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Speed Control of Electric Car Using Field Oriented Controlled Switched Reluctance Motor

Moe Moe[1]
Electrical Power Engineering Department
Yangon Technological University
Yangon, Myanmar

Soe Win[2]
Electrical Power Engineering Department
Yangon Technological University
Yangon, Myanmar

Abstract:- Nowadays, global warming caused by carbon emission threatens the lives of human beings and living organisms. The problem of reducing carbon dioxide (CO_2) has become urgent. Therefore, in the vehicle world, electric vehicles (EV) are being used instead in order for reducing the fuel consumption. The using of electric motor plays a significant role in the performance of electric cars. In most recent research, the application of switched reluctance motor (SRM) can be seen to improve the performance of electric cars. Thus, this research focuses on the testing the performance of SRM. Among the many benefits of SRM, torque ripple is a drawback. For reducing the torque ripple, the closed-loop vector control is applied to motor control. In this research, field oriented control (FOC) to SRM is used for NEVERA TECH EV car. The scenarios for Speed acceleration, deceleration, and torque change are considered for the performance analysis using MATLAB/Simulink.

Keywords:- *Carbon Emission, Electric Vehicles, Field Oriented Control, Switched Reluctance Motor, Speed, Torque.*

I. INTRODUCTION

Nowadays, electric and hybrid electric vehicles are popular products in the market and are accepted internationally. Despite the growing awareness of the global warming problem caused by fossil fuel use, they haven't fully entered the automobile market yet. The large number of automobiles used around the world has caused and continues to cause serious conditions for the environment and human life. Global warming, air pollution and the rapid shortage of the earth's petroleum resources are current problems of paramount concern.

In recent years, researchers have focused on developing transportation activities that are highly efficient, clean and safe. Typically, electric and hybrid cars are proposed to replace conventional cars in the near future. If they can provide better performance to the automobile customers, they will have a dominant position in the automobile market [1].

In electric cars, 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. However, due to the high cost of rare-earth magnets and to the limited supply interior permanent motors are becoming quite expensive. Therefore, the switched reluctance machines (SRM) are becoming of great and popular interest in the recent years [2].

Nowadays, SRM is a predominant option as a motor used for electric cars with the minimum cost and high reliability due to its adjustable speed drive system and can be found by the applications in high speed drives. Due to interesting advantages such as the 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 the high torque ripples [3]. In this paper, for reducing the drawback of torque ripple, the closed loop vector control as FOC of SRM for NEVERA TECH EV car is applied. The case study is modeled and the results are analyzed by using MATLAB/Simulink.

II. CONFIGURATION OF ELECTRIC CAR

The configuration of the EV is more adaptable than the configuration of an internal combustion engine (ICE) car because of the decreased number of moving parts, such as the clutch [4]. Fig.1 demonstrated general EV configuration. There are three main subsystems in the drive train: electric motor propulsion, energy source, and auxiliary.

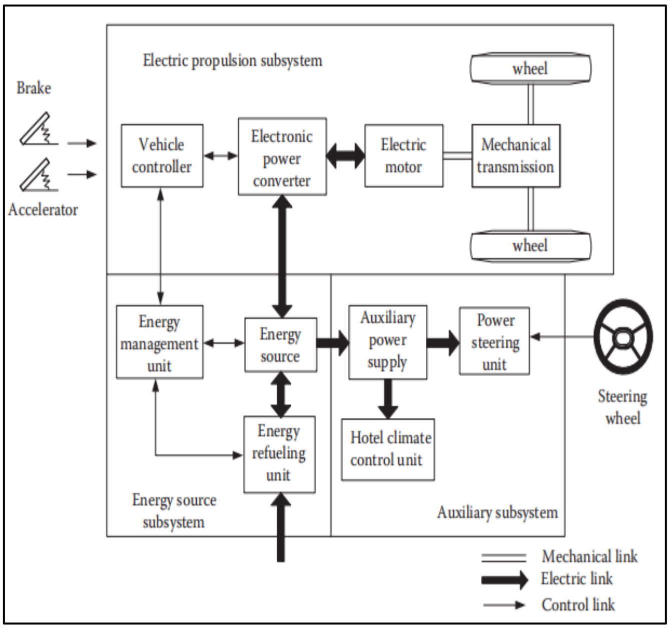

Fig 1 General EV Configuration [1]

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III. ALGORITHM FIELD ORIENTED CONTROL

➢ *The Step by Step Procedures for FOC Algorithm are as Follow:*

- The i_a, i_b and i_c stator phase currents are measured. Being balanced condition, the value of i_c can be calculated from measured values of i_a and i_b as:

$$i_a + i_b + i_c = 0.$$

- These three phase currents i_a, i_b and i_c are transformed to two-axis values i_α and i_β. From this conversion, time-varying quadrature current values i_α and i_β are obtained from the measured current values i_a , i_b and i_c. This conversion is popularly known as Clarke Transformation.
- Calculate the rotor flux and its orientation.
- Rotate the two-axis coordinate system such that it is in alignment with the rotor flux.
- From the calculated transformation angle, the last iteration of control loop can be obtained.
- In this transformation, the i_d and i_q variables are obtained from i_α and i_β. This step is more commonly known as the Park Transformation.
- Flux error signal is generated using reference flux and estimated flux value.
- A PI controller is then used to calculate i*d using this error signal.
- i*d and i*q are converted to a set of three phase currents to produce i*a, i*b, i*c.
- Finally, the inverter gate signals are generated by comparing the reference currents i*a, i*b, i*c with the measured currents i_a, i_b, i_c by using hysteresis comparator [4].

IV. SWITCHED RELUCTANCE MOTOR

The switched reluctance motor (SRM) is a device that uses electromagnetic and electrodynamic technology to convert electrical energy into mechanical energy. The electromagnetic torque is generated by utilizing the variable reluctance principle.

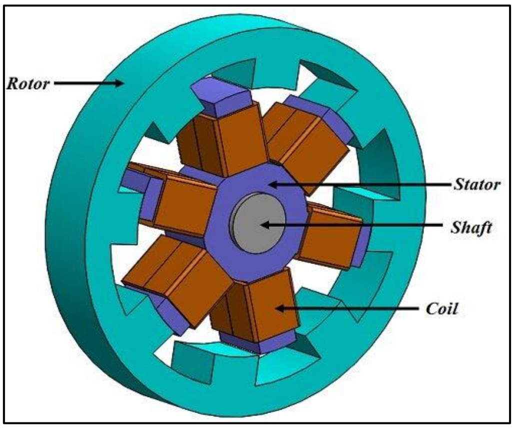

Fig 2 Construction of Switched Reluctance Motor

Fig. 2 shows the construction of SRM. SRMs use rotor position switches to energize the phase windings separated in sequence. The rotor aims to move to the point where there is the least resistance, which can cause torque. The stator has concentrated coils. They are suitable for high speed application due to its' simple and robust configuration, but its main drawbacks are torque ripple and noise [5], [6].

V. MODELING OF CASE STUDY

The case study is chosen as NEVERA TECH electric car which is shown in Fig.3. It uses four motors for four wheels. Each of Nevera's wheels are independently driven by one dedicated electric motor [7]. In this section, the model of switched reluctance motor used in EV using FOC is constructed using MATLAB/Simulink for performance analysis according Table. 1 shows the parameters of NEVERA TECH EV car.

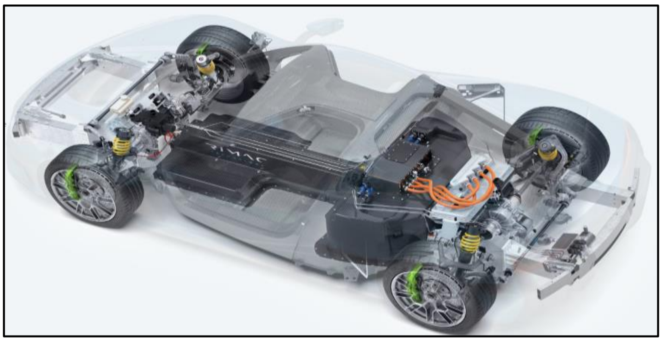
Fig 3 Four Motor Configuration of NEVERA TECH

Table 1 Parameters of Nevera Tech [7]

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/-

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Power Output	480 kW/653 h.p
Max Torque	900 N.m
Inverter Rating	800 V,1000 Arms phase current

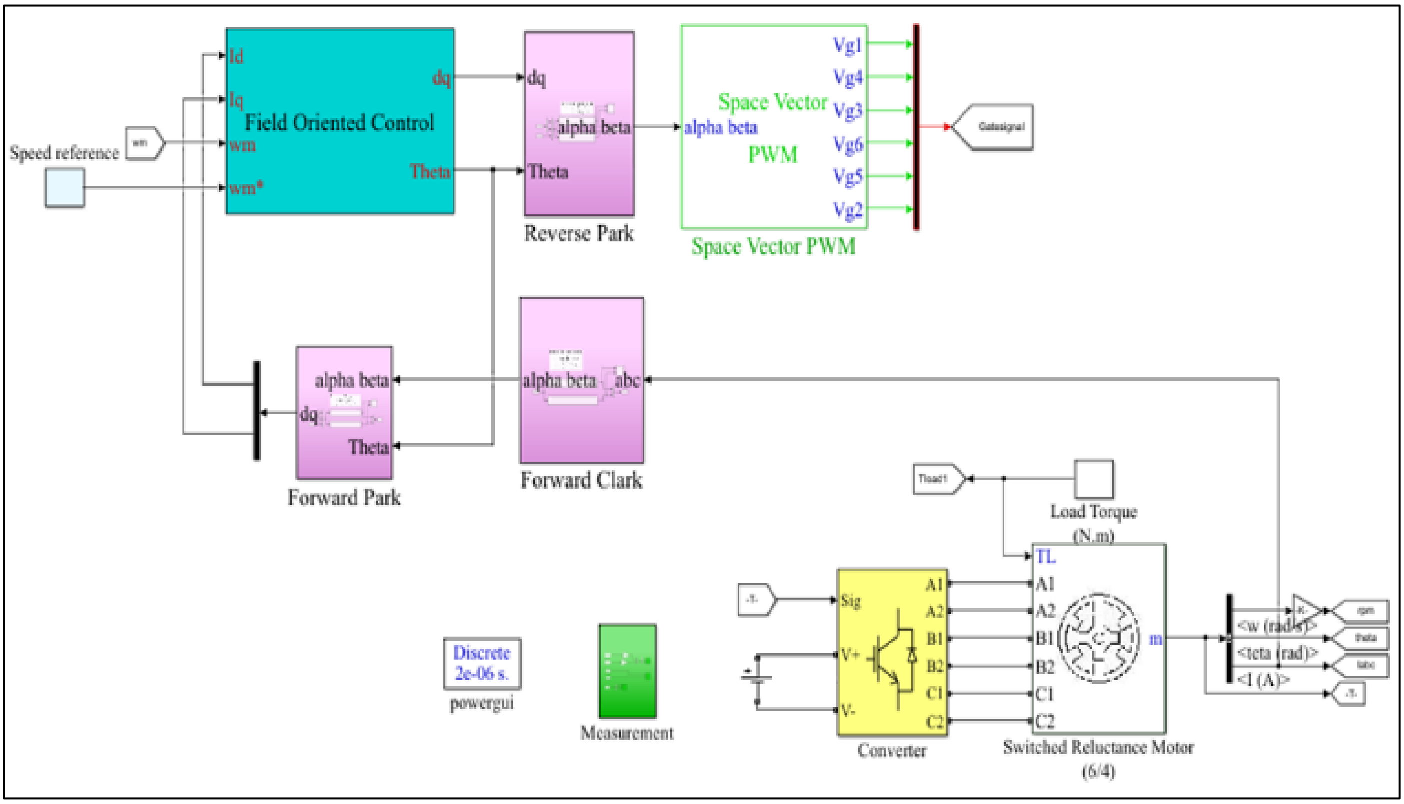

Fig 4 Model of FOC-SRM

The wheel speed is 412 km/h. Therefore, it is 2180 rpm which is assumed to 2200 rpm. In this paper, the front motor is analyzed for front wheels. For front wheel, motor power (P) is 220 kW and maximum torque is (T) 280 N.m. By calculation using motor power and maximum torque, its speed is 7500 rpm. Therefore, gear ratio is chosen as 1:3.5.

Fig. 4 illustrates the Simulink model of SRM with FOC. SRM is supplied with the required AC voltage using a DC-AC converter. Closed-loop control uses feedback from output speed and stator current to achieve the required speed with minimal error and minimum torque ripple through FOC.

VI. SIMULATION AND RESULTS

The simulation is performed with the following scenarios. The speed acceleration, speed deceleration and torque change at speed constant are considered for EV car performance in this research.

➢ *Scenario 1 (Normal Condition)*

N_{ref} is 7500 rpm and T_{ref} is 280 N.m

➢ *Scenario 2 (Speed Deceleration)*

T_{ref} is 280 N.m.

Speed deceleration from 7500 rpm to 7000 rpm at 5 sec, and then to 6000 rpm at 10 sec.

➢ *Scenario 3 (Speed Acceleration)*

T_{ref} is 280 N.m.

Speed acceleration from 6000 rpm to 7000 rpm at 5 sec, and then to 7500 rpm at 10 sec.

➢ *Scenario 4 (Torque Change)*

N_{ref} is 7500 rpm.

At stating, torque is 280 N.m. Next, it is changed to 200 N.m at 5 sec. And then, to 250 N.m at 10 sec.

➢ *Scenario 1 (Normal Condition)*

After simulation, the speed result for normal condition and the torque result for normal condition are shown in Fig. 5 and Fig.6. In speed curve, the overshoot occurs for 4 secs and after that, the steady state speed, 7500 rpm, is reached in which the torque value rises to 886 N.m during starting condition and reached to required value after speed overshoot.

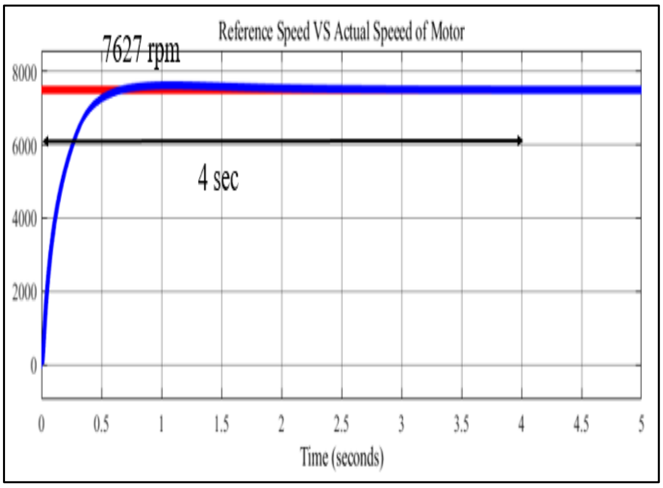

Fig 5 Speed Result of Normal Condition

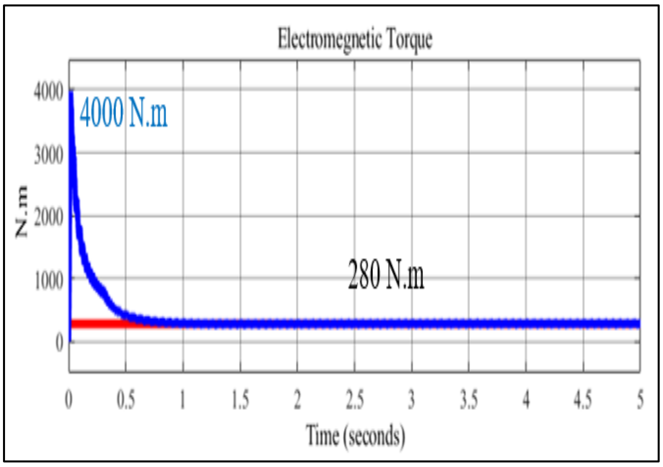

Fig 6 Torque Result of Normal Condition

➢ *Scenario 2 (Speed Deceleration)*

The scenario 2 is considered as speed deceleration. The speed reference is set as 7500 rpm from 0 to 5 sec. And then, it is changed to 7000 rpm from 5 to 10 sec. Ten second later, it changes to 6000 rpm. It is assumed that the torque is constant at 280 N.m. Fig.7 and Fig.8 express the speed and torque results for scenario of speed deceleration.

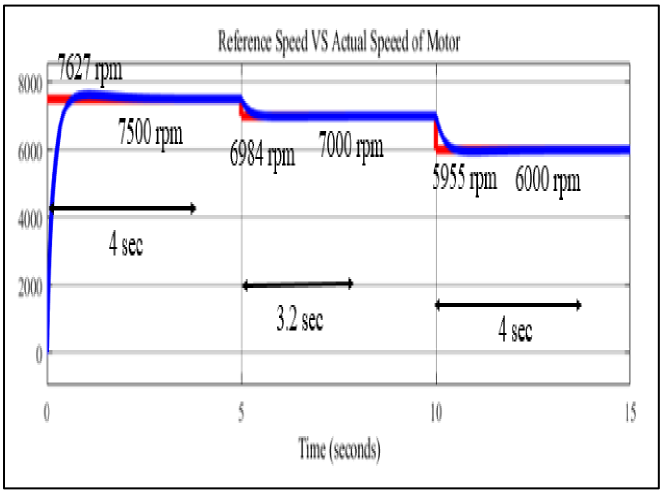

Fig 7 Speed Result for Scenario of Speed Deceleration

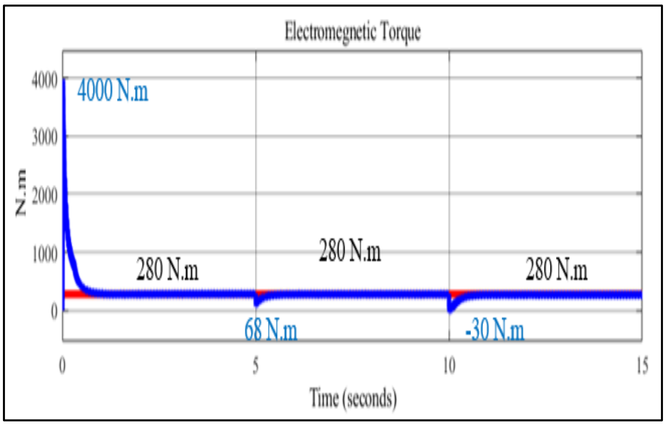

Fig 8 Torque Result for Scenario of Speed Deceleration

According to the analysis of the results, during speed deceleration at torque constant, the speed can change smoothly during seconds to the required speed with little undershoot.

➢ *Scenario 3 (Speed Acceleration)*

Scenario 3 takes into account for speed acceleration. The speed reference is set as 6000 rpm between 0 and 5 sec. Afterwards, it is raised to 7000 rpm between 5 and 10 sec. It is finally changed to 7500 rpm after 10 sec. The reference torque is presumed to be fixed at 280 N.m. The simulation results for speed curve and torque curve for speed acceleration are described in Fig. 9 and Fig. 10.

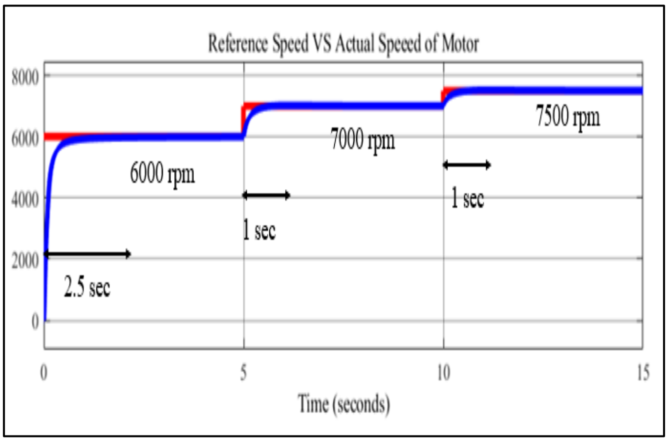

Fig 9 Speed Result for Scenario of Speed Acceleration

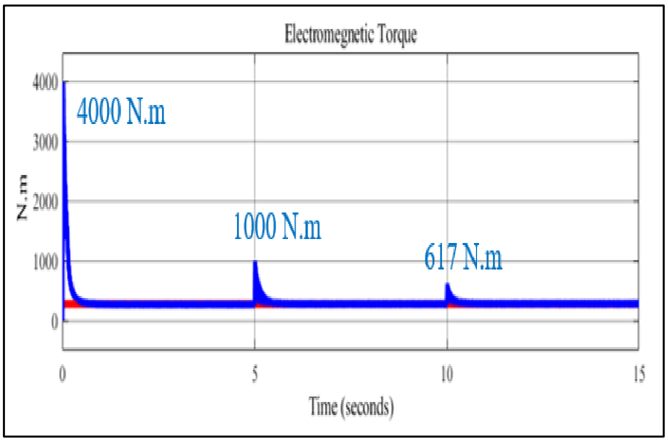

Fig 10 Torque Result for Scenario of Speed Acceleration

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As can be seen from the simulation results, during speed acceleration at torque constant, the required speed can be changed smoothly with little transients.

- *Scenario 4 (Torque Change)*

In scenario 4, the condition of the torque change is taken into consideration. Between 0 and 5 secs, the torque reference is 280 rpm. After 5 to 10 sec, the torque is increased to 200 rpm. The torque was finally reduced to 250 rpm after 10 sec. It is assumed that the reference speed is fixed at 7500 N.m. Fig.11 and Fig.12 expose the speed and torque results for scenario of torque change.

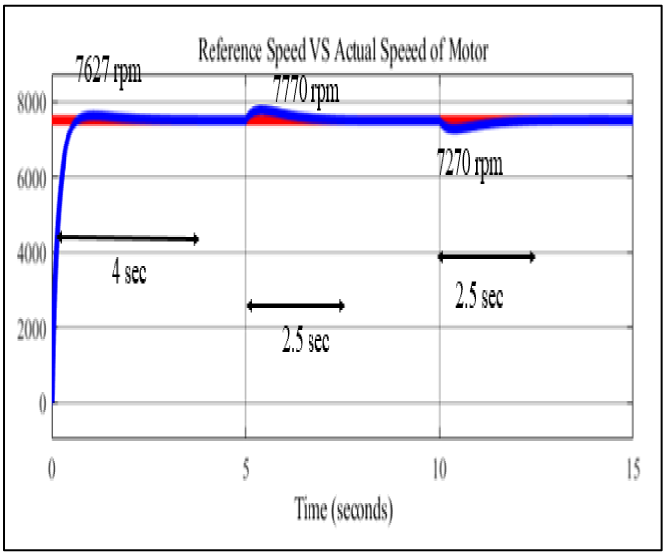

Fig 11 Speed Result for Scenario of Torque Change

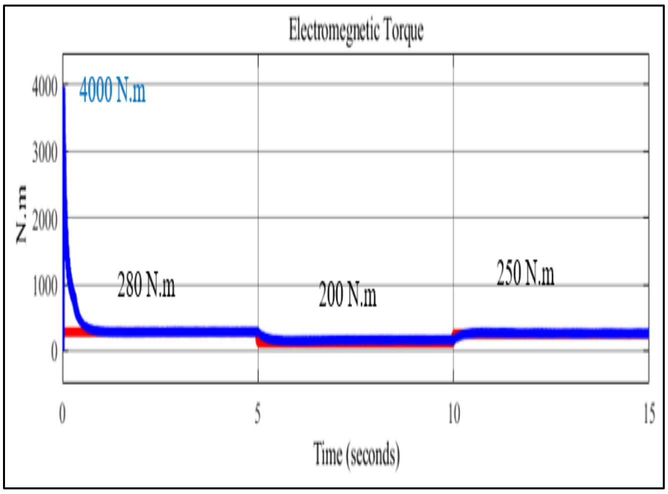

Fig 12 Torque Result for Scenario of Torque Change

VII. CONCLUSION

In conclusion, the performance of switched reluctance motor used in NEVERA TECH EV car is described in this paper. It is evident that the closed-loop field-oriented control of SRM is able to handle the situations of speed acceleration, speed deceleration and torque changes effectively. It is able to reach the desired speed with short transient time and low overshoot and undershoot values. Even in the case of torque change, the rated speed can be maintained. In all scenarios, FOC also reduces torque ripple. In a nutshell, FOC for SRM can guarantee smooth performance for EV.

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