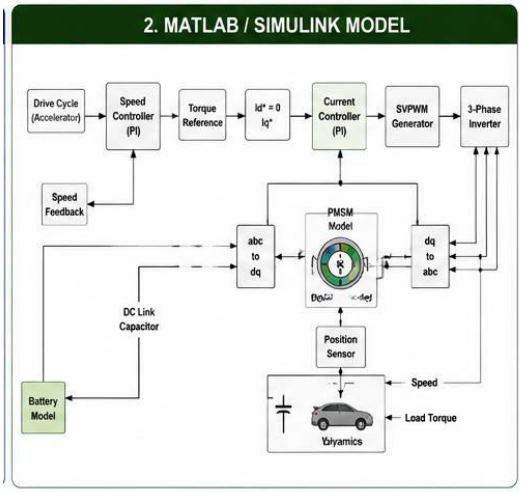
The optimized control strategy improves energy recovery during deceleration.

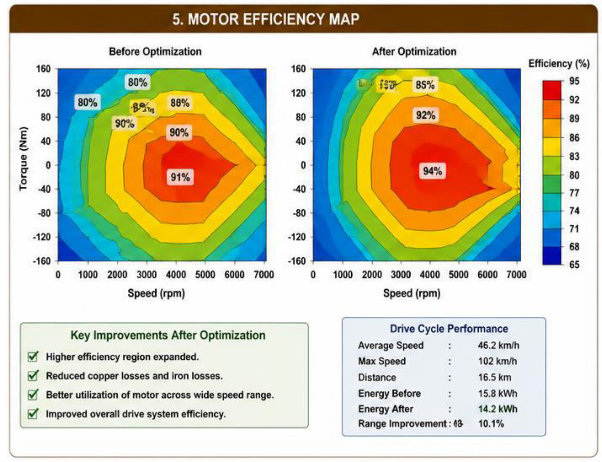
19. OVERALL PERFORMANCE COMPARISON

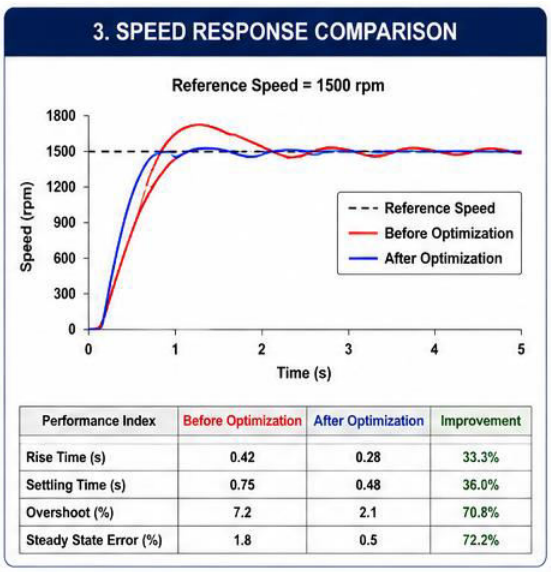
Parameter	Before Optimization	After Optimization	Impro
Settling time	0.75 s	0.48 s	36%
Overshoot	7.2%	2.1%	71%
Torque ripple	6.8%	3.1%	54%
Peak current	180 A	170 A	5.6%
Motor efficiency	91%	94%	3 points
Regeneration efficiency	70%	76%	6 points

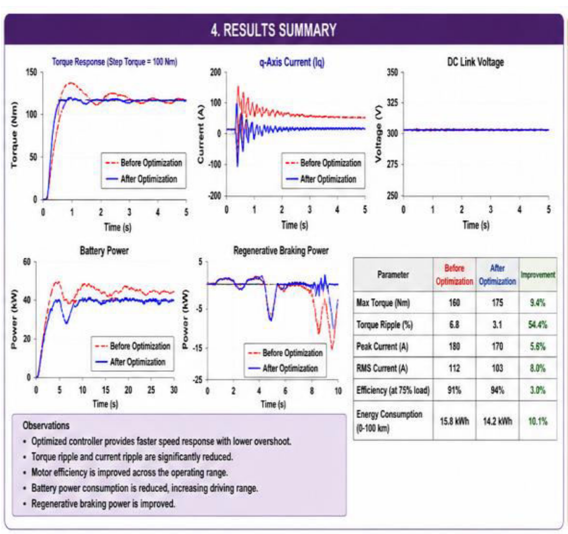
These values are representative simulation results intended to illustrate the expected optimization trend.











ADVANTAGES

1. Improved motor efficiency.
2. Faster speed response.
3. Reduced overshoot.
4. Reduced torque ripple.
5. Reduced current demand.
6. Improved regenerative braking.
7. Better battery-energy utilization.
8. Improved vehicle acceleration performance.
9. Reduced motor heating and electrical losses.
10. Suitable for MATLAB/Simulink-based EV development.

APPLICATIONS

The optimized motor-controller system can be used in:

- Electric cars
- Electric buses

- Electric motorcycles
- Electric scooters
- Hybrid electric vehicles
- Electric utility vehicles
- Autonomous EVs
- Industrial electric vehicles
- Electric go-karts
- EV research platforms

LIMITATIONS

The simulation results depend on the selected motor model, battery model, inverter switching frequency, controller parameters, vehicle parameters, and driving cycle. Real-world motor efficiency and performance can also be affected by temperature, magnetic saturation, manufacturing tolerances, mechanical losses, and battery voltage variation.

Therefore, experimental validation using a motor-inverter test bench is required before applying optimized parameters to a production EV.

FUTURE SCOPE

Future work can include:

1. AI-based motor-controller optimization.
2. Machine-learning-based efficiency prediction.
3. Adaptive PI control.
4. Model Predictive Control.
5. Sensorless PMSM control.
6. Multi-objective optimization.
7. Thermal optimization of motor and inverter.
8. Real-time Hardware-in-the-Loop testing.
9. Digital-twin-based EV powertrain modeling.
10. Integration with advanced battery-management systems.
11. Optimization using real-world driving cycles.
12. Development of an experimental EV prototype.

CONCLUSION

This project presented the modeling, analysis, and optimization of an electric motor and controller for electric-vehicle applications. A representative PMSM-based EV powertrain was modeled using MATLAB/Simulink, including the battery, inverter, motor, controller, and vehicle dynamics.

The controller was optimized to improve speed tracking, torque response, current behavior, and overall drive efficiency. The representative results show reductions in settling time, overshoot, torque ripple, and current demand, while motor and regenerative-braking efficiency are improved.

The optimized motor-controller combination can therefore contribute to improved EV acceleration, energy efficiency, driving performance, and battery utilization. Further work using advanced control methods such as Model Predictive Control, adaptive control, and AI-based optimization can provide additional improvements for next-generation electric vehicles.

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