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Analysis and Simulation of Switched Reluctance Motor Driven Electric Vehicle by Field-Oriented Control

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Abstract **—This paper analyses the performance of Electric Car for speed control of the switched reluctance motor. Closed loop speed control driven by field-oriented control (FOC) is applied for speed control. In these days, electric vehicles are widely used in most of the country because they can reduce the fuel consumption. As a consequence, they can lessen the environmental impact of carbon dioxide emission. The electric motors are the main devices to dive the electric car. The switched reluctance motors are well applied in the recent study instead of other AC motors for the electric vehicle due to their high performance. Using MATLAB/Simulink, the case study model is created and analysis of its results are carried out.**

Keywords— Electric car, FOC, MATLAB/Simulink, Speed Control, Switched Reluctance Motor.

I. INTRODUCTION

Electric and hybrid electric vehicles have gained popularity in today's market and are widely embraced worldwide. Despite increasing awareness of the environmental issues resulting from the use of fossil fuels, their penetration into the automotive market remains incomplete. The extensive use of vehicles globally has led to and continues to pose significant environmental and health hazards. The pressing concerns of our time include global warming, air pollution, and the rapid depletion of the Earth's petroleum resources.

In recent decades, the researcher has emphasized the development activities related to transportation which is high-efficiency, clean, and safe. Electric vehicles (EVs) and hybrid electric vehicles (HEVs) have been typically proposed to replace conventional vehicles in the near future. Therefore, the electric and hybrid electric vehicles will dominate the automobile market if they can provide better and more appropriate products for the present and future needs of the automobile customers [1].

In electric vehicles, the synchronous motors are widely used because they can provide the best performance, in terms of high torque and power density, high speed capability, wide speed range, high efficiency and mass saving. Interior permanent magnet (IPM) motors with rare-earth magnets are mainly used for electric vehicles (EVs). In a wide speed range, they exhibit high torque density and constant power operation. However, due to the high cost of rare-earth magnets and to the limited supply, interior permanent motors are becoming quite expensive. Therefore, the synchronous reluctance machines (SRM) are becoming of great and popular interest in the recent years [2].

In adjustable speed drive system, SRM is a predominant option as a motor with minimum cost and high reliability during these days. The weight of the rotor part decreases due to non-existence of windings on rotor and as a result rotor can rotate at high speeds. SRM can be found by the applications in high speed drives. Due to further inherent advantages like high efficiency, high reliability, excellent fault-tolerance, and high starting torque in initial accelerations, SRMs are recommended to be a competitive to other type of special application electrical machines. The main disadvantage in SRM includes high torque ripples [3]. This problem can be solved by using Field Oriented Control (FOC) method. In this paper, the closed loop FOC of SRM is modeled and the results are analysed by using MATLAB/Simulink.

II. ELECTRIC VEHICLES

The selected case study is the NEVERA TECH electric car depicted in Fig.1, which is equipped with four motors to power its four wheels. Each wheel of the Nevera is driven independently by a dedicated electric motor. Table I presents the parameters of the NEVERA TECH EV car [4].

Fig. 1. NEVERA TECH EV car.

Table I. Specification of NEVERA TECH [4].

Performance	
Speed	412 km/h, 258 mph
Output Power	1408 kW/1914 hp
Total Motor Torque	2340 N.m
Front Motor for Front Wheel	
No. of Motors	2 Nos/-
Power Output	200 kW/299 h.p
Max Torque	280 N.m
Inverter	800 V, 450 Arms phase current
Rear Motor for Back Wheel	
No. of Motor	2 Nos/-
Power Output	480 kW/653 h.p
Max Torque	900 N.m
Inverter Rating	800 V, 1000 Arms phase current

III. DRIVE WHEEL MOTOR TORQUE CALCULATION

Total Tractive Effort (TTE) and wheel motor torque depending upon the slope angle are calculated in this section. Figure 2 shows the forces acting on vehicle moving along a slopped road.

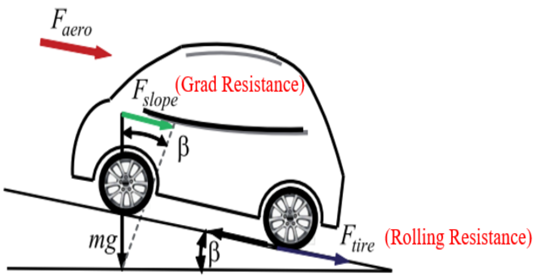

Fig. 2. Forces acting on vehicle moving along a slopped road.

Total Tractive Effort [lb] = RR + GR + F_a (1)

$$T_V = T_{slope} + T_{tire} + T_{aero} \quad (2)$$

Step 1: Determine Rolling Resistance (RR)

Gross vehicle weight = 3800 lb

= 16903 N

For front wheel, vehicle weight = 456 lb

RR [lb] = W_{GV}[lb] × C_{sf}

= 456 × 0.01 (good concrete)

= 4.56 lb

, where W_{GV} = Gross vehicle weight [lb]

C_{sf} = Surface friction coefficient

For concrete road, C_{sf} is 0.01.

Step 2: Determine Grade Resistance

GR [lb] = W_{GV}[lb] × sin β

, where β = maximum incline angle [degrees] and Table II shows the grade resistance depending upon slope angle.

Table II. Grade Resistance Depending upon Slope Angle.

β ° (slope angle)	GR [lb]
5	39.74
10	79.18
15	118
20	156
-5	-39.74
-10	-79.18
-15	-118
-20	-156

Step 3: Determine Acceleration Force [F_a]

F_a[lb] = W_{GV}[lb]×V_{max}[ft/s]/(32.2 ft/s^2 ×T_a[s])

= 575 lb

Step 4: Total Tractive Effort [TTE]

TTE [lb] = RR + GR + F_a

Step 5: Determine Wheel Motor Torque

T_w[lb-in] = TTE [lb] × R_w [in] ×R_F

, where R_w = radius of the wheel/tire [in] (3.5 in)

R_F = resistance factor (Typical values range between 1.1 and 1.5 or 10% to 15%)

Table III. shows the wheel motor torque depending upon slope angle.

Table III. Wheel Motor Torque Depending upon Slope Angle.

α ° (slope angle)	TTE [lb]	T_w[lb-in]	T_w[N-m]
0	579.56	2231	252
5	619.30	2384	269
10	658.74	2536	286
15	697.56	2686	303
20	735.56	2831	320
-5	-39.74	2078	235
-10	-79.18	1926	218
-15	-118	1777	200
-20	-156	1631	184

When wheel speed is 412 km/h (2200 rpm), the speed of front power train is 7500 rpm. Therefore, gear ratio 1:3.5 is used in this EV car.

IV. MODELING AND SIMULATION OF CASE STUDY

In this section, the switched reluctance motor model used in an electric vehicle (EV) with Field-oriented controlled (FOC) is developed using MATLAB/Simulink for performance evaluation.

Figure 3 shows the Simulink model of SRM with Direct-Torque control. A DC-AC converter supplies the appropriate AC voltage to the SRM. Closed-loop control employs feedback from output speed and stator current to produce the desired speed with low error and torque ripple via FOC.

T = 280 N.m

$$\omega = \frac{P}{T} = \frac{220 \times 10^3}{280} = 785 \text{rad/s}$$

$$N = \omega \times \frac{60}{2\pi} = 7496 \approx 7500 \text{rpm}$$

Using Gear Ratio 1:3.5

A. *Modeling of SRM using FOC*

Figure 3 illustrates the Simulink model of SRM with FOC. The required AC voltage is applied to SRM through DC-AC converter. The applied voltage of converter is 800 V DC. The output speed and stator current are feedback for the closed-loop control to gain the required speed with the minimum error and to reduce torque ripple by FOC.

The simulation runs with the following circumstances. In this study, EV automobile performance is measured using speed acceleration, speed deceleration, and torque change at constant speed.

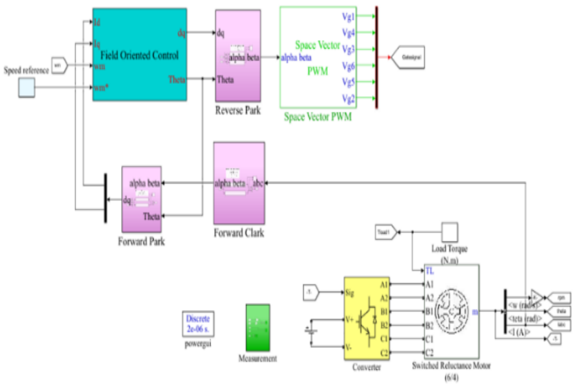

Fig. 3. Simulink Model of SRM with FOC.

- Circumstance 1 (Linear Motion)
  - N_{ref} is 7500 rpm and T_{ref} is 252 N.m.

- Circumstance 2 (Torque Change with Climbing)
  - N_{ref} is 7500 rpm and T is changed to 286 N.m with climbing slope with 10º.
  - N_{ref} is 7500 rpm and T is changed to 218 N.m with descending slope with 10º.

B. *Case 1 (Linear Motion)*

In linear motion, the reference speed is 7500 rpm and reference torque is 252 N.m.

After simulation, the speed curve, the electromagnetic torque and stator current for linear motion are resulted out and the nature and values are shown from Fig. 4 to Fig. 6. The ripple factor of SRM is also analyzed and is shown in Fig. 7.

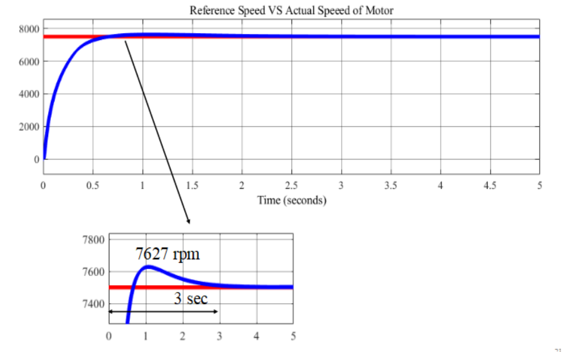

Fig. 4. Speed curve for linear motion.

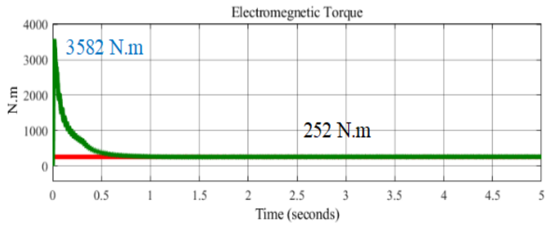

Fig. 5. Torque curve for linear motion.

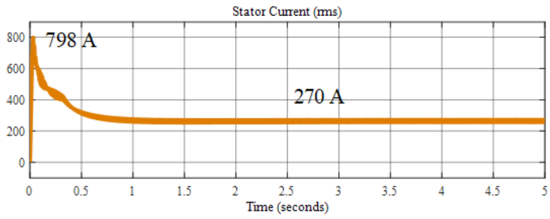

Fig. 6. Stator current of motor for linear motion

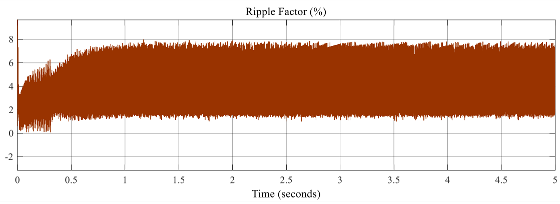

Fig. 7. Ripple factor of motor.

C. *Case 2 (Torque Change)*

In the case of climbing or descending road, torque change is needed to consider. When the car runs from linear to climbing or linear to descending, the torque change occurs. After simulation, the speed curve, the overshoot and undershoot value, the electromagnetic torque and stator current for circumstance 2 are resulted out and the nature of values are shown from Fig. 8 to Fig. 13.

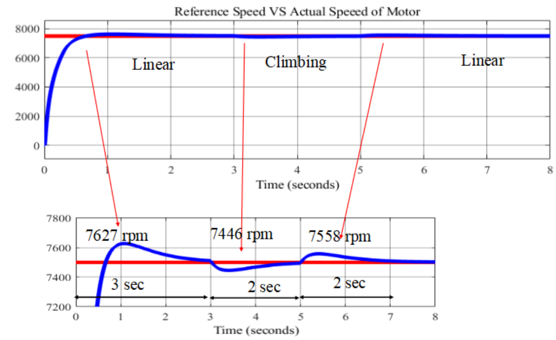

Fig. 8. Speed curve for torque change with climbing slope.

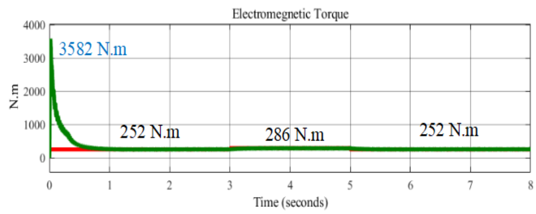

Fig. 9. Torque curve during climbing slope.

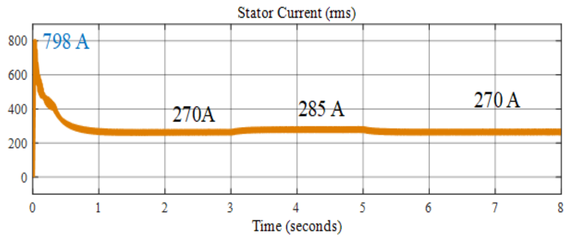

Fig. 10. Stator current during climbing slope.

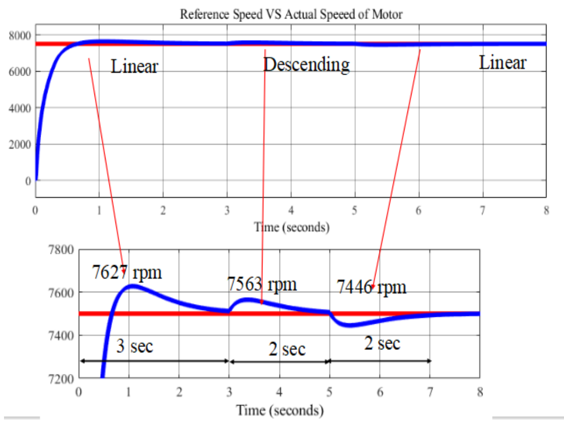

Fig. 11. Speed curve for torque change with descending slope.

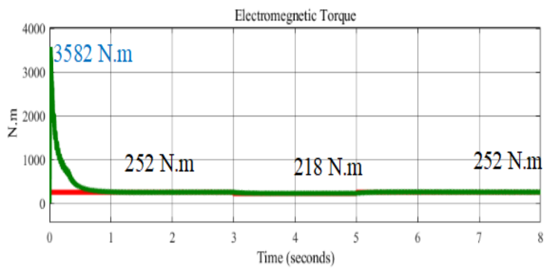

Fig. 12. Torque curve during descending slope.

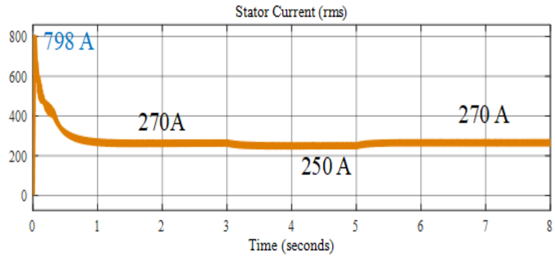

Fig. 13. Stator current during descending slope.

V. RESULTS OF CASE STUDY

The results for SRM driven by DTC are summarized from Table IV to Table IX. The speed overshoot and undershoot conditions and dynamic duration are studied. The speed overshoot to 7627 rpm and after 3 secs the steady state speed is reached. From linear to climbing, climbing to linear, linear to descending, descending to linear motion, the motion can be steadily changed within 2 secs with little overshoot and undershoot. The torque ripple and 7.9 % and efficiency of motor is 92%.

Table IV. Result summary of motor speed for linear motion.

	Overshoot	Over Duration
Circumstance-1 (Linear Motion)		
Speed 7500 rpm	Over-7627 rpm	3 sec
Torque 252 N.m		

Table V. Result summary of motor speed for torque change.

Simulation Time	Over/Under Shoot	Over/Under Shoot Duration
Circumstance-2 (Torque Change)		
Linear to Climbing	Under-7446	2 sec
Climbing to Linear	Over- 7558	2 sec
Linear to Descending	Over- 7563	2 sec
Descending to Linear	Under-7446	2 sec

Table VI. Torque ripple and efficiency.

SRM Driven by DTC	
Torque Ripple (%)	7.9
Efficiency (%)	92

Table VII. Result summary for starting torque and current (Linear motion).

	Linear Motion
Starting Torque (N.m)	3582
Starting Current (A)	798
Normal Current (A)	270

Table VIII. Result summary of motor torque and current for linear motion.

Case	Torque (N.m)	RMS Current (A)
Circumstance-1 (Linear Motion)		
Speed = 7500 rpm Torque = 252 N.m	252	270

Table IX. Result summary of motor torque and current for torque change.

Simulation Time	Case	Torque (N.m)	RMS Current (A)
Circumstance-2 (Torque Change)			
Linear to Climbing	T = 252 to 284 N.m	284	285
Climbing to Linear	T = 284 to 252 N.m	252	270
Linear to Descending	T = 252 to 218 N.m	218	250
Descending to Linear	T = 218 to 252 N.m	252	270

VI. CONCLUSION

According to the simulation results, although most of the EV use PMSM and IM, the SRM is used in this research because it gives the smooth performance and in addition, it is low cost, rigidity in hostile environment and compact in advantages. Switched reluctance motor (SRM) is a special electrical machine in modern day electrical applications due to its superior merits over other type of electrical machines. The main disadvantage in SRM includes high torque ripples. To reduce its high torque ripple and noise, closed-loop vector control is needed. In this paper, the closed loop performance of converter fed switched reluctance motor drive using Field-Oriented Control (FOC) is simulated at fixed speed, variable speed and variable torque conditions to reduce the high torque ripple. The model presented is developed and the results are analyzed using MATLAB/SIMULINK software. It can be seen that the required speed can be smoothly changed by using FOC.

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REFERENCES

[1] M. Ehsani, Y. Gao, S. Longo and K. Ebrahimi, "*Modern Electric, Hybrid Electric, and Fuel Cell Vehicles*," 3rd Edn., CRC Press, 2018.

[2] N. Bianchi, S. Bolognani, E. Carraro, M. Castiello and E. Fornasiero, "Electric Vehicle Traction based on Synchronous Reluctance Motors," *IEEE Trans. Indust. Appl.*, vol. 52, no. 6, pp. 4762 – 4769, 2016.

[3] A. K. Kolluru and M. K. Kumar, "Closed-loop Speed Control of Switched Reluctance Motor Drive Fed from Novel Converter with Reduced Number of Switches," *Int. J. Power Electron. and Drive Syst.*, vol. 11, no. 1, pp. 189-199, 2020.

[4] Nevera - Rimac Automobili, 2023. https://www.rimac-automobili.com/nevera/ [Achieved on 4.8.2024].