International Journal of Power Electronics and Drive Systems (IJPEDS)
Vol. 15, No. 1, March 2024, pp. 1~7
ISSN: 2088-8694, DOI: 10.11591/ijpeds.v15.i1.pp1-7 ❒ 1

Modelling and performance analysis of free body dynamics of electric vehicles

Rajalingam Sakthivelsamy[1], Kanagamalliga Subramaniyan[2]
[1]Department of Electrical and Electronics Engineering, Saveetha Engineering College, Chennai, India
[2]Department of Electronics and Communication Engineering, Saveetha Engineering College, Chennai, India

Article Info

Article history:

Received Feb 27, 2023
Revised Jul 11, 2023
Accepted Jul 29, 2023

Keywords:

Dynamics
Efficiency
Electric vehicles
Modelling
Optimization
Performance analysis
Sustainability

ABSTRACT

The modelling and performance analysis of free body dynamics in electric vehicles (EVs) plays a crucial role in understanding and optimizing the vehicle's behavior and performance. This research focuses on accurately modelling the forces and motions acting on the vehicle body, excluding the powertrain components. By considering factors such as vehicle weight, suspension characteristics, tire properties, and aerodynamic forces, a comprehensive mathematical model is developed. This model enables the simulation and analysis of the vehicle's behavior under various operating conditions. The performance analysis involves evaluating key metrics such as vehicle response, stability limits, and ride comfort. The proposed system is compared with the existing electric vehicle in the market. The findings from this research contribute to the design and development of EVs with improved handling, stability, and energy efficiency. Additionally, they inform the development of advanced driver-assistance systems (ADAS) and autonomous driving technologies. Overall, the modelling and performance analysis of free body dynamics in EVs supports the advancement of sustainable and efficient transportation systems.

Corresponding Author:

Rajalingam Sakthivelsamy
Department of Electrical and Electronics Engineering, Saveetha Engineering College
Chennai, India
Email: rajalingams@saveetha.ac.in

1. INTRODUCTION

The rapid growth in the popularity of electric vehicles (EVs) has revolutionized the automotive industry, offering a sustainable and eco-friendly alternative to conventional internal combustion engine vehicles. The modelling and performance analysis of free body dynamics in electric vehicles (EVs) has gained significant attention in recent years. Free body dynamics refers to the study of forces and motions acting on the vehicle body, excluding the powertrain components. Understanding and accurately modelling these dynamics are crucial for optimizing the vehicle's behavior, handling, stability, and overall performance.

As the automotive industry shifts towards electric mobility, there is a growing need to develop advanced modelling techniques that capture the unique characteristics of electric vehicles. Compared to conventional internal combustion engine vehicles, EVs have different weight distributions, power delivery mechanisms, and handling characteristics. Therefore, specific modelling approaches are required to accurately represent the forces and motions acting on the EV body. The modelling process involves developing mathematical representations that consider various factors influencing the vehicle's dynamics. These factors include weight distribution, suspension characteristics, tire properties, and aerodynamic forces. By incorporating these elements into the model, researchers can simulate and analyze the vehicle's behavior under different operating conditions, such as acceleration, braking, and cornering. Performance analysis is a crucial aspect of studying free-body dynamics in EVs. Through simulations and experimental tests, researchers can evaluate key performance metrics such as vehicle response, stability limits, and ride comfort. These analyses provide insights into the vehicle's handling characteristics, allowing for the identification of areas for improvement and optimization. Optimizing the free-body dynamics of electric vehicles offers several benefits. Firstly, improved handling and stability contribute to enhanced driving experience and safety for EV users. By accurately modelling the forces and motions acting on the vehicle body, potential issues such as excessive body roll, understeer, or oversteer can be identified and addressed during the design phase. Secondly, optimizing the vehicle's dynamics can lead to improved energy efficiency and range. By reducing unnecessary energy losses due to excessive body movements or inefficient weight distribution, EVs can achieve better overall efficiency and extended driving range. Moreover, the findings from modelling and performance analysis studies in free body dynamics can inform the development of advanced driver-assistance systems (ADAS) and autonomous driving technologies. Understanding how the vehicle body responds to external inputs and disturbances is crucial for designing robust control algorithms that enhance safety and stability in various driving conditions.

The modelling and performance analysis of free body dynamics in electric vehicles is essential for understanding and optimizing the behavior, handling, and stability of EVs. The unique characteristics of electric vehicles necessitate specific modelling approaches to accurately represent the forces and motions acting on the vehicle body. By analyzing the performance of EVs under different operating conditions, researchers can improve handling, enhance safety, optimize energy efficiency, and contribute to the development of advanced driver-assistance systems. Continued research and advancements in this field are crucial for realizing the full potential of electric vehicles and promoting sustainable and efficient transportation systems.

The modelling and performance analysis of the power drivetrain in electric vehicles (EVs) has been the subject of extensive research and development efforts. This literature review provides an overview of key studies and advancements in this field, highlighting the contributions and findings of previous research. The modelling of individual components within the power drivetrain is a crucial aspect of understanding their behavior and optimizing system performance. Several studies have focused on the accurate modelling of electric motors, considering factors such as electromagnetic behavior, power losses, and efficiency. A comprehensive model for a permanent magnet synchronous motor (PMSM) that captured the motor's torque characteristics and performance under various load conditions was developed [1]. Similarly, a model for an induction motor, incorporating parameters such as stator and rotor resistance, inductances, and iron losses was proposed [2].

Battery modelling is another critical area of research in power drivetrain analysis. Researchers have aimed to capture the battery's behavior, including state of charge, voltage drop, and internal resistance. A battery model was developed that accounted for capacity fading and ageing effects, providing accurate predictions of the battery's performance over time [3]. A comprehensive model was proposed for lithium-ion batteries that considered temperature variations and voltage hysteresis effects, enabling accurate characterization of battery behavior under different operating conditions [4]. Power electronics components, such as DC-DC converters and inverters, also play a significant role in power drivetrain analysis. Researchers have developed models to analyze their impact on power transfer efficiency and system dynamics. A model for a bidirectional DC-DC converter was proposed that considered switching losses and control strategies, enabling accurate performance analysis of the converter within the power drivetrain system [5]–[7]. Performance analysis is crucial for evaluating the efficiency and effectiveness of power drivetrain systems in electric vehicles. Researchers have conducted simulations and experimental tests to assess various performance metrics. The impact of different electric motor control strategies on powertrain efficiency and dynamic response was investigated [8]–[10]. Field-oriented control, direct torque control, and sensor less control techniques, highlighting the trade-offs between efficiency and control complexity were compared during the instigation. Performance analysis of different battery management strategies was conducted, considering factors such as energy efficiency, charging time, and battery lifespan [11]–[14].

Furthermore, optimization techniques have been employed to improve the performance of power drivetrains in electric vehicles. A multi-objective optimization framework was proposed that simultaneously considered powertrain efficiency, energy consumption, and cost [15]–[18]. The study demonstrated the potential for optimizing motor sizing, battery capacity, and gear ratios to achieve superior performance in terms of energy efficiency and cost-effectiveness. A hybrid optimization algorithm combining a genetic algorithm with a particle swarm optimization to optimize the powertrain control strategy, resulting in improved energy efficiency and reduced energy consumption [19]–[22]. The integration of advanced control algorithms and energy management systems has been a focal point in power drivetrain analysis. Researchers have explored the use of model predictive control (MPC) and artificial intelligence techniques to optimize power distribution and improve overall system performance. MPC-based energy management strategy for hybrid electric vehicles, considering factors such as driver demand, traffic conditions, and energy availability was developed. The study demonstrated improved fuel economy and emissions reduction compared to traditional control strategies [23]–[26].

The literature review highlights significant advancements in the modelling and performance analysis of power drivetrains in electric vehicles. Researchers have developed comprehensive models of individual components, conducted performance analyses, and explored optimization techniques and control strategies. These studies provide valuable insights for designing and optimizing power drivetrains, ultimately leading to more efficient and reliable electric vehicles and contributing to the transition to a sustainable transportation future.

2. PROPOSED METHOD

A battery, motor, power electronic controller, power converter, and vehicle body make up the proposed method as shown in Figure 1. The shaft of the vehicle is joined to the motor. The motor is connected to batteries and a controller through a power converter. The power converter modifies the voltage delivered to the motor, which modifies the vehicle's speed. The performance analysis of the proposed system is carried out using MATLAB. Modelling of an electric two-wheeler was performed and based on the mathematical modelling, the vehicle was constructed in the software and then simulated for analysis.

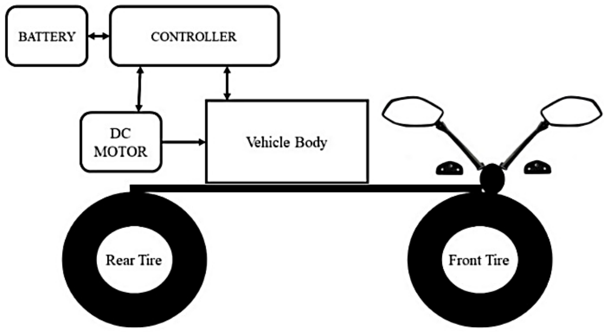

Figure 1. Block diagram of the proposed model

2.1. Components of the proposed system

The real-world components such as a battery, motor, controller, converter and vehicle body are available in the MATLAB Simulink/Simscape library. These Simulink/Simscape components help us to construct and analyze the performance of the proposed electric vehicle. To analyze the free body dynamics, components such as vehicle body, and tire is enough. To measure the speed and distance covered, an ideal translational motion sensor will be used. The details of such components are discussed in this section. For the design of the dimension and chassis of a vehicle, the component “vehicle body” from the Simscape library is used and it represents a two-axle vehicle body that includes specifications such as body mass or kerb weight, aerodynamic drag force, road inclination and weight distribution due to acceleration and road profile. The number of wheels on each axle shall be adjustable. Horizontal motion (H) acts as the mechanical translational port for the vehicle body. Headwind speed (W) and road inclination angle act as input to this component. The output of these components is the velocity (V), normal front wheel force (NF) and normal rear wheel force (NR).

The component “tire magic formula” from the Simscape library is used to represent the vehicle tire. The effect of tire inertia and rolling resistance shall be included as specifications. Port A act as the mechanical rotational port and port H act as the mechanical translational port for the wheel hub. N is the input port that represents the normal force acting on the tire. S is the output port that represents the tire slip. The component “ideal translation motion sensor” from the Simscape library is used to measure the acceleration, velocity, and displacement or distance covered by the vehicle. The output ports A, V and P report the acceleration, velocity, and position of port R relative to port C.

2.2. Modelling

Modelling of the proposed model is carried out in MATLAB Simulink and Simscape environment. The shaft of the vehicle is joined to the motor. MATLAB Simulink and Simscape are powerful software tools developed by MathWorks that offer simulation and modelling capabilities for engineers and scientists across various disciplines.

MATLAB Simulink is a block diagram environment that enables users to model, simulate, and analyze dynamic systems. It provides a graphical user interface where users can build models by connecting functional blocks representing system components and specifying their interconnections. Simulink offers a wide range of pre-built blocks and libraries for modelling electrical, mechanical, control, and signal processing systems. Users can simulate their models and analyze system behavior, making it an invaluable tool for system design, optimization, and validation [27].

On the other hand, Simscape is a physical modelling toolbox within Simulink that focuses on the simulation of physical systems [28]. It utilizes a component-based modelling approach, where system components are represented by fundamental physical elements such as resistors, capacitors, springs, and dampers [29]. Simscape allows engineers to build complex multi-domain physical models that capture the interactions between mechanical, electrical, hydraulic, and thermal components. This enables the simulation and analysis of dynamic systems in a comprehensive and realistic manner [30].

Both Simulink and Simscape offer powerful simulation capabilities with a wide range of built-in solvers, allowing users to study system behavior under various conditions and evaluate performance metrics. These tools are widely used in industries such as automotive, aerospace, energy, and robotics for tasks such as control system design, powertrain analysis, mechatronic system development, and virtual prototyping. Moreover, Simulink and Simscape provide integration with MATLAB, allowing users to incorporate custom algorithms, perform data analysis, and automate complex workflows. The tools also support code generation, enabling the implementation of real-time systems and the deployment of models onto hardware platforms. The various specifications used to model the proposed vehicle is shown in Table 1. Tire modelling is done with a rolling radius of 9 inches. The tire inertia is 1×10-3 and with an initial velocity of 0 rad/s. The rolling resistance constant is 0.005.

Table 1. Free-body specification of the proposed vehicle

S. No	Name of the data	Specification
1	Mass of the vehicle	150 kg
2	Mass of the person	150 kg
3	Number of wheels per axle	1
4	The horizontal distance from the centre of gravity to the front axle	615 mm
5	The horizontal distance from the centre of gravity to the rear axle	666 mm
6	CG height above ground	200 mm
7	Frontal area	1.12 m^2
8	Drag coefficient	1.2
9	Air density	1.3 kg/m^3

3. RESULTS AND DISCUSSION

The performance analysis of the proposed vehicle is discussed in this section. The specification of the proposed system is compared with the available market vehicle as shown in Table 2. Key parameters such as Ker weight, maximum load capacity, length of the vehicle body, width of the vehicle body and ground clearance are considered for effective comparison and analysis. The term weight is the total mass of the vehicle body with all parts and fuel excluding the load or passenger.

Table 2. Comparison of the proposed system with the existing model

S. No	Specification	Ola S1	Ather 450x Gen-3	Ampere Magnux-ex	Revolt RV 400	Proposed model
1	Ker weight in Kg	121	111.6	82	108	150
2	Maximum load capacity in Kg	150	150	150	150	150
3	Length in mm	1859	1837	1920	2156	2000
4	Width in mm	712	734	685	813	800
5	Ground clearance/height in mm	165	153	147	215	180

The MATLAB Simscape/Simulink diagram of the proposed free-body vehicle is shown in Figure 2. All 'H' port of the tire and the vehicle body is connected. The normal front (NR) wheel and normal rear (NR) wheel force of the vehicle body is connected normal force (N) of the tire. The Simscape component "rotational free end" is connected to port 'A' of the tire since the motor is not connected, as it is free body modelling.

The headwind speed is negligibly small for horizontal free body analysis; hence it is ignored the performance analysis at the inclination angle or gradient of 0 rad, 10 rad and -10 radian has been simulated. When the gradient is zero, there is no motion. At the negative gradient of -10 rad, the vehicle starts to move in the forward direction and it reaches the maximum speed of 82.23 km/hr. It also reaches 13.48 km or 13480 m in 10 minutes. The simulation results at the negative gradient of -10 rad are shown in Figure 3. From the simulation results, it is also found that it takes 78 seconds to reach the maximum speed of 82.23 km/hr.

At the positive gradient of +10 rad, the vehicle starts to move in the reverse direction and it reaches the maximum speed of 82.23 km/hr. It also reaches 13.48 km or 13480 m in 10 minutes in the reverse direction. The simulation results at the positive gradient of +10 rad are shown in Figure 4. From the simulation results, it is also found that it takes 78 seconds to reach the maximum speed of 82.23 km/hr. The performance of the proposed vehicle is compared with the existing market vehicles. Table 3 shows the simulated results of various existing electric vehicles with the proposed vehicle.

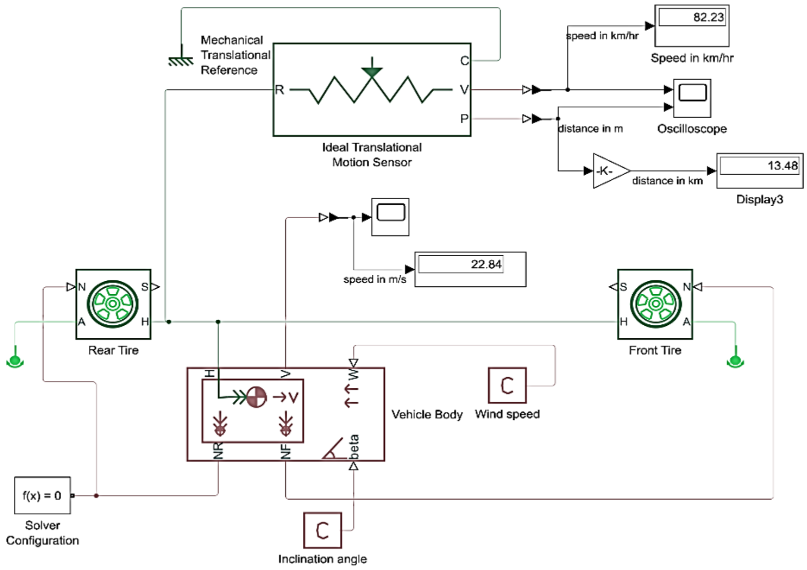

Figure 2. Simulink/Simscape diagram of the proposed system

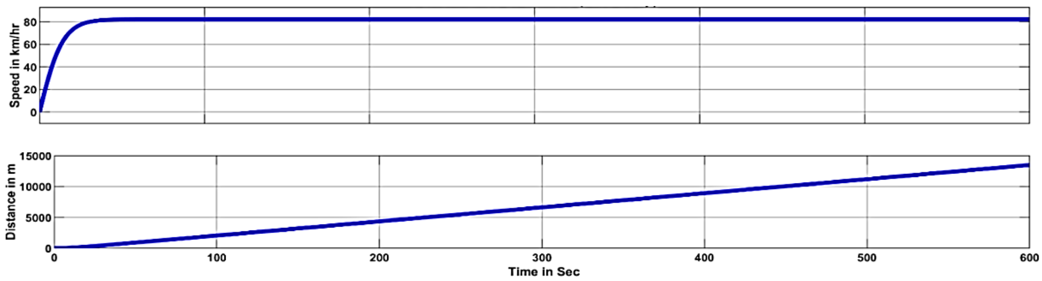

Figure 3. Performance of vehicle during negative gradient (-10 rad)

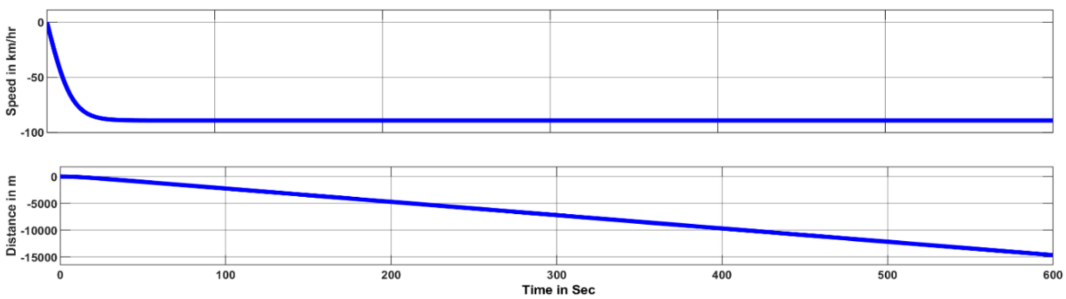

Figure 4. Performance of vehicle during positive gradient (+10 rad)

Table 3. Comparative performance analysis of the simulated models

S. No	Type of vehicle	Maximum speed (Free body) in km/hr	Time to reach the maximum speed in seconds	The maximum distance covered in 600 seconds or 10 minutes expressed in km
1	Ola S1	75.21	71	12.35
2	Ather 450x Gen-3	73.83	67	12.12
3	Ampere Magnux-ex	69.32	67	11.39
4	Revolt RV 400	73.29	62	12.04
5	Proposed model	82.23	78	13.48

The comparison results show that the proposed model achieves a speed that is higher than other vehicles. The proposed model takes 78 seconds to reach its maximum which is higher than the existing models. The distance covered at 10 minutes is also higher comparatively. The higher free body performance analysis reveals that the steady state capability is greater than the existing vehicle models. The initial torque requirement will be a little higher whereas the steady-state torque requirement will be lower than other models. Thus, the proposed model will have better steady-state stability and higher distance coverage. This can be further developed by connecting suitable batteries, motors and controllers to analyze the performance of power drive train characteristics. By conducting simulations of power drive train modelling, researchers can assess key performance metrics, such as power output, torque characteristics, energy consumption, and thermal management.

4. CONCLUSION

The modelling and performance analysis of free body dynamics in electric vehicles is essential for optimizing their performance, enhancing safety, and promoting sustainable and efficient transportation systems. To analyze the performance of vehicle dynamics, the modelling of the proposed vehicle is developed in MATLAB Simulink and Simscape environment. Various dynamic forces such as rolling resistance force, aerodynamic force, and hill-climbing force were considered for modelling. From the simulated results, it is shown that the maximum speed of 82.23 km/hr. and the distance covered in 10 minutes is 13.46 km which is the highest in the category. The Proposed model has better performance with greater speed dynamics and long-distance coverage validating the better stability. The comparative analysis shows the current market trend in the dynamics and the gap to improve. This article shall be further developed by connecting different power drive train systems and their performance such as power output, torque characteristics, energy consumption, and thermal management shall be analyzed accordingly. In conclusion, the modelling and performance analysis of free body dynamics of electric vehicles holds immense promise in researching for budding young researchers to start in the area of electric vehicle technologies to analyze its various performance characteristics.

ACKNOWLEDGEMENTS

We thank the Director, Principal and HOD of Saveetha Engineering College, Chennai, for providing the facilities and research support in carrying out the work in the Department. No other research grant or contracts are applicable for this research.

REFERENCES

[1] M. S. Rafaq, W. Midgley, and T. Steffen, "A Review of the State of the Art of Torque Ripple Minimization Techniques for Permanent Magnet Synchronous Motors," *IEEE Transactions on Industrial Informatics*, 2023, doi: 10.1109/TII.2023.3272689.

[2] K. V and B. Singh, "Optimized Reference Points Based Vector Control of Induction Motor Drive For Electric Vehicle," *IEEE Transactions on Industry Applications*, 2023, doi: 10.1109/TIA.2023.3272534.

[3] J. Shi, A. Rivera, and D. Wu, "Battery health management using physics-informed machine learning: Online degradation modeling and remaining useful life prediction," *Mechanical Systems and Signal Processing*, vol. 179, 2022, doi: 10.1016/j.ymssp.2022.109347.

[4] H. Löbberding *et al.*, "From cell to battery system in BEVs: Analysis of system packing efficiency and cell types," *World Electric Vehicle Journal*, vol. 11, no. 4, pp. 1–15, 2020, doi: 10.3390/wevj11040077.

[5] A. A. E. B. A. El Halim, E. H. E. Bayoumi, W. El-Khattam, and A. M. Ibrahim, "Electric vehicles: a review of their components and technologies," *International Journal of Power Electronics and Drive Systems*, vol. 13, no. 4, pp. 2041–2061, 2022, doi: 10.11591/ijpeds.v13.i4.pp2041-2061.

[6] S. Chakraborty *et al.*, "Real-Life Mission Profile-Oriented Lifetime Estimation of a SiC Interleaved Bidirectional HV DC/DC Converter for Electric Vehicle Drivetrains," *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 10, no. 5, pp. 5142–5167, 2022, doi: 10.1109/JESTPE.2021.3083198.

[7] P. V. Nandankar, P. P. Bedekar, and P. V. Dhawas, "Efficient DC-DC converter with optimized switching control: A comprehensive review," *Sustainable Energy Technologies and Assessments*, vol. 48, 2021, doi: 10.1016/j.seta.2021.101670.

[8] M. Haji Akhoundzadeh, S. Panchal, E. Samadani, K. Raahemifar, M. Fowler, and R. Fraser, "Investigation and simulation of electric train utilizing hydrogen fuel cell and lithium-ion battery," *Sustainable Energy Technologies and Assessments*, vol. 46, 2021, doi: 10.1016/j.seta.2021.101234.

[9] Y. Qin *et al.*, "Noise and vibration suppression in hybrid electric vehicles: State of the art and challenges," *Renewable and Sustainable Energy Reviews*, vol. 124, 2020, doi: 10.1016/j.rser.2020.109782.

[10] W. Cai, X. Wu, M. Zhou, Y. Liang, and Y. Wang, "Review and Development of Electric Motor Systems and Electric Powertrains for New Energy Vehicles," *Automotive Innovation*, vol. 4, no. 1, pp. 3–22, 2021, doi: 10.1007/s42154-021-00139-z.

[11] F. Zhang *et al.*, "Comparative study of energy management in parallel hybrid electric vehicles considering battery ageing," *Energy*, vol. 264, 2023, doi: 10.1016/j.energy.2022.123219.

[12] Y. Amry, E. Elbouchikhi, F. Le Gall, M. Ghogho, and S. El Hani, "Optimal sizing and energy management strategy for EV workplace charging station considering PV and flywheel energy storage system," *Journal of Energy Storage*, vol. 62, 2023, doi: 10.1016/j.est.2023.106937.

[13] N. G. Panwar, S. Singh, A. Garg, A. K. Gupta, and L. Gao, "Recent Advancements in Battery Management System for Li-Ion Batteries of Electric Vehicles: Future Role of Digital Twin, Cyber-Physical Systems, Battery Swapping Technology, and

Nondestructive Testing," *Energy Technology*, vol. 9, no. 8, 2021, doi: 10.1002/ente.202000984.
[14] A. K. Podder, O. Chakraborty, S. Islam, N. Manoj Kumar, and H. H. Alhelou, "Control Strategies of Different Hybrid Energy Storage Systems for Electric Vehicles Applications," *IEEE Access*, vol. 9, pp. 51865–51895, 2021, doi: 10.1109/ACCESS.2021.3069593.
[15] J. Zhou *et al.*, "The Multi-Objective Optimization of Powertrain Design and Energy Management Strategy for Fuel Cell–Battery Electric Vehicle," *Sustainability (Switzerland)*, vol. 14, no. 10, 2022, doi: 10.3390/su14106320.
[16] S. B. Pandya, S. Ravichandran, P. Manoharan, P. Jangir, and H. H. Alhelou, "Multi-Objective Optimization Framework for Optimal Power Flow Problem of Hybrid Power Systems Considering Security Constraints," *IEEE Access*, vol. 10, pp. 103509–103528, 2022, doi: 10.1109/ACCESS.2022.3209996.
[17] F. Verbruggen, M. Salazar, M. Pavone, and T. Hofman, "Joint Design and Control of Electric Vehicle Propulsion Systems," *European Control Conference 2020, ECC 2020*, pp. 1725–1731, 2020, doi: 10.23919/ecc51009.2020.9143869.
[18] M. K. Tran, M. Akinsanya, S. Panchal, R. Fraser, and M. Fowler, "Design of a Hybrid Electric Vehicle Powertrain for Performance Optimization Considering Various Powertrain Components and Configurations," *Vehicles*, vol. 3, no. 1, pp. 20–32, 2021, doi: 10.3390/vehicles3010002.
[19] M. Nivas, R. K. P. R. Naidu, D. P. Mishra, and S. R. Salkuti, "Modeling and analysis of solar-powered electric vehicles," *International Journal of Power Electronics and Drive Systems*, vol. 13, no. 1, pp. 480–487, 2022, doi: 10.11591/ijpeds.v13.i1.pp480-487.
[20] K. Ye, P. Li, and H. Li, "Optimization of Hybrid Energy Storage System Control Strategy for Pure Electric Vehicle Based on Typical Driving Cycle," *Mathematical Problems in Engineering*, vol. 2020, 2020, doi: 10.1155/2020/1365195.
[21] N. Ding, K. Prasad, and T. T. Lie, "Design of a hybrid energy management system using designed rule-based control strategy and genetic algorithm for the series-parallel plug-in hybrid electric vehicle," *International Journal of Energy Research*, vol. 45, no. 2, pp. 1627–1644, 2021, doi: 10.1002/er.5808.
[22] J. Oncken and B. Chen, "Real-Time Model Predictive Powertrain Control for a Connected Plug-In Hybrid Electric Vehicle," *IEEE Transactions on Vehicular Technology*, vol. 69, no. 8, pp. 8420–8432, 2020, doi: 10.1109/TVT.2020.3000471.
[23] V. Sidharthan Panaparambil, Y. Kashyap, and R. Vijay Castelino, "A review on hybrid source energy management strategies for electric vehicle," *International Journal of Energy Research*, vol. 45, no. 14, pp. 19819–19850, 2021, doi: 10.1002/er.7107.
[24] P. Dong *et al.*, "Practical application of energy management strategy for hybrid electric vehicles based on intelligent and connected technologies: Development stages, challenges, and future trends," *Renewable and Sustainable Energy Reviews*, vol. 170, 2022, doi: 10.1016/j.rser.2022.112947.
[25] C. Yang, M. Zha, W. Wang, K. Liu, and C. Xiang, "Efficient energy management strategy for hybrid electric vehicles/plug-in hybrid electric vehicles: Review and recent advances under intelligent transportation system," *IET Intelligent Transport Systems*, vol. 14, no. 7, pp. 702–711, 2020, doi: 10.1049/iet-its.2019.0606.
[26] J. Hao, S. Ruan, and W. Wang, "Model Predictive Control Based Energy Management Strategy of Series Hybrid Electric Vehicles Considering Driving Pattern Recognition," *Electronics (Switzerland)*, vol. 12, no. 6, 2023, doi: 10.3390/electronics12061418.
[27] V. Saini, P. Shah, and R. Sekhar, "MATLAB and Simulink for Building Automation," *IBSSC 2022 - IEEE Bombay Section Signature Conference*, 2022, doi: 10.1109/IBSSC56953.2022.10037485.
[28] L. Thyagarajan and G. Venkataramanan, "Design of Electric Drive Dynamics using Impedance Separation and Impedance Shaping," *2022 IEEE Transportation Electrification Conference and Expo, ITEC 2022*, pp. 172–179, 2022, doi: 10.1109/ITEC53557.2022.9813994.
[29] L. Almatrafi, S. Badaam, and S. M. Qaisar, "Electric Vehicle Performance Evaluation Using UDDS, NYCC and WLTP Drive Cycles," *20th International Learning and Technology Conference, L and T 2023*, pp. 103–108, 2023, doi: 10.1109/LT58159.2023.10092321.
[30] K. B. Tawfiq, M. N. Ibrahim, E. E. El-Kholy, and P. Sergeant, "Approach to couple MATLAB Simscape and Simulink blocks for dynamic analysis of multiphase drive systems," *AIP Conference Proceedings*, vol. 2456, 2022, doi: 10.1063/5.0074473.

BIOGRAPHIES OF AUTHORS

Rajalingam Sakthivelsamy currently working as Associate Professor in the department of Electrical and Electronics Engineering, Saveetha Engineering College, Chennai, India. He holds a Bachelor degree in Electrical and Electronics Engineering, Master degree in Power Electronics and Drives, and a Ph.D., degree in Electrical Engineering from Anna University, Chennai. His research interests include Energy Management, Power Electronics and Drives, power quality, Electric vehicle. He has great experience in the field of research, having published over 30 technical papers in various international journals and conferences. He is a Professional member of IEEE and an Associate member of IE (I). He can be contacted at email: rajalingams@saveetha.ac.in.

Kanagamalliga Subramaniyan is an Associate Professor, with the Department of ECE, Saveetha Engineering College, Chennai, India. She received her B.E degree in ECE and her M.E degree in Communication Systems and Ph.D. degree in Information and Communication Engineering at Anna University, India. She is the author of more than 50 Technical papers in International Journals, and International/National Conferences. Her research interests include artificial intelligence, computer vision, video surveillance, image, video and audio signal processing. She is a Life member of the Institution of Electronics and Telecommunication Engineers. She can be contacted at email: malliga87@gmail.com.