Modeling and simulation of hybrid electric vehicles

Cite as: AIP Conference Proceedings **2333**, 090035 (2021); https://doi.org/10.1063/5.0041853
Published Online: 08 March 2021

Gergana Vacheva, and Nikolay Hinov

Modeling and Simulation of Hybrid Electric Vehicles

Gergana Vacheva[a)] and Nikolay Hinov[b)]

Department of Power Electronics, Faculty of Electronic Engineering and Technologies
Technical University of Sofia 8 Kliment Ohridski blvd., 1000 Sofia, Bulgaria

[a)]Corresponding author: gergana_vacheva@tu-sofia.bg
[b)]hinov@tu-sofia.bg

Abstract. In the current research modeling and simulation of a hybrid electric vehicle (HEV) in PSIM environment is presented. A review of the frequently used structure of for realization of the HEVs are proposed. Consistently, the individual stages of modeling are presented including the choice of electric motor, power electronic converters and energy storage devices. The simulation results of the most important electrical and mechanical parameters which characterized the HEVs are presented. This modeling method is very useful and suitable for the purposes of the training of the power and automotive electronics.

INTRODUCTION

With the development of human progress, at a rapid pace over the last two centuries, significant environmental problems are beginning to emerge. Despite the good economic indicators in industry and human life, they have a negative impact on our environment. These influences include global warming, problems in the planet's ozone layer, which leads to melting glaciers, rising sea levels and much more.

The main causes of these problems are related to the rapid increase of gases such as carbon dioxide (CO_2), methane, water vapor and others. The causes of the above problems could hinder the development of life on our planet. Vehicles, such as cars with internal combustion engines, buses, ships, airplanes, trains, etc., rank after thermal power plants worldwide.

Another major problem that stimulates the development of hybrid electric vehicles is the limited oil reserves. World oil consumption is constantly increasing and cannot be compensated. Accordingly, this leads to an increase in its price and strong dependence on the countries in which it is mined. For these reasons, it is important to find a new technological solution to reduce this consumption.

Descriptive models can give the most general idea of the content and nature of the problem. This allows to easily analyze the processes developing in them. Mathematical models can describe real physical objects with simple or detailed mathematical descriptions and algorithms. They are currently the most widespread, due to their indisputable advantages in terms of their applicability in structural approaches to the analysis of systems with a large number of different types of elements, space-time constraints, economic efficiency, requirements for small computational times, not requiring high computer power, the convenience of presenting the results, etc. For these reasons in this research a mathematical model and simulation results of a hybrid electric vehicles are presented.

HYBRID ELECTRIC VEHICLE

There are different architectures for connecting different mechanical converters. The two most used of them for serial and parallel architecture are shown in Figure 1 and Figure 2. The presence of reversible energy sources supercapacitor and fuel cell helps to recover energy during regenerative braking of the HEV. The use of an internal combustion engine with an electric motor are an advantage [1-5].

Applications of Mathematics in Engineering and Economics (AMEE'20)
AIP Conf. Proc. 2333, 090035-1–090035-8; https://doi.org/10.1063/5.0041853
Published by AIP Publishing. 978-0-7354-4077-7/$30.00

HEV is driven by traction motor. It is powered by a battery and / or a motor / generator unit that assists the system when it's necessary higher load or charge requirements. The traction motor control system manages it in order to achieve the required power of the HEV. Acceleration, the ability to climb the vehicle and the maximum speed are decisive for the size and characteristics of the traction unit.

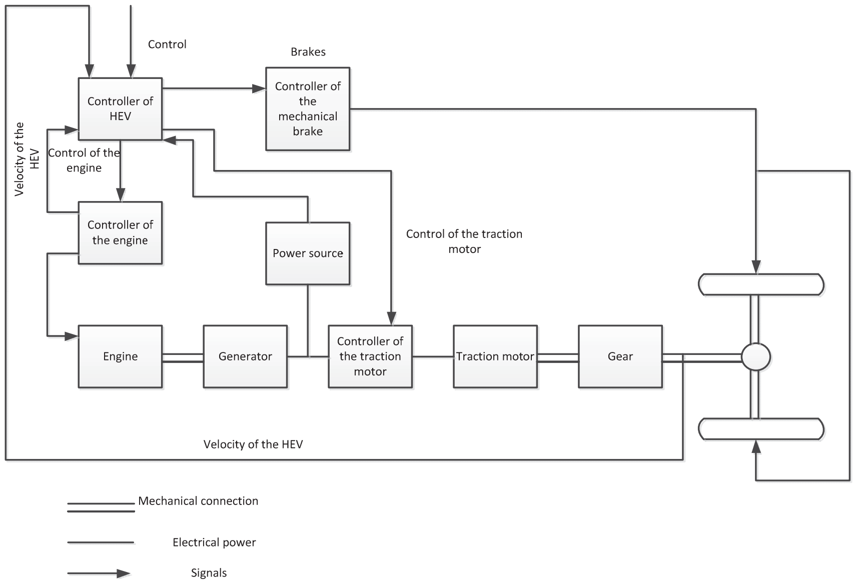

FIGURE 1. Architecture of a typical series HEV

Unlike serial hybrid drive, parallel drive has some advantages that allow the internal combustion engine and traction motor to directly transmit mechanical power to the drive wheels. In this case a generator is not needed, the traction motor is smaller and the transmission of energy from the internal combustion engine to the drive wheels is not necessary. Accordingly, this increases the efficiency of the HEV. Last but not least, the control of the parallel drive is more complex, which is due to the mechanical connection between the motor and the drive wheels [5-10].

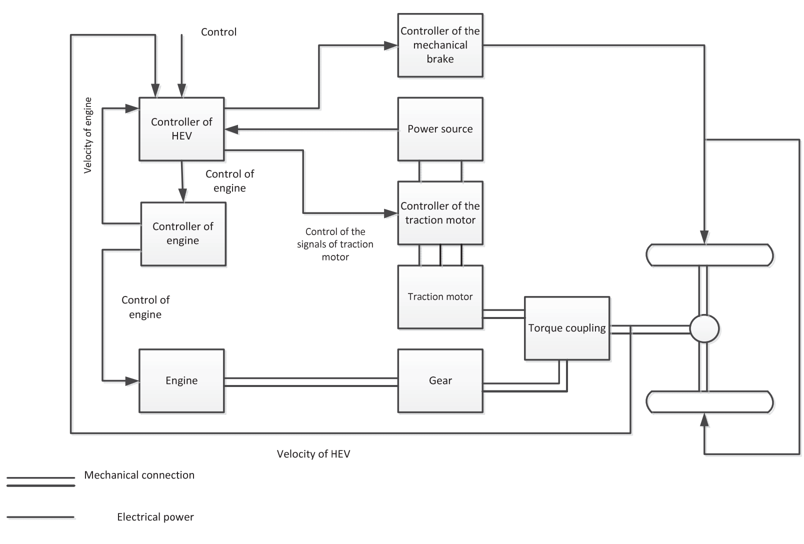

FIGURE 2. Architecture of a typical parallel HEV

In Figure 3 a block diagram of the studied structure is presented. It consist of model of the HEV which include an engine, a generator, a traction motor, a DC-DC converter, a stack of batteries and a control system [10-12].

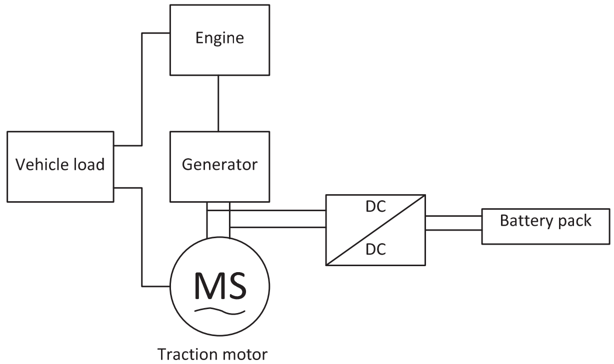

FIGURE 3. Structure of a hybrid electric vehicle

In Figure 4 the realized model in PSIM environment is proposed.

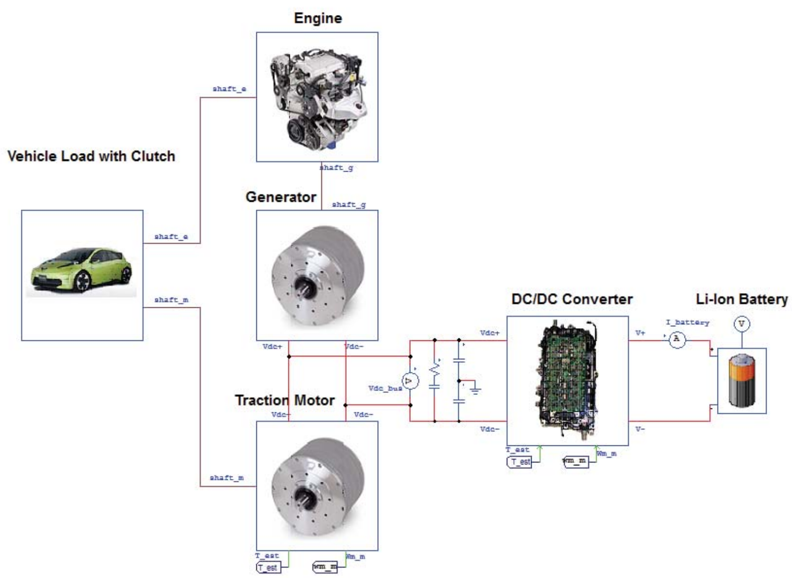

FIGURE 4. Model of hybrid electric vehicle in PSIM

Bidirectional DC-DC Converter

In Figure 5 a bidirectional four quadrant DC-DC converter is presented. The circuits work as a two quadrant converter and has 4 different modes.

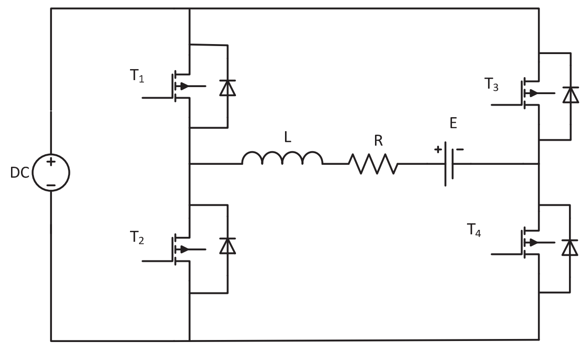

FIGURE 5. Four quadrant converter

In Figure 6 is presented topology of bidirectional DC-DC converter. Based on the mathematical model of the DC-DC converter realized in PSIM environment.

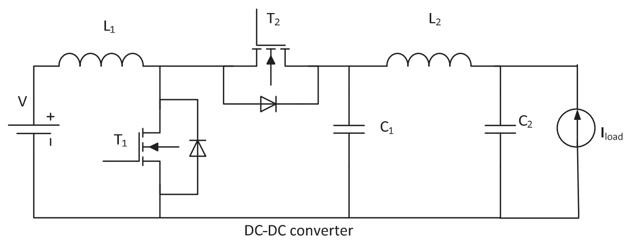

FIGURE 6. Two quadrant converter

With the following equations (1-4) are described the operation modes of the converter:

$$\frac{d}{dt}i_{L1}(t) = \frac{1}{L_1}(v(t) - R_{L1}i_{L1}(t) - v_{C1}(t).(1 - d(t))) \quad (1)$$

$$\frac{d}{dt}i_{L2}(t) = \frac{1}{L_2}(v_{C1}(t) - R_{L2}i_{L2}(t) - v_{C2}(t)) \quad (2)$$

$$\frac{d}{dt}v_{C1}(t) = \frac{1}{C_1}(i_{L1}(t).(1 - d(t)) - i_{L2}(t)) \quad (3)$$

$$\frac{d}{dt}v_{C2}(t) = \frac{1}{C_2}\left(i_{L2}(t) - \frac{v_{C2}(t)}{R} - I_{load}\right) \quad (4)$$

where L_1, L_2 are the inductors, R_{L1}, R_{L2} are their internal resistance, C_1, C_2 are the capacitors and R is the equivalent load considered in the direction of the current from the power supply to the energy storage element. The switching function *d(t)* in first half period is equal to 0, and 1 in the second half period. In the current research a two quadrant DC-DC converter is used. The realized model in PSIM environment of this converter is presented in Figure 5.

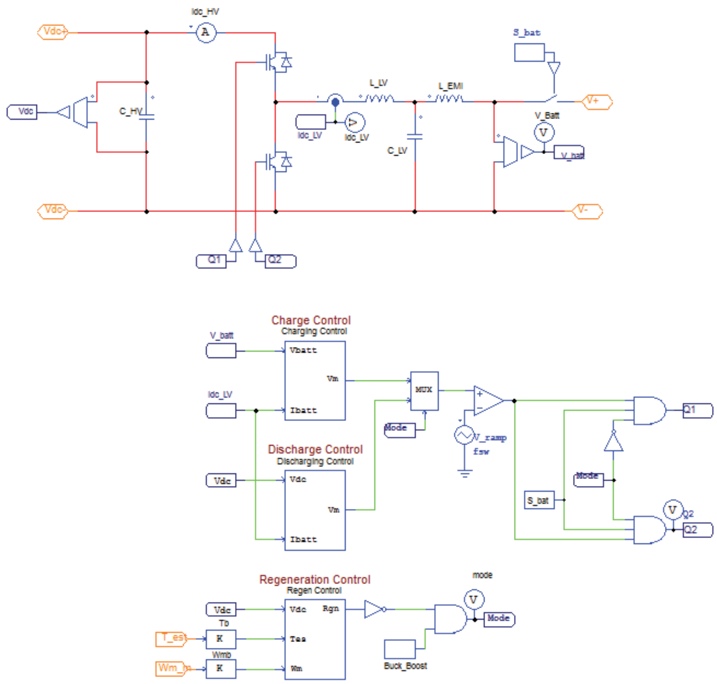

FIGURE 7. Model of bidirectional DC-DC converter

Controllers

It consists of a charge controller, discharge controller, and regeneration controller. Their functions are described below. All input and output quantities are in real value.

Charge Control:

- Input: - V_{batt}: Battery-side voltage
- I_{batt}: Current flowing into the battery
- Output: V_m: Modulation signal for PWM generator

This block implements Constant-Voltage-Constant-Current battery charging. When the battery voltage is less than the battery float voltage, it is constant current charging. The outer voltage loop is disabled and the inner current loop charges the batteries at a constant current rate. When the battery voltage reaches the battery float voltage, it is constant voltage charging. The outer voltage loop generates the current reference for the inner current loop.

Discharge Control:

- Input: - V_{dc}: DC bus voltage
- Ibatt: Current flowing into the battery
- Output: V_m: Modulation signal for PWM generator

This block implements constant-voltage or constant-current battery discharging. When the dc/dc converter control mode is set to Voltage Mode (V_I_mode = 1), the converter regulates the dc bus voltage, and the outer voltage loop generates the reference for the inner current loop. When the control mode is set to Current Mode (V_I_mode = 0), the converter regulates the current injected to the dc bus according to the current reference I_HV_REF.

Regeneration Control:

- Input: - V_{dc}: DC bus voltage feedback
- Tes: Estimated traction motor torque
- Wm: Vehicle speed
- Output: - R_{gn}: Regeneration flag (1: regeneration; 0: no regeneration)

This block generates the regeneration flag based on the motor power. When the motor power is negative and it exceeds the regeneration power threshold level, and if the dc bus voltage exceeds the maximum voltage, the regeneration flag will be set.

Traction Motor

It consist of a 3-phase PWM inverter, a linear PMSM traction motor and the traction motor controller. The motor consist of space vector PWM, Current control, Maximum Torque per Ampere Control, Torque control, Dynamic torque limit control and speed control.

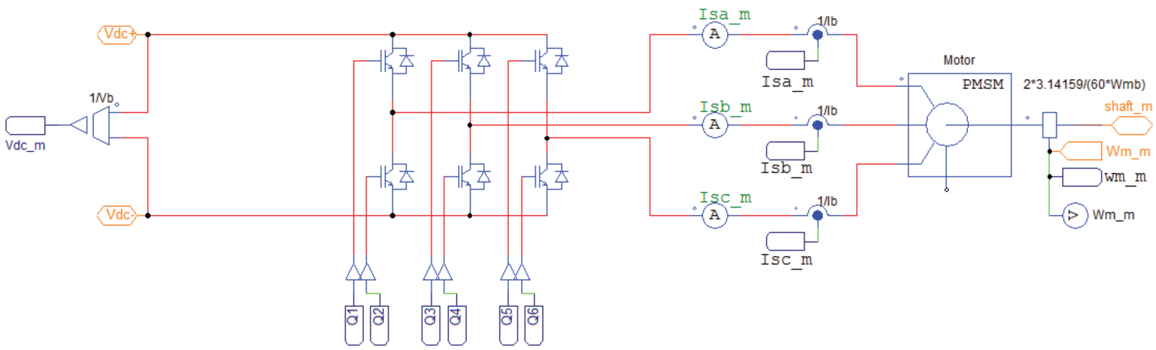

FIGURE 8. Model of the traction motor

Traction Motor Controller

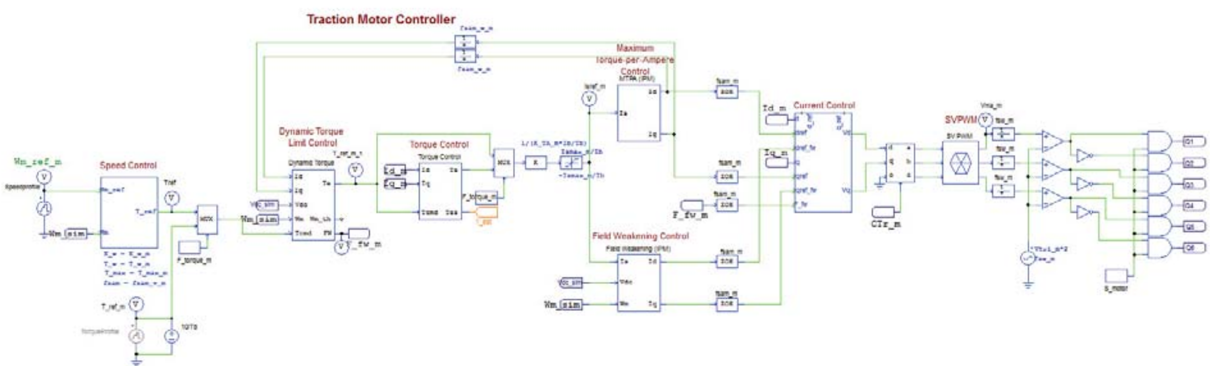

FIGURE 9. Model of the traction motor controller

The functions of the key control blocks are described below. Note that all input and output quantities are in per unit.

Current Control:

- Input: - I_d, I_q:Currents id and iq feedback
- - I_{dref}, I_{qref}: i_d and i_q current references from the MTPA Control block
- - I_{dref_fw}, I_{qref_fw}: id and iq current references from the Field Weakening Control block

- F_fw:Flag from the Dynamic Torque Limit Control block (1 when in field weakening control; otherwise 0).

Output: V_d, V_q: d-axis and q-axis voltage references

SIMULATION RESULTS

For understanding the basic operation mode of the traction motor developed torque is presented in Figure 10.

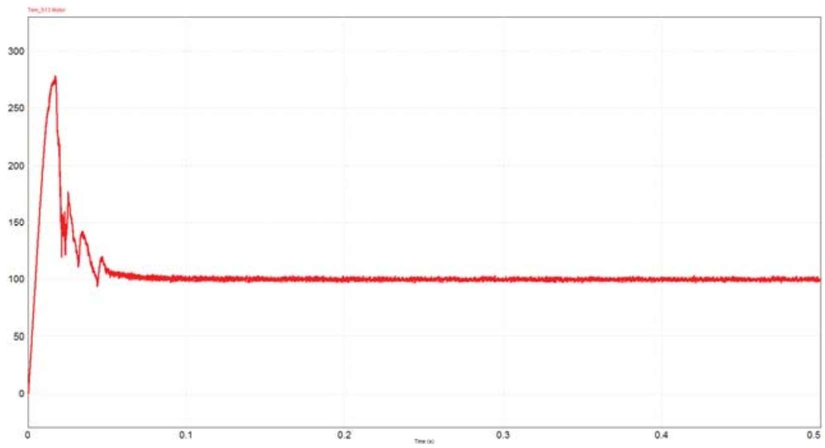

FIGURE 10. Traction motor developed torque

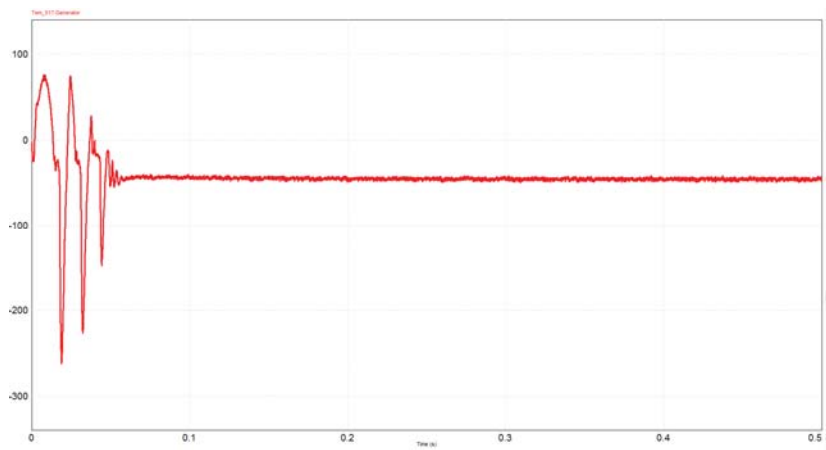

FIGURE 11. Generator developed torque

In Figure 11 simulation results from vehicle torque is presented. It can be observed that the curve reaches the set value.

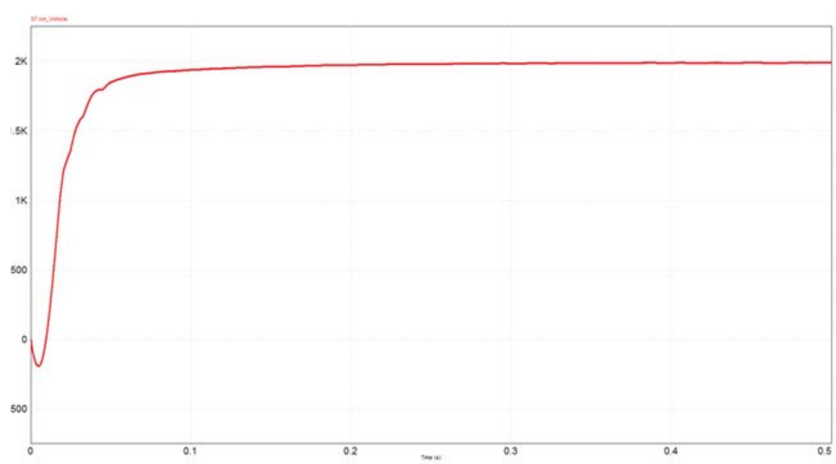

FIGURE 12. Torque [N/m]

CONCLUSIONS

The proposed model allows significant benefit and advantages to engineers and students such as:

- It can help system engineers evaluate system requirements and understand the interactions among major subsystems such as batteries, DC/DC converters, traction motor and controller, generator and controller, engine, and vehicle load.
- It can help subsystem engineers derive detailed hardware and software specifications of subsystems, and gain a better insight of the operations of the subsystems.
- It can help hardware engineer carry out hardware component selection and design, and help software/control engineers develop control algorithms and DSP control software.
- It can help system integration engineers integrate and test the system based on system and subsystem requirements.

ACKNOWLEDGMENTS

The research has been conducted within the framework of ДН07/06/15.12.2016 project “Model Based design of power electronics devices with guaranteed parameters” of the Bulgarian Scientific Fund.

This work was supported by the European Regional Development Fund within the Operational Programme “Science and Education for Smart Growth 2014 - 2020” under the Project CoE “National center of mechatronics and clean technologies “BG05M2OP001-1.001-0008".

REFERENCES

1. D. W. Gao, C. Mi and A. Emadi, "Modeling and Simulation of Electric and Hybrid Vehicles," in Proceedings of the IEEE, vol. 95, no. 4, pp. 729-745, April 2007, doi: 10.1109/JPROC.2006.890127.
2. C. C. Lin, Z. Filipi, Y. Wang, L. Louca, H. Peng, D. Assanis, et al., "Integrated feed-forward hybrid electric vehicle simulation in Simulink and its use for power management studies", Proc. SAE 2001 World Congr., 2001-Mar.
3. W. Gao, "Performance comparison of a hybrid fuel cell—Battery powertrain and a hybrid fuel cell—Ultracapacitor powertrain", IEEE Trans. Vehicular Technol., vol. 54, no. 3, pp. 846-855, May 2005.
4. W. Gao and S. Porandla, "Design optimization of a parallel hybrid electric powertrain", *Proc. IEEE Vehicle Power Propulsion Conf.*, pp. 530-535, 2005-Sep.
5. S. Onoda and A. Emadi, "PSIM-based modeling of automotive power systems: Conventional electric and hybrid electric vehicles", *IEEE Trans. Vehic. Technol.*, vol. 53, no. 2, pp. 390-400, Mar. 2004.
6. B. Zhonghao and W. Yaonan, "Research on modeling and simulation of hybrid electric vehicle energy control system," *2005 International Conference on Electrical Machines and Systems*, Nanjing, 2005, pp. 849-852 Vol. 1, doi: 10.1109/ICEMS.2005.202658.
7. Y. Wang and Y. Chen, "Research and implementation of numerical simulation software in parallel hybrid electric vehicle performance analysis based on object-oriented technology," *2011 International Conference on Electrical and Control Engineering*, Yichang, 2011, pp. 4036-4039, doi: 10.1109/ICECENG.2011.6057148.
8. A. Benny, L. Geevarghese Tharakan, "Simulation of multi-mode parallel hybrid electric vehicle using fuzzy logic", Green Technologies (ICGT) 2012 International Conference on, pp. 240-245, 2012.
9. Y. Cheng, S. Cui and C. C. Chan, "Control strategies for an electric variable transmission based hybrid electric vehicle," *2009 IEEE Vehicle Power and Propulsion Conference*, Dearborn, MI, 2009, pp. 1296-1300, doi: 10.1109/VPPC.2009.5289441.
10. Ch. Yuan, Ch. Keyu, Chan C.C., Bouscayrol Alain, Cui Shumei. Global modeling and control strategy simulation for a hybrid electric vehicle using electrical variable transmission. Proceedings of IEEE VPPC 2008, Harbin, China.
11. M. Meradji, C. Cecati, G. Wang and D. Xu, "Dynamic modeling and optimal control for hybrid electric vehicle drivetrain," *2016 IEEE International Conference on Industrial Technology (ICIT)*, Taipei, 2016, pp. 1424-1429, doi: 10.1109/ICIT.2016.7474967.
12. I. Sefik and T. Hiyama, "Performance evaluation of hybrid powertrain system simulation model for Toyota Prius car", Electrical Machines and Power Electronics and 2011 Electromotion Joint Conference (ACEMP) 2011 International Aegean Conference on, pp. 404-407, 8–10 Sept. 2011.