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Comparative Study of Induction Motor Drive in Electric Vehicle Integration: A Simulation Approach

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Abstract

This paper aims in developing and analyzing a simulation model of induction motor for electric vehicles. A mathematical model of electric vehicles is developed using induction motors, sinusoidal pulse width modulation (SPWM), and space vector pulse width modulation (SVPWM). The control strategies were used to analyze the motor performance, and found that SVPWM is better. The mathematical model is simulated using MATLAB/Simulink with the variations in the current, THD, and voltage of both strategies and the results are analysed.

Keywords: Induction motor, Electric Vehicle, SVPWM, SPWM.

1. Introduction

Because of the growing population and daily requirements, there are more cars on the road and more transportation options available to move goods. The demand for fossil fuels is rising in tandem with the number of vehicles. Electric vehicles (EVs) can be utilized as a substitute for fossil fuels. The propulsion system of an EV is a major factor in determining the efficiency of the EV system. Therefore, it is essential to assess the propulsion system's performance using various control methods. The induction motor (IM) is the subject of this paper's evaluation, and several controllers are used to examine the IM's performance. Its effectiveness and efficiency as an electric vehicle are examined using the space vector pulse width modulation (SVPWM) and sinusoidal pulse width modulation (SPWM) [1-5].

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Electric vehicles (EVs) are crucial for mitigating environmental concerns and reducing dependence on fossil fuels. Induction motors play a vital role in EVs, offering simplicity, high power density, regenerative braking, low maintenance, and cost-effectiveness. The advantages of induction motors in EVs include reduced environmental impact, energy independence, lower operating costs, and long-term sustainability, contributing to a cleaner and more sustainable transportation future compared to traditional fossil fuel-powered vehicles [6-8].

The Electric vehicle dynamics are calculated and listed in the Table 1.

Table 1. Electric Vehicle Dynamics

Vehicle Parameters	Value
Kerb weight(kg)	110
Payload(kg)	100
Coefficient of rolling resistance	0.002
Air Density(kg/m3)	1.25
Width(m)	1.765
Height(m)	1.595
Frontal Area(m2)	2.815175
Drag Coefficient	0.5
Speed(kmph)	55
Velocity(m/s)	15.27777778

2. Motor and Controllers

The induction motor finds application in diverse industrial sectors such as pumps, fans, paper and textile mills, elevators, electric vehicles, and subway transportation. In current motor applications, Simulink models are utilized for motor drives [9-12]. Scalar control methods and vector control methods are gaining popularity for efficient induction motor control. In the vector control approach, the induction motor is regulated using the DC motor control technique.

An inverter is employed to provide power to the induction motor. The PWM (Pulse Width Modulation) technique is employed for controlling these inverters, with the SPWM (Sinusoidal Pulse Width Modulation) technique being particularly prevalent among various PWM methods.

2.1 Sinusoidal Pulse Width Modulation

A comparator compares the reference and carrier signals to generate gate pulses in the sinusoidal pulse width modulation technique. The reference signal is made up of three-phase sine waves at the fundamental frequency. The size of the reference signal determines the modulation index, whereas the frequency of the reference signal governs the output voltage frequency. As the carrier signal, a high-frequency triangle wave is used. When the magnitude of the reference signal exceeds that of the carrier signal, the comparator generates a gate signal. Three-phase sine waves with a 120-degree phase difference form the gate signal. The higher lag signal is supplied into a NOT gate to notice a larger lag in an inverter switch, whereas the lower lag signal requires a 180-degree phase difference from the top lag. While the sinusoidal pulse width modulation technique is simple to understand, it does not completely utilise the DC bus voltage. [13-16].

2.2 Space Vector Pulse Width Modulation

By using Park and Clark transformations to translate three-phase values into their corresponding two-phase quantities, the rotating field notion seen in AC machines is applied to the space vector to enable modulation of the inverter output [17–19]. An oscillating magnetic field is produced in the air gap of AC machines fueled by a three-phase supply. The Park and Clark transformations establish the magnitude and angle of this field, which can be represented by a single rotating voltage vector.

For the voltage source inverter, six power switches are utilized, with S1, S3,and S5 being upper switches, and S4, S6, and S2 serving as lower switches. When an upper switch is on, it is assigned a lag value of '1', and when a lower switch is on, it is assigned a lag value of '0'. The ABC-to- d-q transformation equation is then applied in this context.

$$Vd = Va - \frac{1}{2}Vb - \frac{1}{2}Vc \text{ and } Vq = \frac{\sqrt{3}}{2}Vb - \frac{\sqrt{3}}{2}Vc \quad (1)$$

For use in a three-phase inverter, the switching control signals are produced using the space-vector PWM (SVPWM) approach. The SVPWM inverter has reduced output harmonic distortions and offers a 15% boost in dc link voltage utilisation over the traditional sinusoidal PWM inverter. The voltage/frequency control approach, which is based on the space-vector modulation technique, is the control strategy used in the SVPWM inverter.

A notable differentiation between SVPWM and SPWM revolves around the incorporation of two extra zero voltage states, specifically V0 (000) and V7 (111). In contrast to the six voltage vectors associated with the Voltage Source Inverter (VSI), the two zero voltage states that is associated with activating either all three positive pole switches or all three negative pole switches are added. This feature facilitates the production of a higher output voltage, taking into account the existence of the third harmonic component. As a result, SVPWM is frequently described as an eight-state operation.

3. Simulation and Analysis

3.1 Modelling of an Electric Vehicle

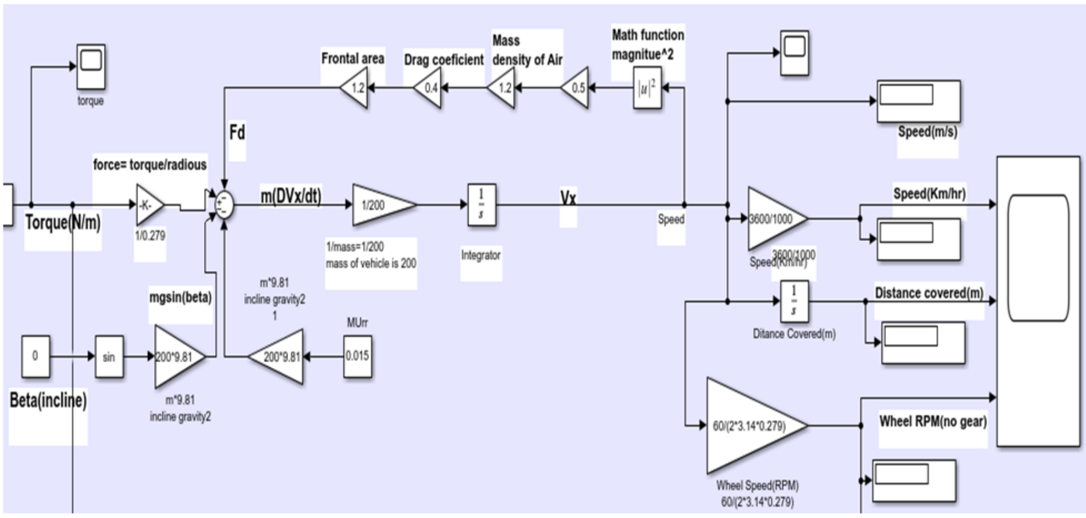


Figure 1. Design of an Electric Vehicle

In this context, the mathematical representation of diverse forces impacting a vehicle has been simulated using MATLAB. This encompasses the constant forces of rolling resistance and aerodynamic drag, which persist consistently. Conversely, the forces related to hill climbing and acceleration manifest for specific durations. Consequently, when formulating a propulsion system for an electric vehicle, it becomes crucial to determine the force and power essential for propelling the vehicle. Additionally, the selection of the electric motor involves considerations of both continuous power and maximum power.

3.2 Modelling of SPWM based Inverter

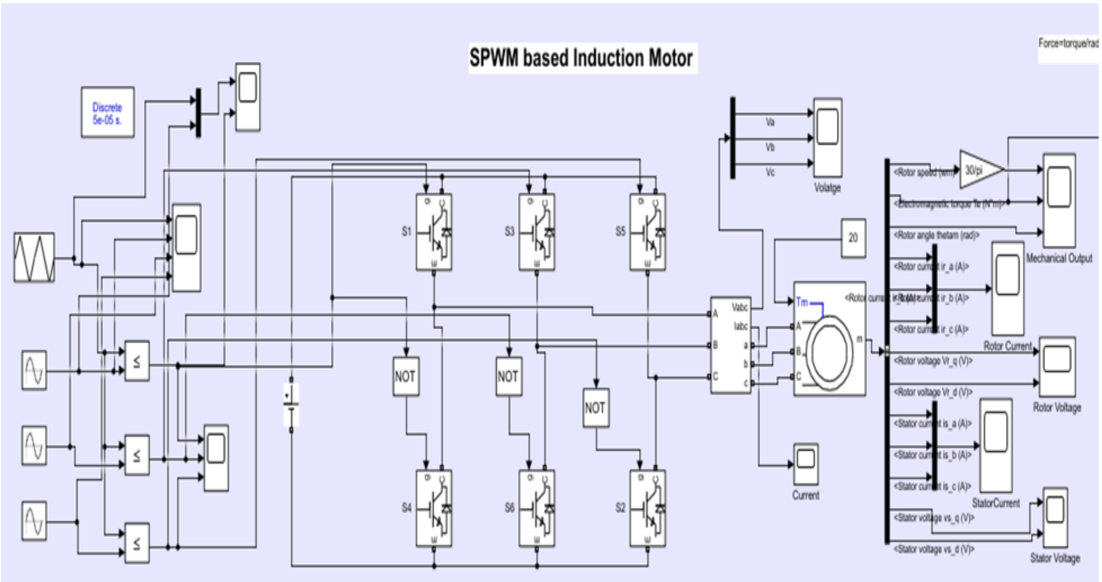


Figure 2. SPWM based Induction Motor

In this scenario, the simulation of a three-phase inverter using Sinusoidal Pulse Width Modulation (SPWM) has been conducted. The sinusoidal PWM waveform is generated comparing the desired modulated waveform with the high-frequency triangular waveform. The output voltage of the DC bus is determined as either negative or positive, irrespective of whether the signal voltage is smaller or larger than that of the carrier waveform.

3.3 Mathematical Modelling of SVPWM based Inverter.

This section describes the modelling of a SVPWM based inverter. It can be simulated by using the function block available in the MATLAB library.

The mathematical model for electric vehicles (EVs) with induction motors involves several key equations that describe the dynamic behavior of the vehicle. One essential equation is the torque-speed relationship for the induction motor, incorporating parameters such as stator and rotor resistance, inductances, and rotor speed. The dynamic equations of motion consider forces acting on the vehicle, including aerodynamic drag, rolling resistance, and gravitational forces. The battery model incorporates energy storage dynamics, considering factors like state of charge and internal resistance. These equations are integrated into a comprehensive vehicle dynamics model, often implemented in simulation environments. Control algorithms for motor drives, regenerative braking, and overall vehicle management further refine the model. In summary, the mathematical model integrates motor characteristics, vehicle dynamics, and energy storage dynamics, providing a comprehensive framework for analyzing and optimizing the performance of electric vehicles with induction motors.

The mathematical model can be done by calculating the total tractive force required by the vehicle,

Rolling resistance force $$\boldsymbol{F_{rr} = \mu_{rr} m g} \qquad (2)$$

Where μ_{rr} is the coefficient of rolling resistance, m is the gross vehicle weight and g is the acceleration due to gravity.

Aerodynamic drag force $$\boldsymbol{F_{ad} = \frac{1}{2}\rho A C_d v^2} \qquad (3)$$

Where ρ is the density of the air, A is the frontal area, v is the velocity and C_d is a constant called the drag coefficient.

Hill climbing force $$\boldsymbol{F_{hc} = m\ g\ sin(\Psi)} \qquad (4)$$

Where ψ is the inclination angle of the slope

Linear acceleration force $$\boldsymbol{F_{la} = m.a} \qquad (5)$$

The sum of all forces will provide the total tractive force using these equations. Multiplying this force with velocity will give the tractive power required by the vehicle and help to model the electric vehicle.

SPWM

- Approximates a sinusoidal waveform by modulating the width of pulses.
- May exhibit voltage distortion and harmonic content in the output waveform.
- Relatively simpler to implement.

- Suitable for applications where simplicity is prioritized over precision.

SVPWM

- Represents three-phase voltages as vectors in a rotating reference frame.
- Calculates optimal voltage vectors to closely follow the desired sinusoidal waveform.
- Offers better voltage utilization and reduced harmonic distortion.
- More complex to implement but provides higher control precision and better overall motor performance.

i) Clark's Transformation

- The three-phase stator currents are first transformed into a two-phase stationary reference frame using Clarke transformation.
- Then, a Park transformation is applied to convert the stationary frame into a rotating frame aligned with the rotor flux.

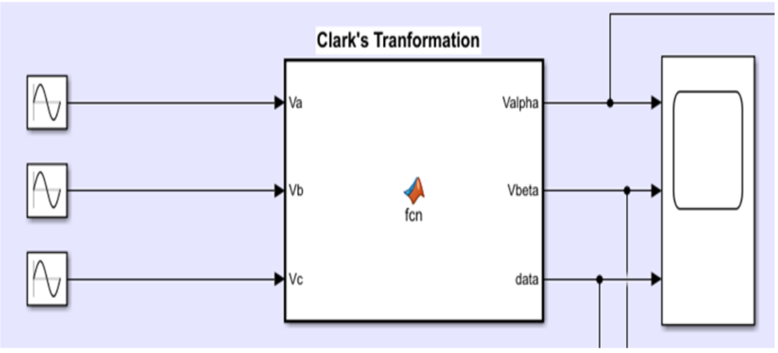


Figure 3. Clark's Transformation

ii) Sector Detection and Angle Calculation

- The desired reference voltage is represented as a space vector in a two-dimensional plane. This vector represents the magnitude and phase of the desired voltage.

- The space vector is divided into six sectors, each corresponding to a specific combination of voltage vectors in a three-phase system. The active voltage vectors are identified based on the sector in which the space vector lies.

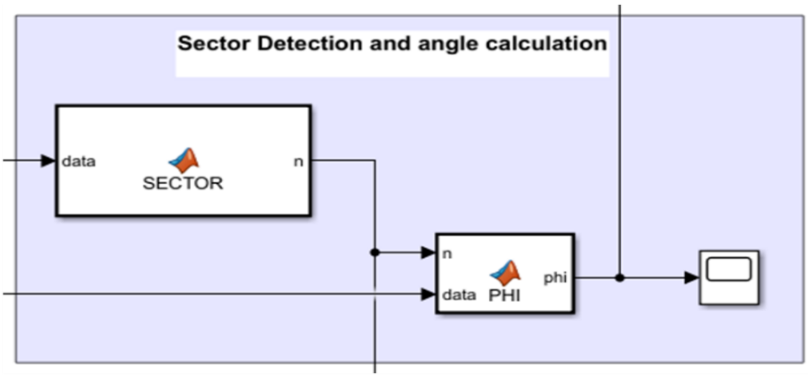


Figure 4. Sector Detection and Angle Calculation

iii) Voltage Reference Vector

- The durations for which the active voltage vectors are applied are calculated based on the modulation index and the position of the space vector within the sector.

- The active voltage vectors are modulated to generate the optimal three-phase voltage waveform. This modulation involves adjusting the pulse widths of the voltage vectors to approximate the desired space vector.

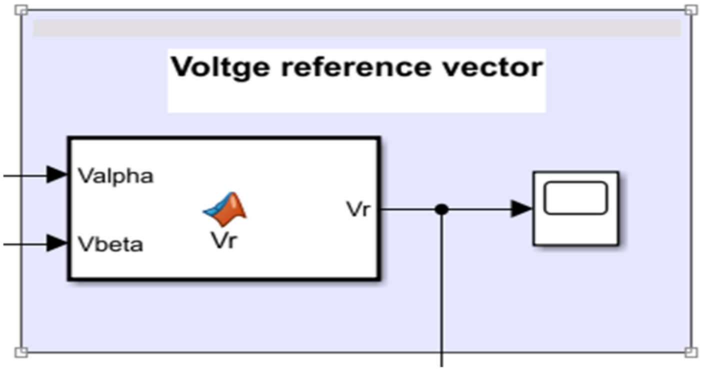


Figure 5. Voltage Reference Vector

iv) Time Calculation

The modulated voltage vectors are used to generate the PWM signals for the inverter. The PWM signals control the switching of the power semiconductor devices in the inverter.

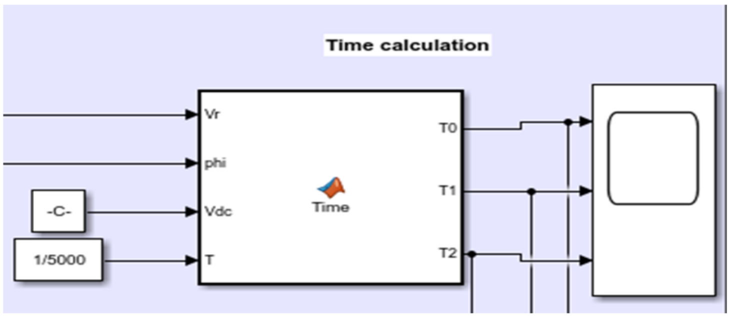


Figure 6. Time Calculation

v) M-W Signal Generation

- The PWM signals are applied to the inverter switches, which control the flow of current to the motor windings.
- After the inverter switching, inverse Clarke and Park transformations are applied again to obtain the three-phase voltage waveforms in the stator reference frame.

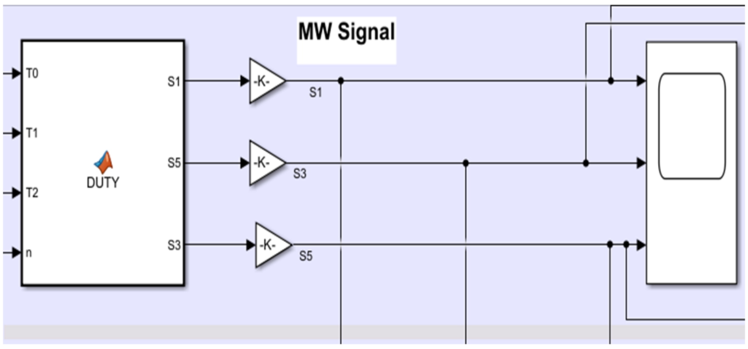


Figure 7. M-W Signal Generation

3.4 The Overall Model

The calculated voltages are applied to the stator windings of the induction motor, resulting in the desired control of the motor's speed and torque.

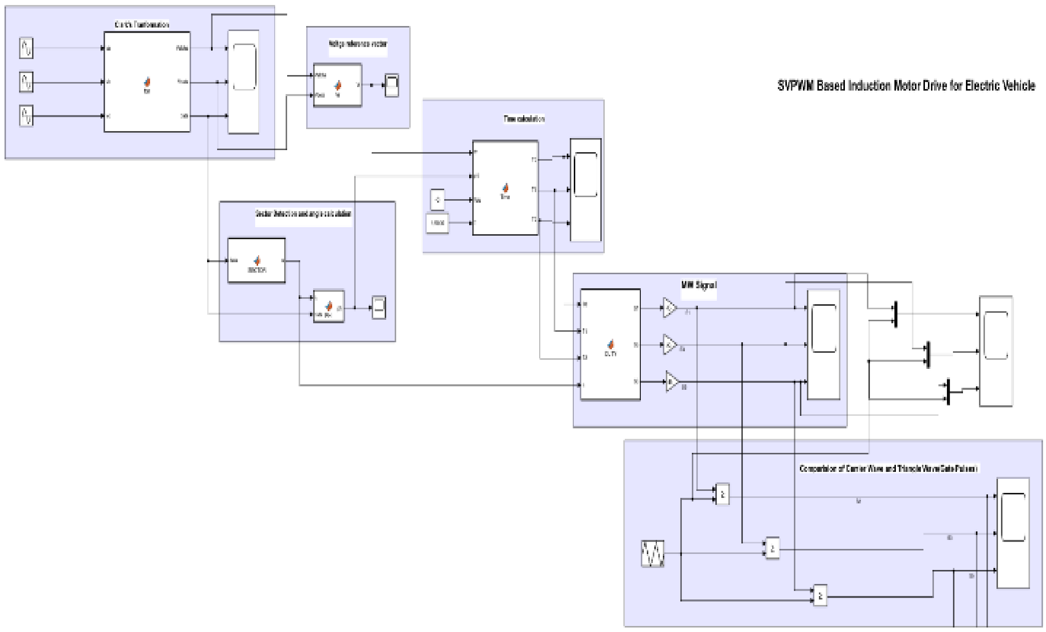


Figure 8. Overall Model of SVPWM based Induction Motor

4. Result Analysis

4.1 SPWM based IM for EV

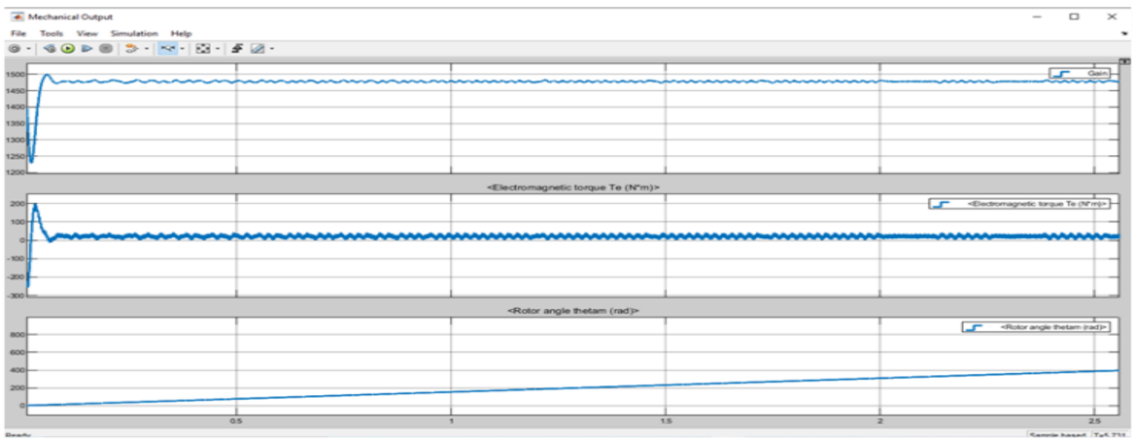


Figure 9. Mechanical Output

This graph shows the speed in RPM, Electromagnetic Torque and Rotor angle of an induction motor. Speed of the motor is around 1450 RPM.

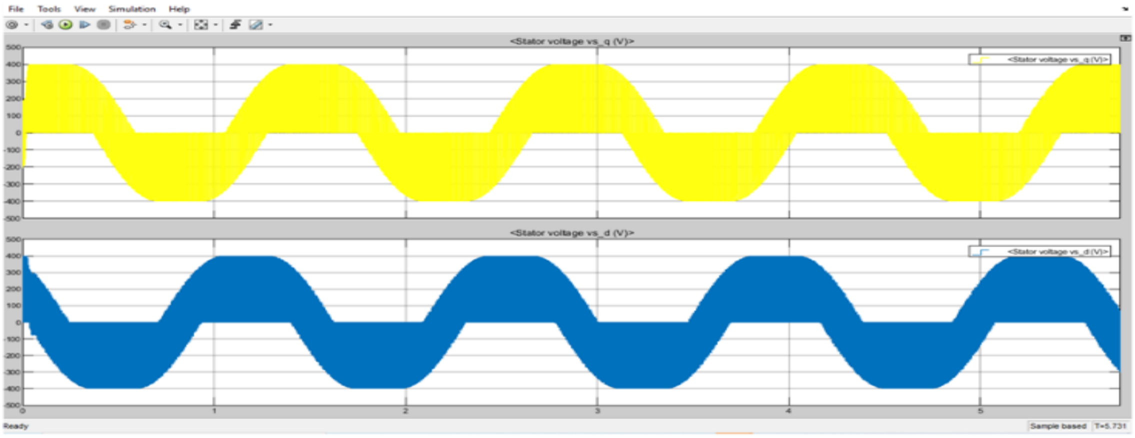


Figure 10. Stator Voltage

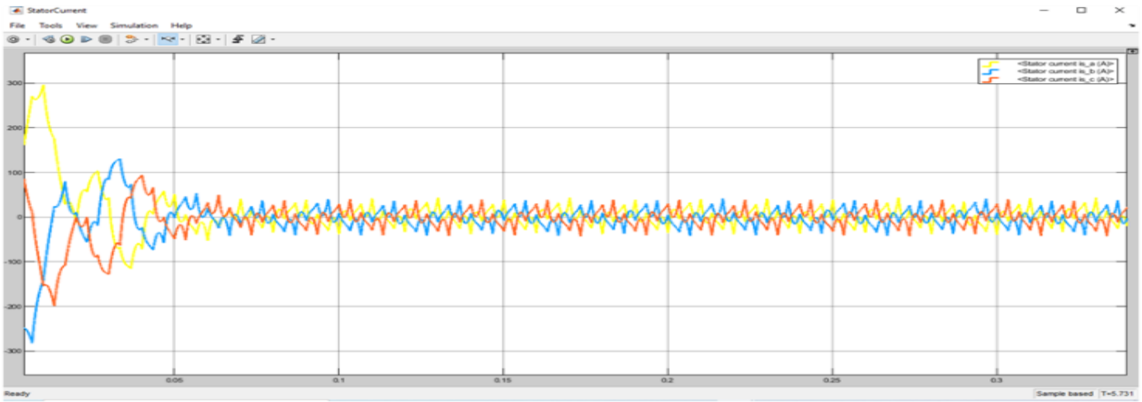


Figure 11. Stator Current

This graph shows the three-phase stator current of the induction motor. As we can see that it is having the harmonic content in it. Here the THD analysis has been done for the same.

4.2 SVPWM based IM for EV

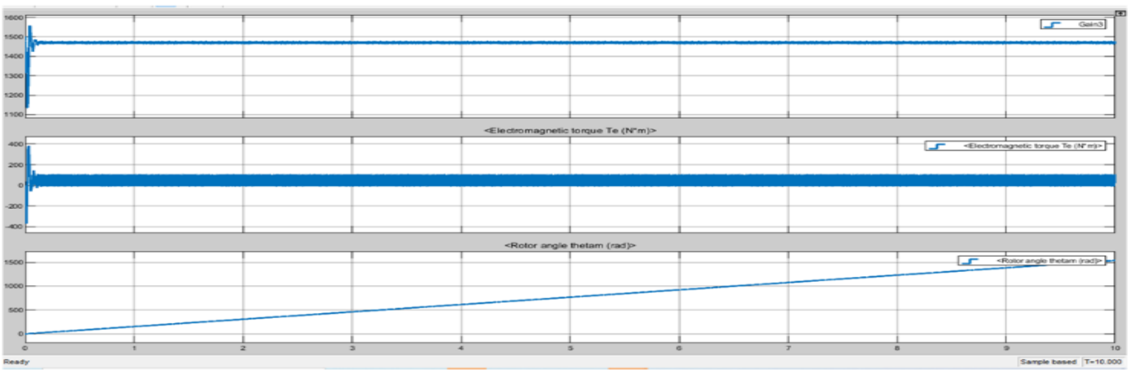


Figure 12. Mechanical Output

This graph shows the speed in RPM, Electromagnetic Torque and Rotor angle of an induction motor. Speed of the motor is around 1450 RPM.

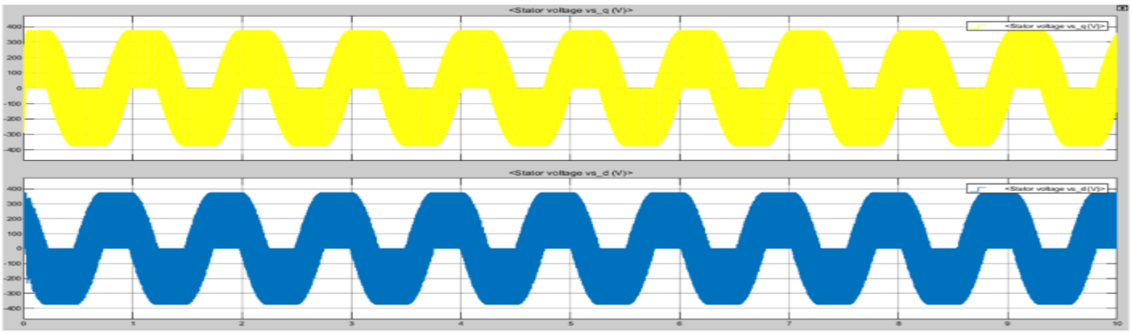


Figure 13. Stator voltage

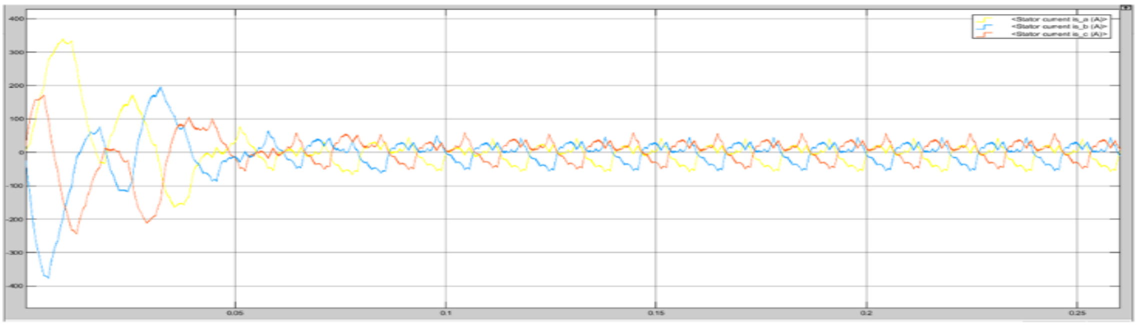
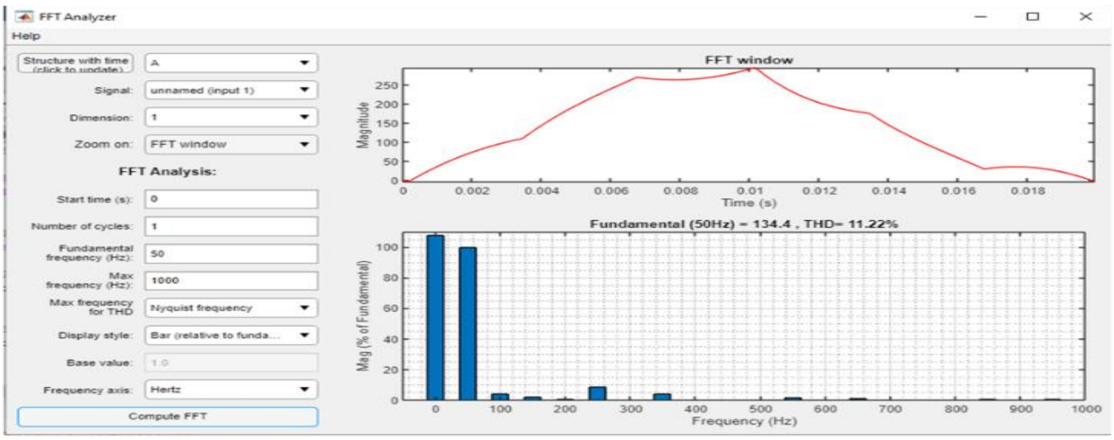


Figure 14. Stator Current

This graph shows the three-phase stator current of the induction motor. As we can see that it is having the harmonic content in it. Here the THD analysis has been done for the same.

4.3 Comparative Analysis of Stator Current THD



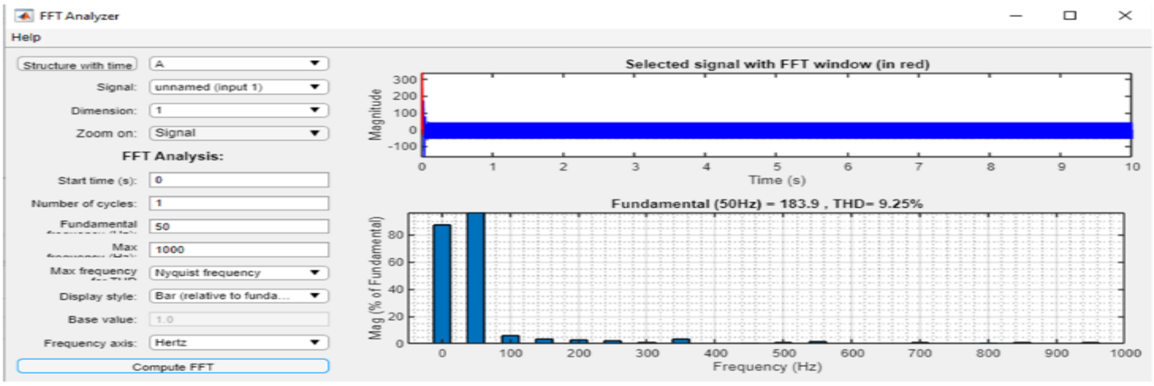


Figure 15. THD values of SPWM and SVPWM

As shown in Figure 15, the THD is reduced in SVPWM when compared to the SPWM, which in turn reduces the mis-operation of the components and the heat losses generated due to the THD.

Table 2. Comparison between the Methods

S. No	Method	Stator Current THD
1	SPWM	11.2%
2	SVPWM	9.25%

Table 2 shows the comparative analysis of stator current of SPWM and SVPWM based IM for EV. Reducing the THD can improves the live cycle and reduces the heat generated in all the components involved in the EV (motor, controller and battery). By using the SVPWM method the THD of stator current for the machines are reduced.

5. Conclusion

Three phase induction motor using SPWM and SVPWM technique for electric vehicles has been evaluated in this research using MATLAB/SIMULINK. Both techniques' comparative performances were presented. According to the simulation results, the SVPWM technique performs better in terms of eliminating stator current harmonics and reducing torque ripple while maintaining the other system characteristics. The THD produced by the SVPWM technique is comparably low as shown in Table 2.

Conflict of interest

The authors have declared no conflict of interests.

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References

[1] Sanguesa, Julio A., Vicente Torres-Sanz, Piedad Garrido, Francisco J. Martinez, and Johann M. Marquez-Barja. "A review on electric vehicles: Technologies and challenges." *Smart Cities* 4, no. 1 (2021): 372-404.

[2] Ehsani, Mehrdad, Krishna Veer Singh, Hari Om Bansal, and Ramin Tafazzoli Mehrjardi. "State of the art and trends in electric and hybrid electric vehicles." Proceedings of the IEEE 109, no. 6 (2021): 967-984.

[3] Muratori, Matteo, Marcus Alexander, Doug Arent, Morgan Bazilian, Pierpaolo Cazzola, Ercan M. Dede, John Farrell et al. "The rise of electric vehicles—2020 status and future expectations." Progress in Energy 3, no. 2 (2021): 022002.

[4] Husain, Iqbal, Burak Ozpineci, Md Sariful Islam, Emre Gurpinar, Gui-Jia Su, Wensong Yu, Shajjad Chowdhury, Lincoln Xue, Dhrubo Rahman, and Raj Sahu. "Electric drive technology trends, challenges, and opportunities for future electric vehicles." Proceedings of the IEEE 109, no. 6 (2021): 1039-1059.

[5] Bhatti, Ghanishtha, Harshit Mohan, and R. Raja Singh. "Towards the future of smart electric vehicles: Digital twin technology." Renewable and Sustainable Energy Reviews 141 (2021): 110801.

[6] Tran, Manh-Kien, Asad Bhatti, Reid Vrolyk, Derek Wong, Satyam Panchal, Michael Fowler, and Roydon Fraser. "A review of range extenders in battery electric vehicles: current progress and future perspectives." World Electric Vehicle Journal 12, no. 2 (2021): 54.

[7] Wu, Wei, and Boqiang Lin. "Benefits of electric vehicles integrating into power grid." Energy 224 (2021): 120108.

[8] Bai, Shengxi, and Chunhua Liu. "Overview of energy harvesting and emission reduction technologies in hybrid electric vehicles." Renewable and Sustainable Energy Reviews 147 (2021): 111188.

[9] Poorfakhraei, Amirreza, Mehdi Narimani, and Ali Emadi. "A review of multilevel inverter topologies in electric vehicles: Current status and future trends." IEEE Open Journal of Power Electronics 2 (2021): 155-170.

[10] İnci, Mustafa, Mehmet Büyük, Mehmet Hakan Demir, and Göktürk İlbey. "A review and research on fuel cell electric vehicles: Topologies, power electronic converters, energy management methods, technical challenges, marketing and future aspects." Renewable and Sustainable Energy Reviews 137 (2021): 110648.

[11] Hussain, Muhammad Tayyab, Nasri Bin Sulaiman, Muhammad Sabir Hussain, and Muhammad Jabir. "Optimal Management strategies to solve issues of grid having Electric Vehicles (EV): A review." Journal of Energy Storage 33 (2021): 102114.

[12] Abid, Meryem, Mohammed Tabaa, Asmae Chakir, and Hanaa Hachimi. "Routing and charging of electric vehicles: Literature review." Energy Reports 8 (2022): 556-578.

[13] Puma-Benavides, David Sebastian, Javier Izquierdo-Reyes, Juan de Dios Calderon-Najera, and Ricardo A. Ramirez-Mendoza. "A systematic review of technologies, control methods, and optimization for extended-range electric vehicles." Applied Sciences 11, no. 15 (2021): 7095.

[14] Zhao, Jianyu, Xi Xi, Qi Na, Shanshan Wang, Seifedine Nimer Kadry, and Priyan Malarvizhi Kumar. "The technological innovation of hybrid and plug-in electric vehicles for environment carbon pollution control." Environmental Impact Assessment Review 86 (2021): 106506.

[15] AL-Dhaifallah, Mujahed, Ziad M. Ali, Mohana Alanazi, Sajjad Dadfar, and Mohammad Hosein Fazaeli. "An efficient short-term energy management system for a microgrid with renewable power generation and electric vehicles." Neural Computing and Applications 33, no. 23 (2021): 16095-16111.

[16] Zhou, Yang, Alexandre Ravey, and Marie-Cécile Péra. "Real-time cost-minimization power-allocating strategy via model predictive control for fuel cell hybrid electric vehicles." Energy Conversion and Management 229 (2021): 113721.

[17] Lotfi, Mohamed, Tiago Almeida, Mohammad S. Javadi, Gerardo J. Osório, Cláudio Monteiro, and João PS Catalão. "Coordinating energy management systems in smart cities with electric vehicles." Applied Energy 307 (2022): 118241.

[18] Rajkumar G & Ajna K I (2022) Design and Performance Evaluation of Efficiency Enhanced Solar Food Processor, Smart Science, 10:4, 283-293, DOI: 10.1080/23080477.2021.2012009

[19] Ganesamoorthy, Rajkumar, and Sekar Srinivasan. "An improved intermittent power supply technique for electrostatic precipitators." Energy Harvesting and Systems (2022).

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