



Design and simulation of hybrid system PV/PEMFC/Battery/Super Capacitor powered PMSM motor for electric Vehicle

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Super capacitor

ABSTRACT

Hybrid electric vehicles (HEVs) play a crucial role in the development of sustainable transportation solutions by integrating several power sources. This study centers on a novel modelling system that drives a synchronous motor with permanent magnet (PMSM) in the context of hybrid electric vehicles (HEVs) utilizing solar (PV) panels, batteries, fuel cells, and super capacitors. The objective of integrating these diverse energy storage technologies is to enhance vehicle efficiency and optimize energy management. The FC, or fuel cell, is utilized alongside the PV panels to ensure uninterrupted power generation throughout the day. Batteries and super capacitors serve as energy storage devices to regulate power fluctuations and provide rapid energy surges during acceleration. The PMSM motor is renowned for its exceptional efficiency and torque characteristics, making it seamlessly integrate into the vehicle's drive train. This study evaluates the overall viability, energy efficiency, and dynamic performance of the hybrid power system using comprehensive simulations. Examining crucial elements such as energy conversion efficiency, charging/discharging methodologies, and system integration challenges is necessary to assess if the system can meet HEV performance standards. The results demonstrate the potential of the hybrid PV/FC/battery/SC-powered PMSM motor system to enhance vehicle range, reduce emissions, and promote eco-friendly transportation alternatives in MATLAB Simulink. This study enhances the progress of next-generation hybrid electric vehicles by employing improved power management techniques and renewable energy sources.

1. Introduction

The emergence of hybrid power systems has significantly transformed transportation by offering ecologically beneficial alternatives to conventional internal combustion engine vehicles. One of the improvements that will enhance the efficiency and reduce the environmental impact of hybrid electric vehicles (HEVs) is the modelling of a hybrid system comprising solar (PV) panels, batteries, super capacitors, a permanent magnet synchronous motor (PMSM), and proton exchange membrane fuel cells (PEMFC). This research investigates the simulation of a sophisticated hybrid power system that is specifically intended for hybrid electric vehicles (HEVs). This system enhances energy management by incorporating photovoltaic (PV) panels, proton exchange membrane fuel cell (PEMFC) technology, batteries, and super capacitors to meet the evolving requirements of vehicle propulsion. This type of integration not only enhances vehicle performance but also mitigates pollution and extends operational range, thereby addressing significant challenges confronting the automotive industry. This research analyses the relationships among these components using comprehensive simulation experiments, evaluating their collective contribution to enhance the reliability, efficiency, and ecological sustainability of HEVs. This study aims to emphasize the potential of a hybrid PV/PEMFC/battery/super capacitor powered PMSM motor system for HEVs in promoting sustainable transportation solutions. It will examine the design considerations, operating methods, and performance characteristics of this system.

Due to the urgent necessity to address the depletion of fossil fuels and mitigate greenhouse gas emissions, there is a global transition towards

clean and efficient power sources, such as fuel cells and renewable energy sources like photovoltaics and wind. Fuel cells (FCs) are recognized for their high specific energy and are considered a promising alternative power source for the future. Due to its high-power density, reliability, and efficiency, fuel cells (FCs) are a highly desirable and ecologically friendly energy source for microgrids. According to the studies cited in the literature, Both the injection system (consisting of a compressor, valves, and hydrogen reformer) and temperature have an impact on the time constant. As a result, a sharp decrease in voltage occurs due to a quick change in demand (known as the stack starving effect). In order to prevent voltage drops and ensure continuous power supply to the trainset, the hybrid power system requires at least one auxiliary source or storage device. It is recommended to employ a current control loop while utilizing the FC to avoid overloads and improve its functionality. Multiple distributed generators (DGs) integrated into a power grid are widely acknowledged to potentially cause problems such as system instability and increased voltage levels [1]. These problems have the potential to damage electrical loads that are susceptible to damage.

Hybrid energy storage systems (HESS) that combine batteries with super capacitors (SCs) present a compelling solution to prolong the lifespan of an electric vehicle (EV) batteries due to their complementary technical characteristics [2]. Batteries and super capacitors, on the other hand, possess mutually enhancing technological characteristics. Batteries exhibit a greater specific energy and a longer duration of power output compared to super capacitors. Nevertheless, as compared to batteries, super capacitors (SCs) exhibit superior efficiency, higher specific power, and a longer

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lifespan, as evidenced by their ability to undergo numerous charge/discharge cycles [3]. The combination of batteries and super capacitors has been effectively utilized in several transportation applications, such as the tramway. The article mentions a solar-powered car [1] and an electric hybrid car [4]. The electric vehicle (EV) was created in multiple research articles. This article analyses the problem of charging in the context of smart grid technology and its relationship with renewable energy. The text is referenced by the number [5]. Parking lots have the capability to harness solar energy in order to charge electric vehicles. This is demonstrated in reference [6]. Due to the scarcity of fuel, the energy crisis, and growing environmental apprehensions, the hybrid electric vehicle (HEV) has gained significant popularity and efficiency as a transportation choice for both private and public use in urban areas [7]. The advancement and widespread acceptance of HEVs rely on the presence of robust and efficient electric motors [8]. An induction motor offers several advantages, including a broad range of operating speeds and a low cost [9]. However, even with the use of loss reduction processes, its effectiveness is still inferior to that of the PMSM [10]. Despite its wide speed range, the switching reluctance motor has drawbacks such as severe torque ripple and a poor power factor [11]. The Permanent Magnet Synchronous Motor (PMSM) is an excellent option for Hybrid Electric Vehicle (HEV) propulsion applications because to its exceptional energy efficiency and power density. Due to the battery's restricted capacity [12], the electric motors for hybrid electric vehicles (HEVs) are consistently designed to maximize energy efficiency within a particular volume range [13]. Nevertheless, Permanent Magnet Synchronous Motors (PMSM) generally function in the low torque range when used for driving in urban or suburban environments [14]. The low overall energy efficiency is attributed to a discrepancy between the areas of high energy efficiency and the frequent operational situations related to the PMSM. In earlier hybrid electric vehicle (HEV) motor design projects, motor optimization was conducted using static efficiency maps to determine the motor characteristics before establishing the performance objectives [15]. The design concepts were based on the relationship between the sizes of Permanent Magnet Synchronous Motors (PMSMs) and their performance attributes [16]. Nevertheless, the earlier motor models were empirical and static due to their reliance on the steady state experiment. In addition, some articles have developed mathematical motor models by directly using circuit formulas [17], or by employing empirical equations that establish a relationship between performance measures and design [18]. This study investigates the performance characteristics of a Permanent Magnet Synchronous Motor (PMSM) that is driven by a hybrid system consisting of a Proton Exchange Membrane (PEM) fuel cell, a Photovoltaic (PV) system, and an energy storage system. The aim of this research is to analyze the behavior of this hybrid system in the context of a hybrid electric vehicle. An effective approach to regulate the speed of the motor is by implementing a PI-controller framework. The structure of the work is as follows: Section II introduces the modelling and optimization systems. The simulation results are presented and analyzed in Section III. Section IV, ultimately, encompasses the Conclusion.

2. System and modeling

The For a PMSM motor powered by a PV, fuel cell, battery, or super capacitor, the hybrid simulation system offers a comprehensive tool for developing, evaluating, and optimizing sophisticated hybrid power trains. The technology aids in the creation of hybrid electric vehicles that are more effective, sustainable, and high-performing by precisely simulating the integration of these parts. In Figure.1, the suggested driving scheme is shown.

Photovoltaic system

Photovoltaic systems (PVS) are devices that use light energy conversion to produce electricity. The power supply is the only component of the diode model, and each photovoltaic (PV) panel is represented by a parallel diode with two resistors. In PVS, the maximum power point tracker (MPPT) controller has a DC/DC converter built in. Using MPPT controllers allows for optimal performance in typical radiation environments [19]. The performance of a photovoltaic system is dependent on temperature and sun radiation.

MPPT is the best way to get the most electricity out of a photovoltaic system . To raise the MPP voltage, the MPPT controller engages the frequency converter's duty cycle (minimum power point) [20].

Fuel cell system

Fuel cells powered by renewable energy sources are advised due to their benefits, which include zero emissions and a higher power output than wind and other renewable energy sources [21]. Because of its special qualities and general fuel efficiency, the proton exchange membrane fuel cell (PEMFC) is a promising part of hybrid systems. PEMFCs have great power and a very low temperature. Through an electrochemical reaction involving hydrogen and oxygen, the PMFC uses hydrogen to make electricity. The only byproduct of this reaction is water, which is why it emits water.

Battery

We have used lithium-ion batteries in our study because they have proven to have a higher energy density and efficiency than other battery types, such lead-acid batteries. You may find the battery's SOC and output voltage in the following methods We have used lithium-ion batteries in our study because they have proven to have a higher energy density and efficiency than other battery types, such lead-acid batteries. You may find the battery's SOC and output voltage in the following methods [22]:

$$U_B = E - R_b I_{bat} = E_0 - K \frac{Q}{Q-it} + A_b \exp(-B * it) - Polres * i * R_b I_{bat} \tag{1}$$

$$SOC_b = 100 * [1 - \frac{1}{Q} \int ib(t)dt] \tag{2}$$

Super Capacitors

Also referred to as an electrochemical capacitor or an ultra-capacitor, a super capacitor is a device that stores a large quantity of energy in a small amount of space. However, in order to increase the energy density, the super capacitor's power density is compromised. Rather than using insulating dielectric materials as in a conventional capacitor, the electrodes are separated by an electrolyte saturated separator. They have been widely employed in many different applications, particularly in EVs, because of their enhanced capacity, efficiency, and ease of operation. A similar series resistance is linked to a capacitance in this manner. The super capacitor SCV's voltage is calculated using the equation that follows [23]:

$$V_{SC} = \frac{SC_E}{SC_C} - R_{SC} * I_{SC} \tag{3}$$

Where R_{SC} stands for super capacitor resistance, I_{SC} for super capacitor current, SC_E for super capacitor electricity quantity, and SC_C for super capacitor capacitance.

Permanent magnet synchronous motor

An AC synchronous machine is the PMSM. The permanent magnet provides the PMSM with the field excitation. With a permanent magnet rotor and stator winding, PMSMs are the preferred alternative to induction motors and brushless DC motors. A hybrid of an induction motor with a brushless DC motor is the PMSM. The stator windings and permanent magnet rotor function similarly to the brushless DC motor. Nonetheless, the motor's air gap experiences a sinusoidal flux density thanks to the stator's winding construction, just like in an induction motor [24].

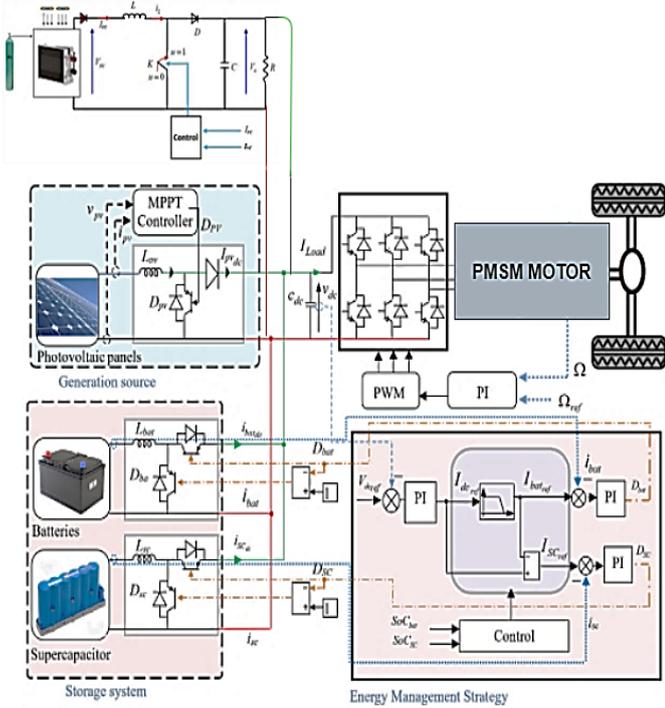


Fig. 1: Diagrammatic illustration of a hybrid vehicle featuring PMSM motors, solar power, fuel cells, and energy storage.

3. Simulation results and discuss

System PV, PEMFC, Battery, Super Capacitor with PMSM Motor simulations are run in MATLAB/Simulink to examine the resilience and performance of the suggested system. PI controller modelling and energy management are applied, simulated, and implemented. Table 1 lists the specifications and features of every power source. Figure 2, depicts a MATLAB/Simulink simulation of a PMSM motor drive with energy storage and renewable energy sources.

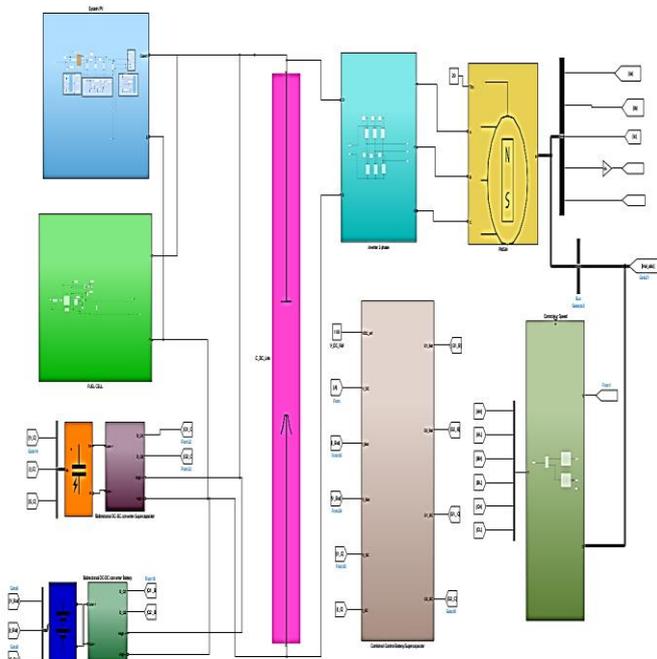


Fig. 2 : Displays the Simulink model of the hybrid system and energy storage with PMSM motor.

Table 1: Computational elements

FC parameters	
Nominal power (W)	6000
Current at nominal operating point(A)	133.3

Voltage at nominal operating point(V)	45
Current at max operating point(A)	225
Voltage at max operating point(V)	37
Number of cells	65
Battery parameters	
Nominal voltage (V)	24
Rated capacity (Ah)	14
Initial state-of-charge (%)	50
Super Capacitor parameters	
Rated capacitance (F)	29
Equivalent DC series resistance (Ohms)	0.003
Rated and initial voltage (V)	32
PV Panel	
Cells per module	44
Open circuit voltage (V)	29.1228224
Short-circuit current (A)	3.49638405
Voltage at maximum power point (V)	22.7059294
Current at maximum power point (A)	3.08504475
Parallel strings	10
Series string	44
PMSM motor	
Stator phase resistance (Ohm)	0.129
Armature inductance (H)	0.00153
Flux linkage	0.1821
PI control speed motor	
Proportional (P)	5
Integral (I)	2.5

Figures 3 and 4 show changed of the different input of power system PV and PEMFC.

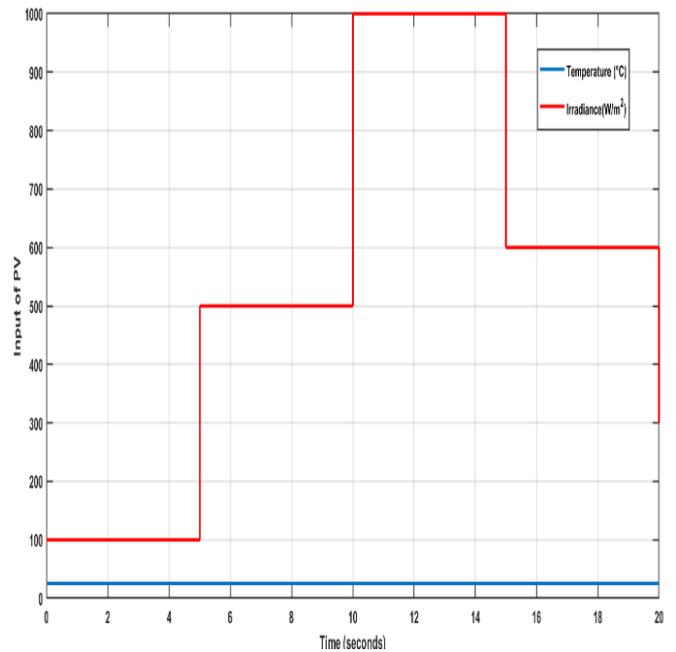


Fig. 3: Input of panel PV.

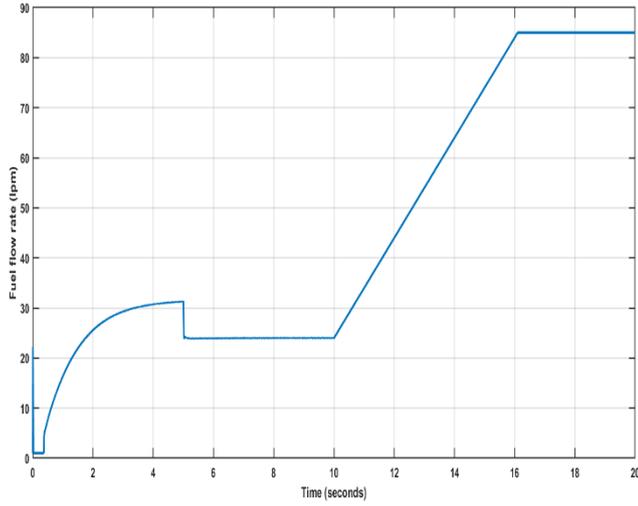


Fig. 4: Input of fuel cell.

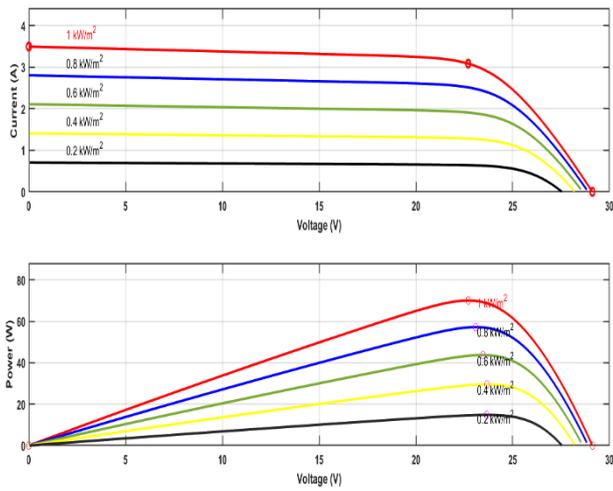


Fig. 5: Displays the PV generator's P-V and I-V characteristics that were employed in this investigation.

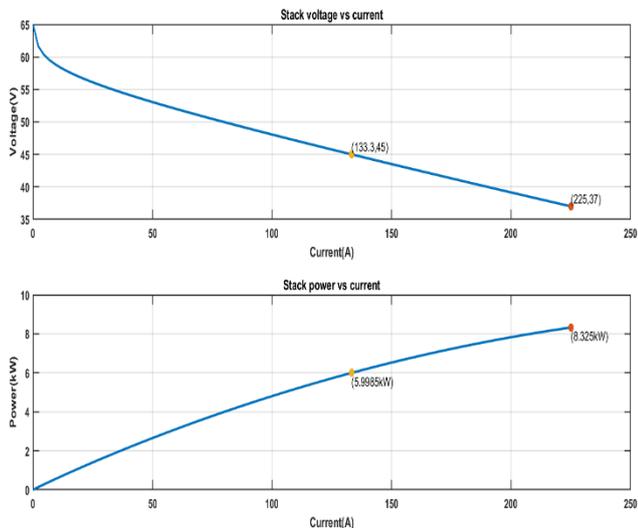


Fig. 6: Characteristic current curves of the PEMFC.

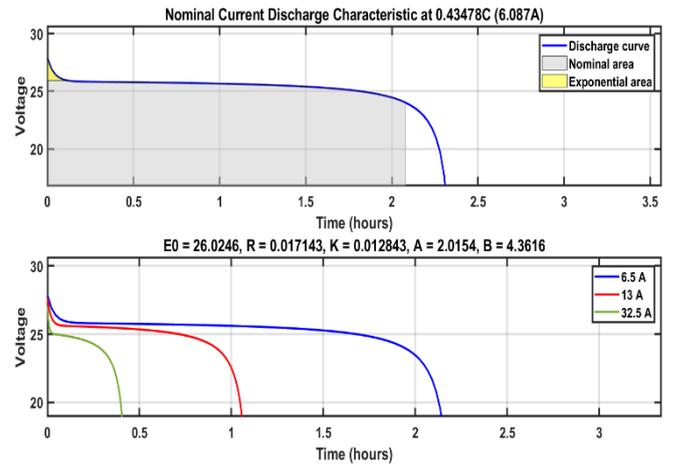


Fig. 7: Characteristic of Battery.

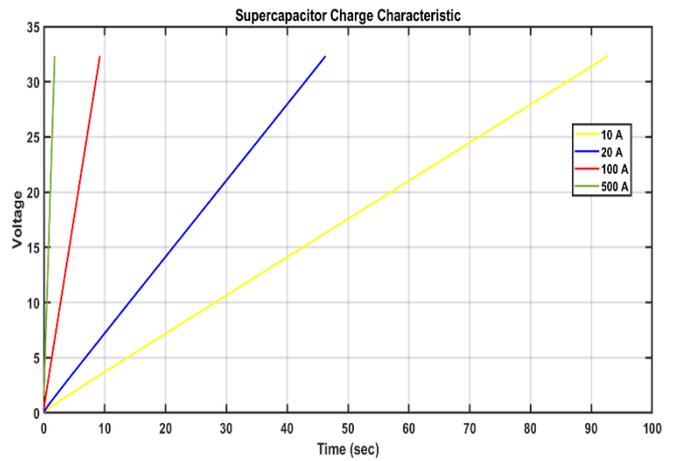


Fig.8: Characteristic of super capacitor

The different change values of power, current and voltage the component the system simulate, are shows in figures belows:

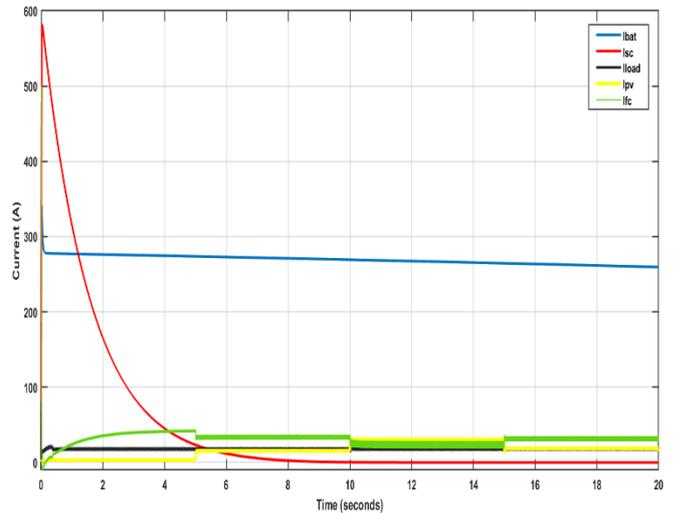


Fig. 9: The load, FC, PV, battery, and super capacitor current curves.

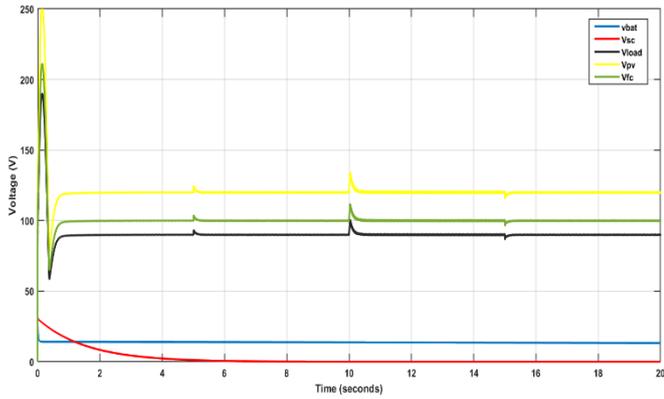


Fig. 10: Voltage curves for the battery, super capacitor, load, FC, and PV.

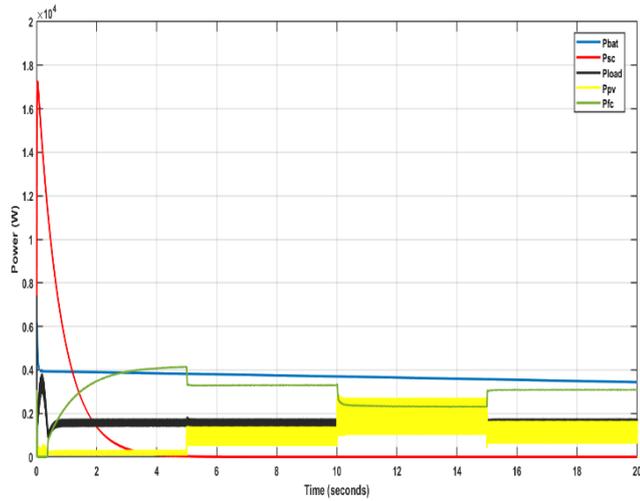


Fig. 11: Power curves for the battery, super capacitor, PV, FC, and load.

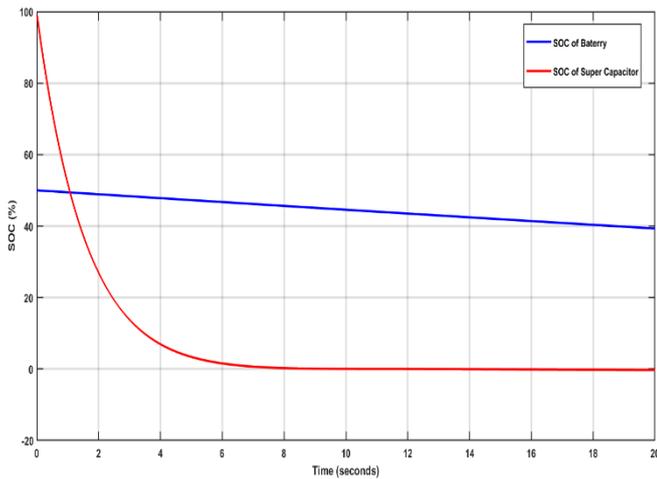


Fig.12: SOC for the super capacitor and battery.

Figure 13 shows the load torque and torque of PMSM motor.

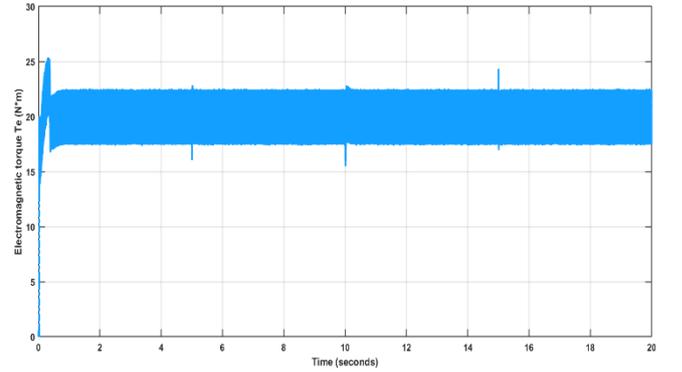
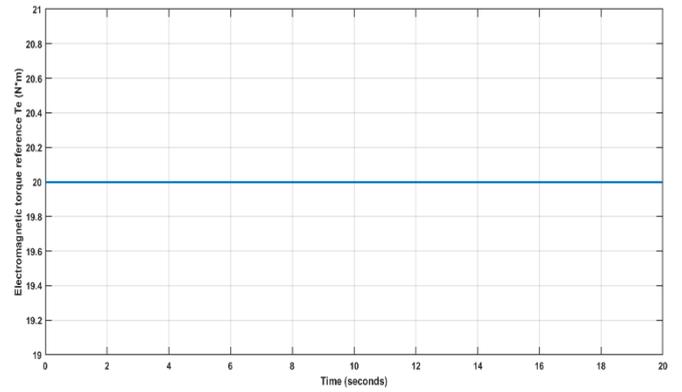


Fig 13: Electromagnetic Torque (N-m) vs Time (sec)

Figure 14 shows the speed tracking of a PMSM motor with a PI controller in respect to a reference speed.

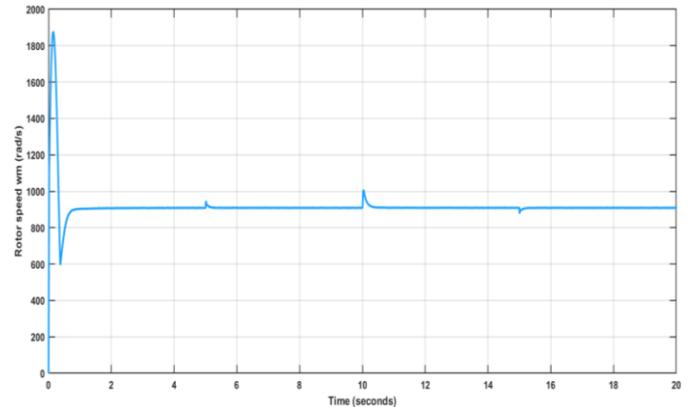
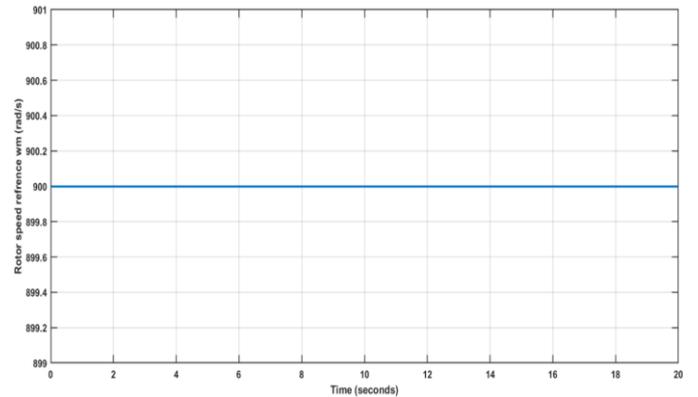


Fig.14: Speed (RPM) vs Time (sec).

4. Conclusion

The integration of PEMFC, system PV, battery, and super capacitor in a hybrid system for PMSM-driven electric vehicles offers a robust solution to the challenges faced by conventional electric vehicles. The combination enhances power efficiency, extends driving range, and reduces emissions. Ongoing research focuses on refining energy management strategies and improving the dynamic response of the

fuel cell to further optimize the performance of these hybrid electric vehicles

5. Reference

- [1] S. Ferahtia, A. Djerioui, S. Zeghlache, A. Houari, (2020), A hybrid power system based on fuel cell, photovoltaic source and supercapacitor, Springer Nature Journal.
- [2] V. Herrera, A. Milo, H. Gaztañaga, I. Etxeberria-Otadui, I. Villarreal, H. Camblong, (2016), Adaptive energy management strategy and optimal sizing applied on a battery-supercapacitor based tramway., *Appl. Energy*, 169, 831–845.
- [3] Z. Cabrane, M. Ouassaid, M. Maaroufi, (2016), Performance enhancement of solar vehicle by integration of supercapacitors in the energy storage system., *Proc. IEEE Conf. IRSEC, Morocco*.
- [4] Q. Zhang, W. Deng, S. Zhang, J. Wu, (2016), A rule-based energy management system of experimental battery/supercapacitor hybrid energy storage system for electric vehicles., *J. Control Sci. Eng.*
- [5] P. Nunes, R. Figueiredo, M. C. Brito, (2016), The use of parking lots to solar-charge electric vehicles., *Renew. Sustain. Energy Rev.*, 66, 679–693.
- [6] Bai, Y., et al., (2019), Battery anti-aging control for a plug-in hybrid electric vehicle with a hierarchical optimization energy management strategy., *J. Clean Prod.*, 237, 117841. DOI: 10.1016/j.jclepro.2019.117841.
- [7] He, H., et al., (2018), Real-time global driving cycle construction and the application to economy driving pro system in plug-in hybrid electric vehicles., *Energy*, 152, 95e107. DOI: 10.1016/j.energy.2018.03.061.
- [8] Gao, D., et al., (2016), Development and performance analysis of a hybrid fuel cell/battery bus with an axle integrated electric motor drive system., *Int. J. Hydrogen Energy*, 41(2), 1161e9. DOI: 10.1016/j.ijhydene.2015.10.046.
- [9] Lim, J., Park, D.-Y., Jeong, J.-H., (2018), A study on optimal operating point of linear induction motor considering normal force and efficiency in MAGLEV vehicle., *IEEE Trans. Magn.*, 54(11), 1e5. DOI: 10.1109/TMAG.2018.2846767.
- [10] Payan, M. B., et al., (2019), Techno-economic optimal power rating of induction motors., *Appl. Energy*, 240, 1031e48. DOI: 10.1016/j.apenergy.2019.02.016.
- [11] Li, S., He, H., Li, J., (2019), Big data-driven lithium-ion battery modeling method based on SDAE-ELM algorithm and data pre-processing technology., *Appl. Energy*, 242, 1259e73. DOI: 10.1016/j.apenergy.2019.03.154.
- [12] Ruan, J., Song, Q., (2019), A novel dual-motor two-speed direct drive battery electric vehicle drivetrain., *IEEE Access*, 7, 54330e42. DOI: 10.1109/ACCESS.2019.2912994.
- [13] Hung, Y.-H., Wu, C.-H., (2015), A combined optimal sizing and energy management approach for hybrid in-wheel motors of EVs., *Appl. Energy*, 139, 260e71. DOI: 10.1016/j.apenergy.2014.11.028.
- [14] Fellini, R., et al., (1999), Optimal design of automotive hybrid powertrain systems., *Proc. First Int. Symp. on Environmentally Conscious Design and Inverse Manufacturing.*, IEEE, 400e5. DOI: 10.1109/ECODIM.1999.747645.
- [15] Rizzoni, G., Guzzella, L., Baumann, B. M., (1999), Unified modeling of hybrid electric vehicle drivetrains., *IEEE/ASME Trans. Mechatronics*, 4(3), 246e57. DOI: 10.1109/3516.789683-
- [16] Chiba, A., Fukao, T., (1998), Optimal design of rotor circuits in induction type bearingless motors., *IEEE Trans. Magn.*, 34(4), 2108e10. DOI: 10.1109/20.706817.
- [17] Yoon, S.-B., Hur, J., Hyun, D.-S., (1997), A method of optimal design of single-sided linear induction motor for transit., *IEEE Trans. Magn.*, 33(5), 4215e7. DOI: 10.1109/20.619714.
- [18] Jegha, A. D. G., Nallapaneni, M. S. P. S., Kumar, M., Subramaniam, U., Sanjeevikumar, P., (2020), A high gain DC-DC converter with grey wolf optimizer based MPPT algorithm for PV fed BLDC motor drive., *Appl. Sci.*, 10(8), 2797. DOI: 10.3390/app10082797.
- [19] Alqaisi, Z., Mahmoud, Y., (2019), Comprehensive study of partially shaded PV modules with overlapping diodes., *IEEE Access*, 7, 172665e172675. DOI: 10.1109/ACCESS.2019.2956916.
- [20] Anowar, M. H., Roy, P., (2019), A modified incremental conductance based photovoltaic MPPT charge controller., *Proc. Int. Conf. on Electrical, Computer and Communication Engineering (ECCE)*, 1–5. DOI: 10.1109/ECACE.2019.8679308.
- [21] Hayder, W., Ogliari, E., Dolara, A., Abid, A., Hamed, M. B., Sbita, L., (2020), Improved PSO: a comparative study in MPPT algorithm for PV system control under partial shading conditions., *Energies*, 13(8), 2035. DOI: 10.3390/en13082035.
- [22] Bizon, et al., (2021), Multi-Objective Energy Management Strategy for PV/FC Hybrid Power Systems., *Electronics*.
- [23] Hegazy, R., et al., (2021), Comparison among various energy management strategies for reducing hydrogen consumption in a hybrid fuel cell/supercapacitor/battery system., *Int. J. Hydrogen Energy*.
- [24] Loganayaki, A., Kumar, B., (2019), Permanent Magnet Synchronous Motor for Electric Vehicle Applications., *Proc. 5th Int. Conf. on Advanced Computing & Communication Systems (ICACCS)*.