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Proposed energy management strategy in electric vehicle for recovering power excess produced by fuel cells

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Main Reference Paper

1. Z. Mokrani and D. Rekioua and N. Mebarki and T. Rekioua and S. Bacha, “Proposed energy management strategy in electric vehicle for recovering power excess produced by fuel cells”, *International Journal of Hydrogen Energy*, vol. 42, no. 30, pp. 19556-19575, 2017.

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Electric Vehicle (EV): An Energy Management of Battery - PEM Fuel Cell (PEMFC) Hybrid Energy Storage.

Abstract

This paper highlights an energy management of battery-PEM fuel cell hybrid energy storage for electric vehicle. Generally, fuel cells (FCs) are not sufficient to satisfy the load demand, so batteries are added to make the system more sustainable. The studied system consists of fuel cells and battery bank storage to produce energy without interruption. The hybrid source is sized for feeding an electric vehicle of 3 kW. The mathematical model topology and the identification of each subsystem are presented. The power management control (PMC) is developed to supply electric vehicle without interruption. Two algorithms of PMC are developed in this paper. The first one, based on power balance, is used just to show the power flow between the different storage sources. The second one is proposed to recover fuel cells energy in case of energy excess. Obtained results under Matlab/Simulink and some experimental ones are presented and discussed.

Keywords: Batteries, Fuel cells, Energy management, Electric vehicle.

References:

2. Zahra Mokrani, Djamila Rekioua, Toufik Rekioua, "Modeling, control and power management of hybrid photovoltaic fuel cells with battery bank supplying electric vehicle", *International Journal of Hydrogen Energy*, Volume 39, Issue 27, pp. 15178-15187, 2014.

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3. N. Mebarki, T. Rekioua, Z. Mokrani, D. Rekioua, "Supervisor control for stand-alone photovoltaic/hydrogen/ battery bank system to supply energy to an electric vehicle", *International Journal of Hydrogen Energy*, Volume 40, Issue 39, pp. 13777-13788, 2015.

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System Modelling

In this project, a study of hybrid Fuel cells/Battery bank system supplying an electric vehicle is presented. The different parts of the proposed system are to be simulated separately and then the power management control is used to coordinate between sources to supply the EV. The simulation model of the hybrid system has been developed using MATLAB/Simulink.

Fig. 1 shows the model of proposed system developed in MATLAB/Simulink with PEMFC and Battery supplying the EV which is driven by an induction motor with Space Vector Pulse Width Modulation (SVPWM) based Direct Torque Control (DTC) along with an auxiliary source (Supercapacitor) to absorb excess power produced in the energy management process which can be stored and used during peak load period ensuring efficient use of energy.

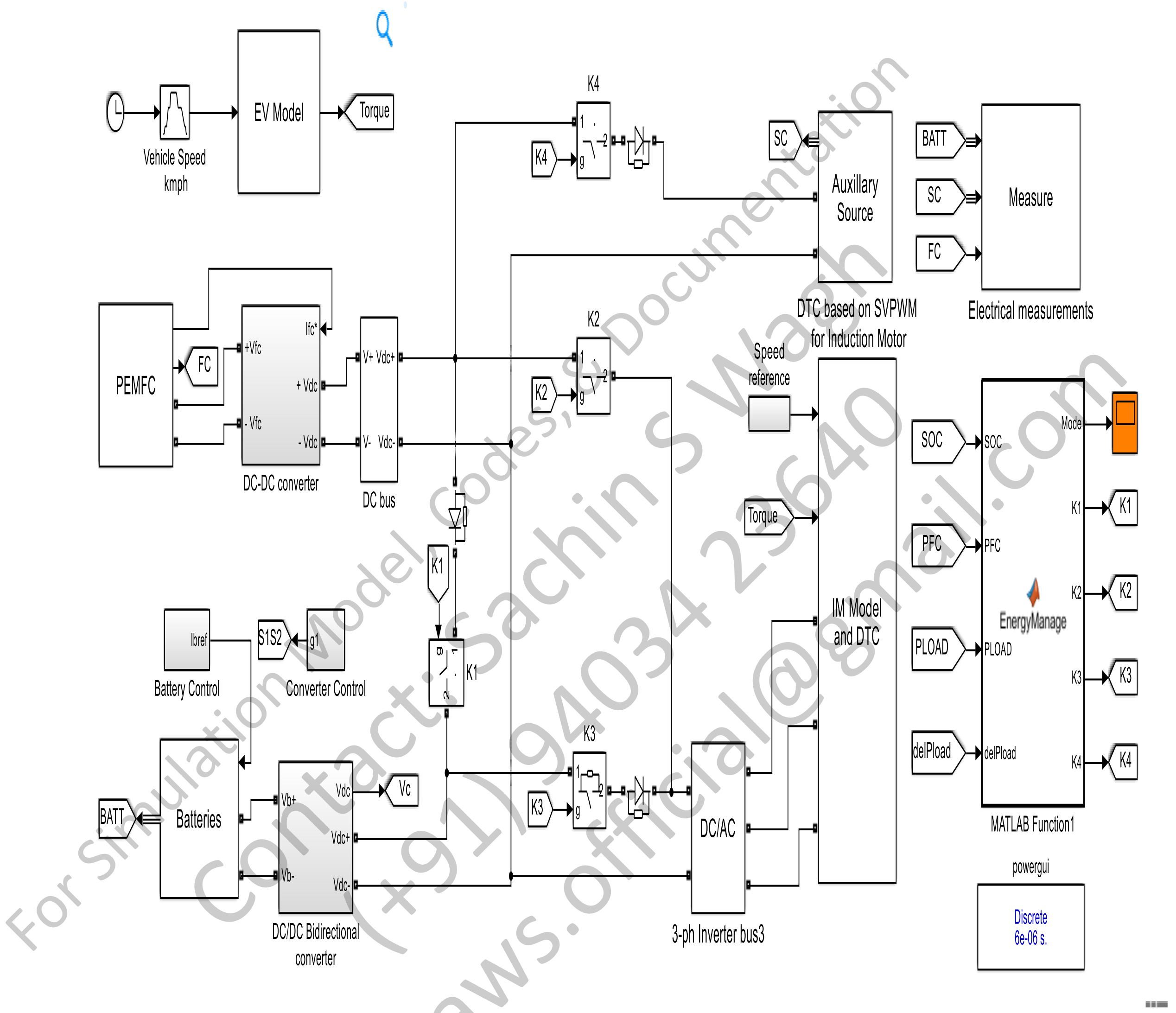

Fig. 1. MATLAB/Simulink Model of The Proposed System.

1. PEMFC Model

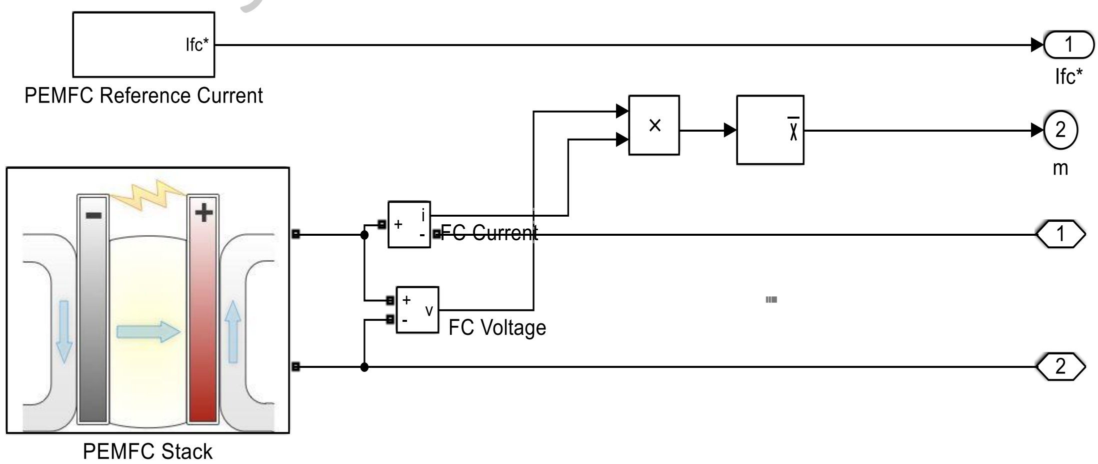

Fig. 2. MATLAB/Simulink Model (PEMFC).

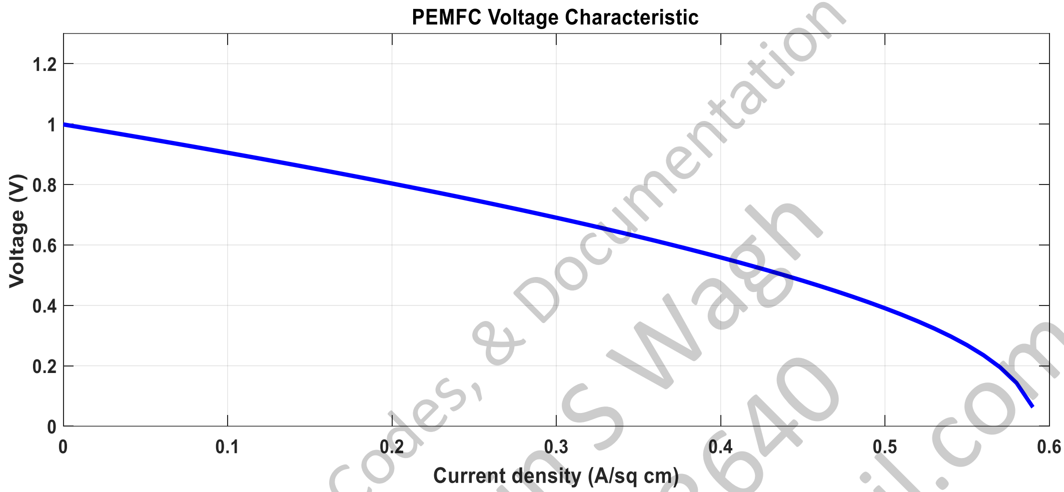

Fig. 3. Voltage Characteristic of PEMFC.

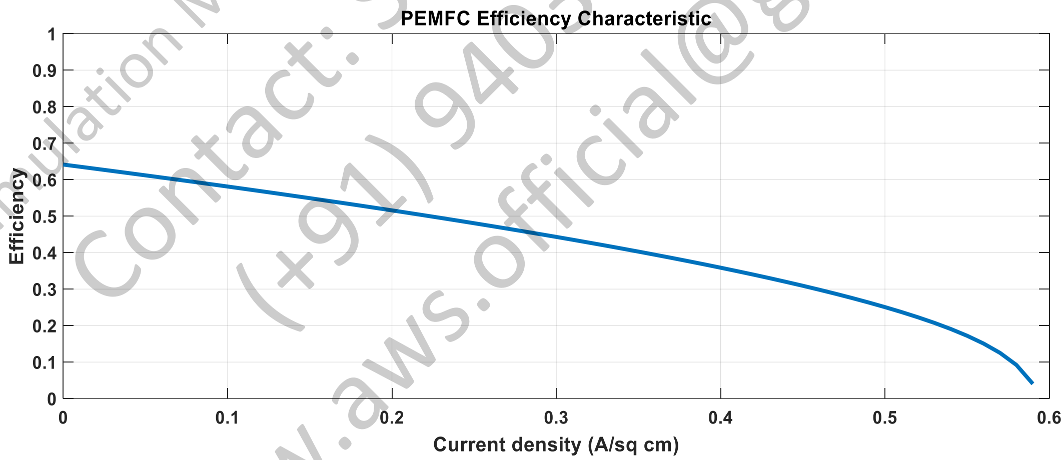

Fig. 4. Efficiency Characteristic of PEMFC.

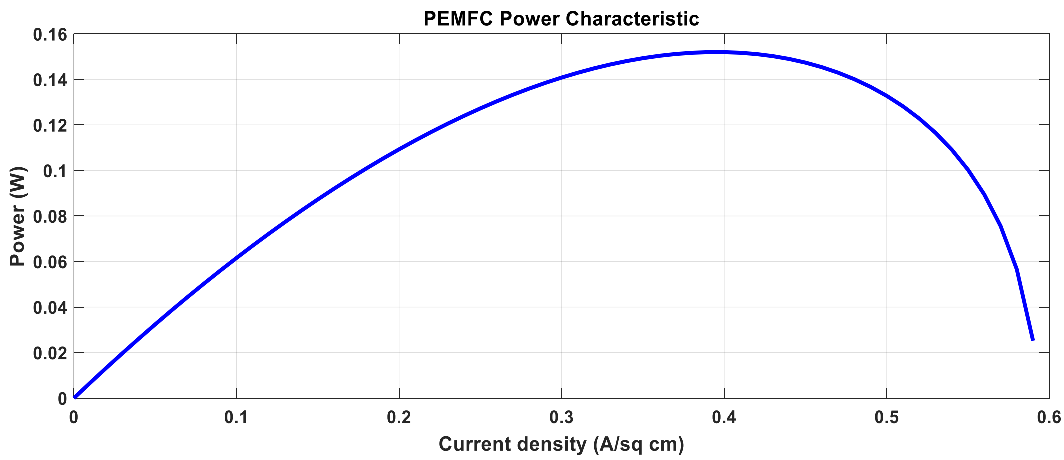

Fig. 5. Power Characteristic of PEMFC.

2. Electric Vehicle Model

Table 1. Parameters of the Electric Vehicle.

Fig. 6. MATLAB/Simulink Model of EV.

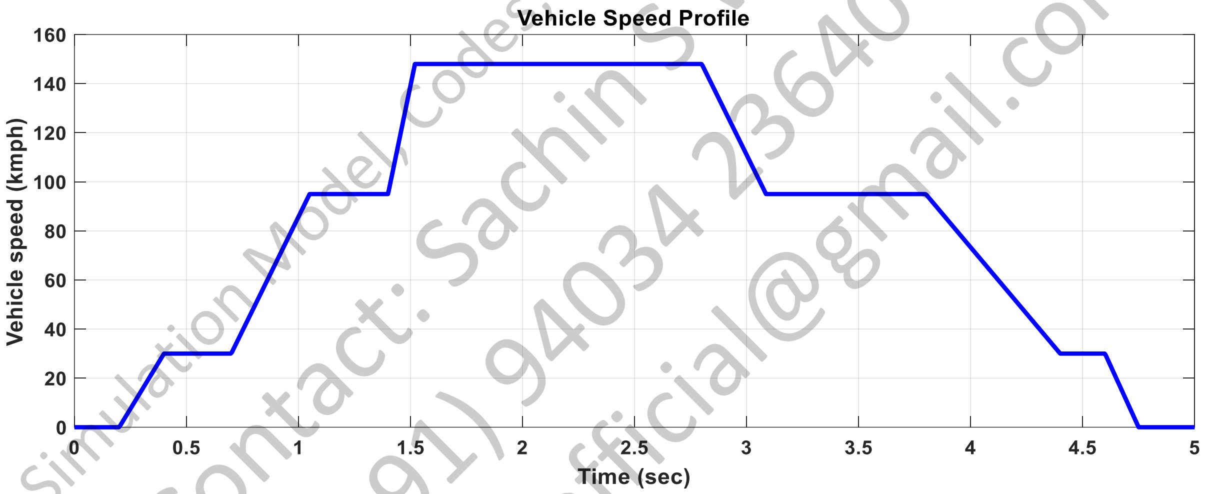

Fig. 7. Speed Profile of EV.

3. Battery Model

Fig. 8. MATLAB/Simscape Model of Lead Acid Battery (12 V, 100 Ah)

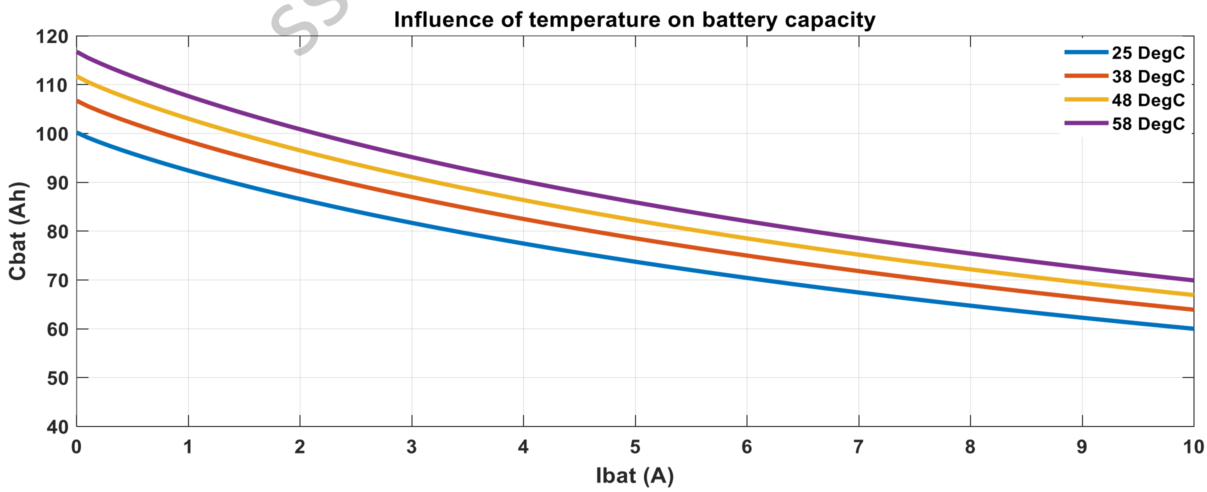

Fig. 9. Effect of Temperature on Battery Capacity.

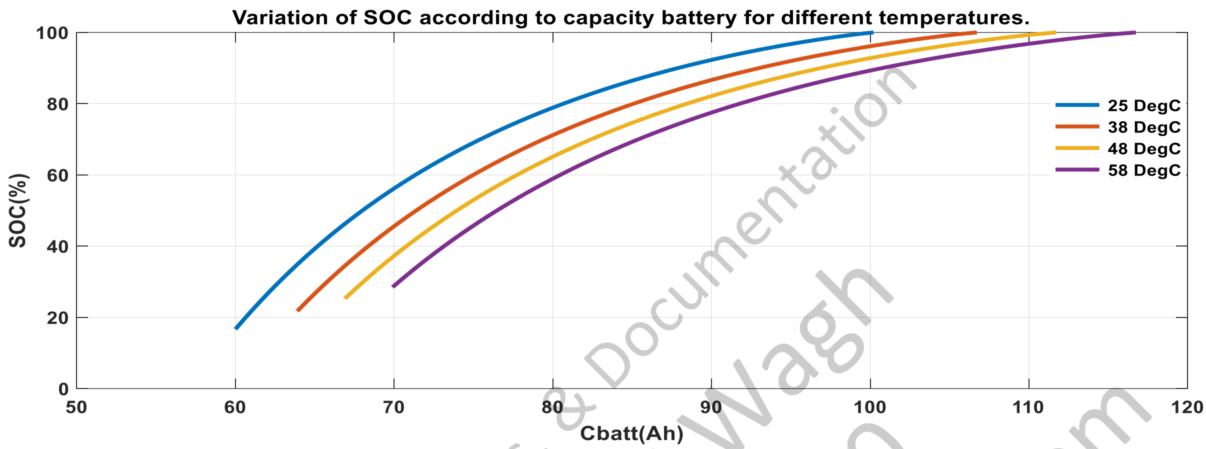

Fig. 10. Variation of SOC According to Capacity of Battery for Different Temperatures.

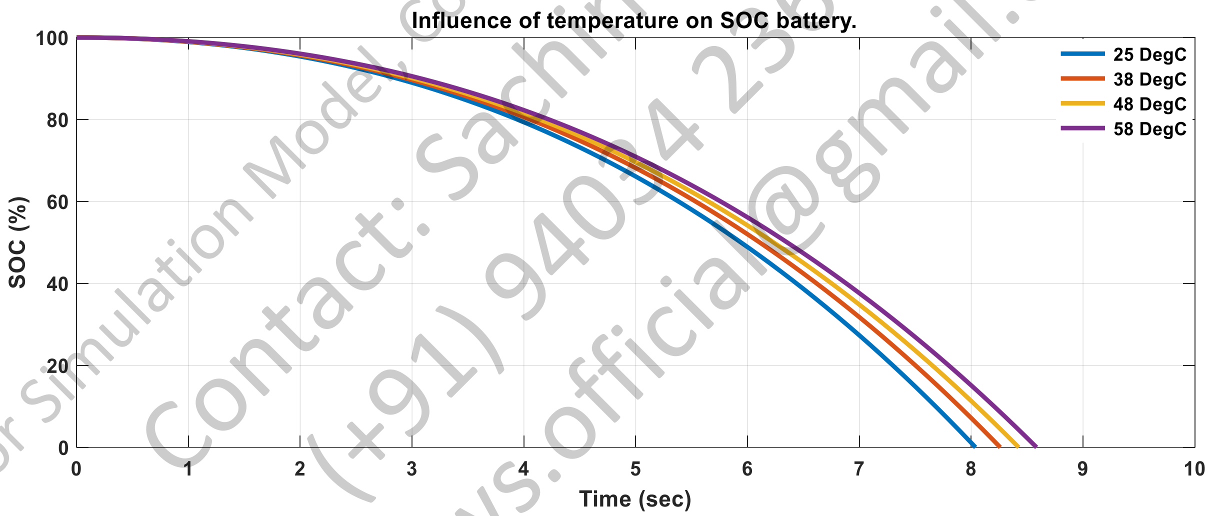

Fig. 11. Effect of Temperature on The SOC of Battery.

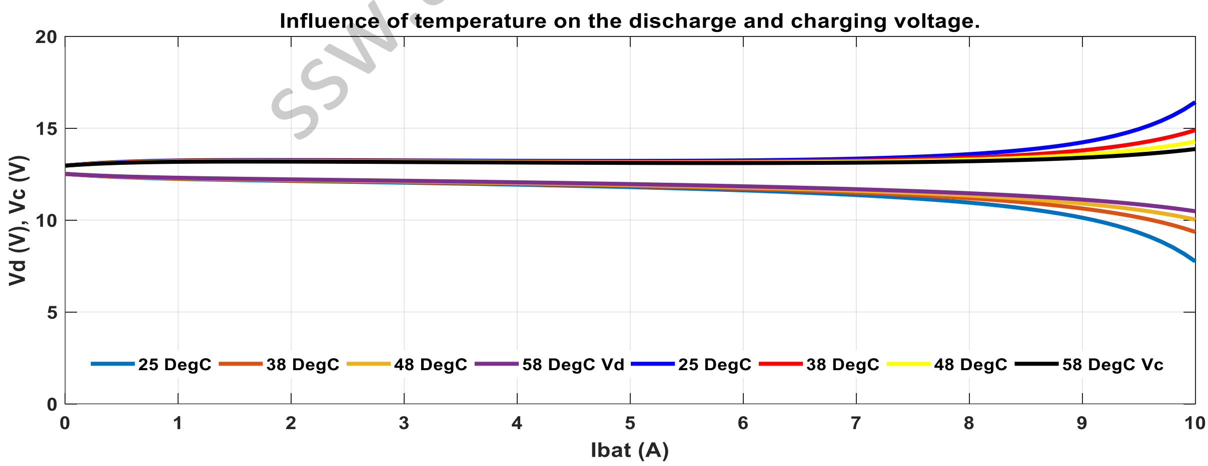

Fig. 12. Effect of Temperature on The Discharge and Charging Voltage of The Battery.

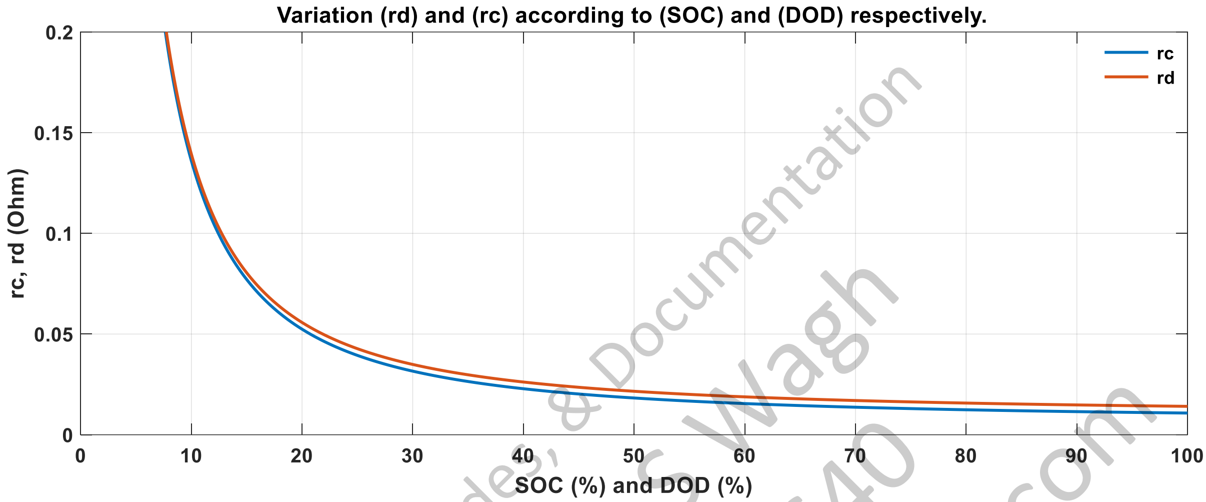

Fig. 13. Variation of Resistance of Battery with SOC and DOD.

Fig. 14. Model of Three Phase Inverter.

4. Induction Motor (IM) model and its SVPWM based DTC

Fig. 15. SVPWM based DTC of IM.

5. Simulation Results

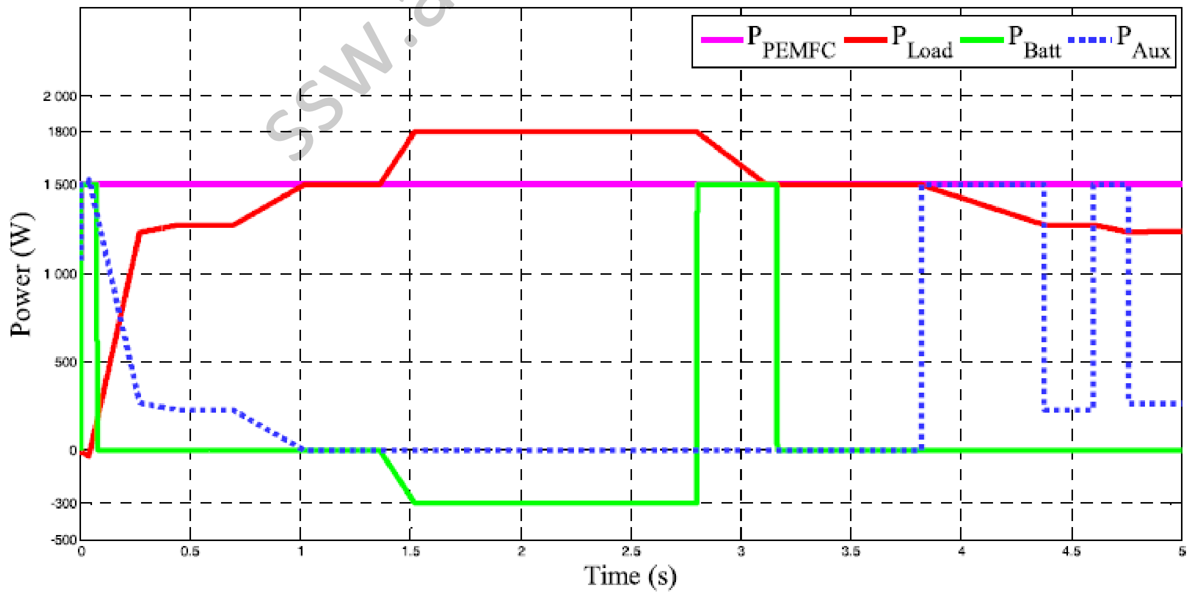

Fig. 16. Different Powers Generated in The System.

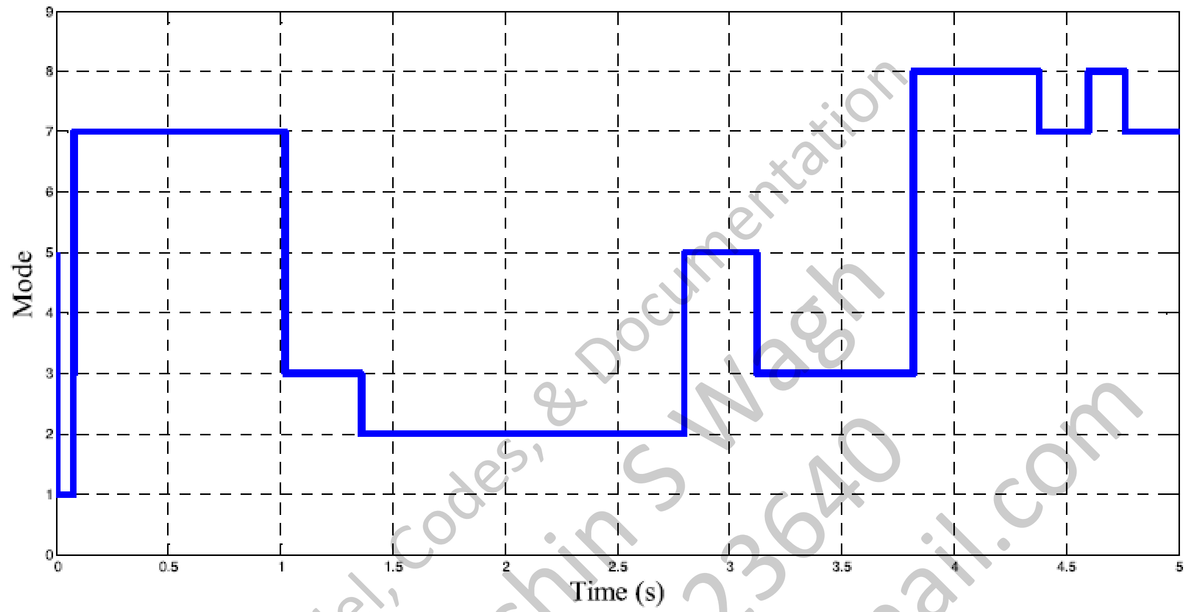

Fig. 17. Timewise Operating Modes.

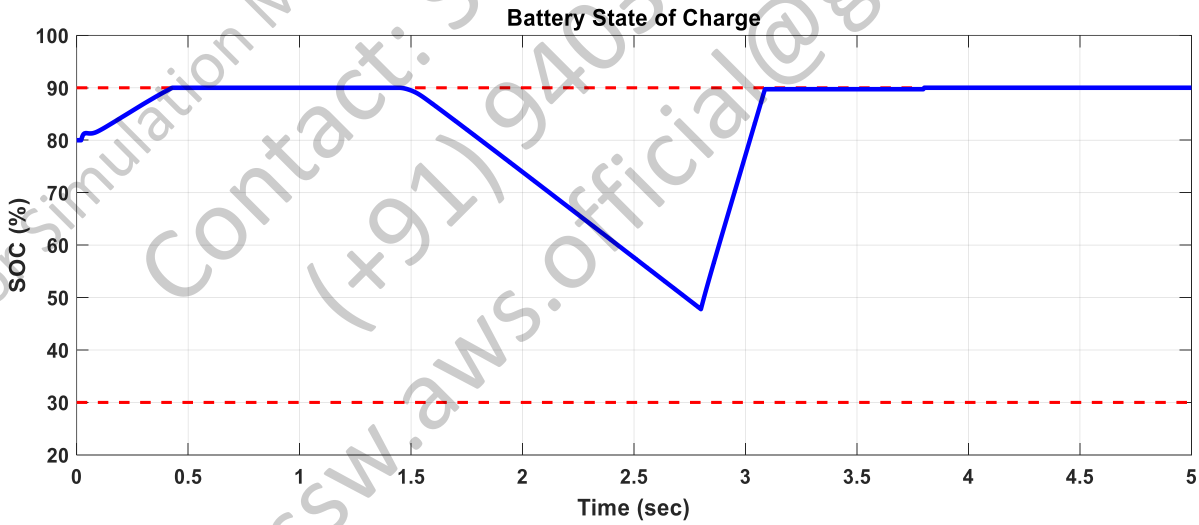

Fig. 18. Battery SOC.

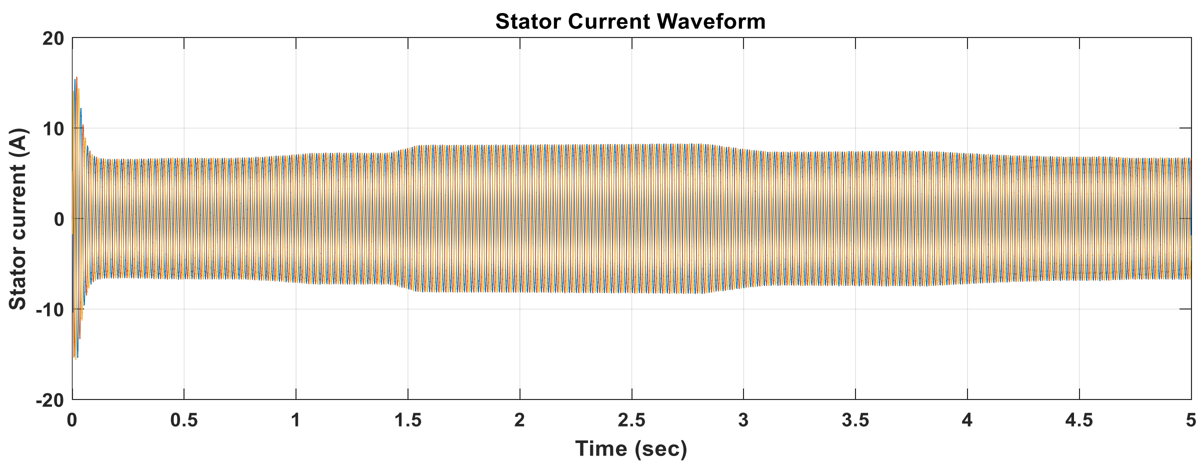

Fig. 19. Stator Current Waveform.

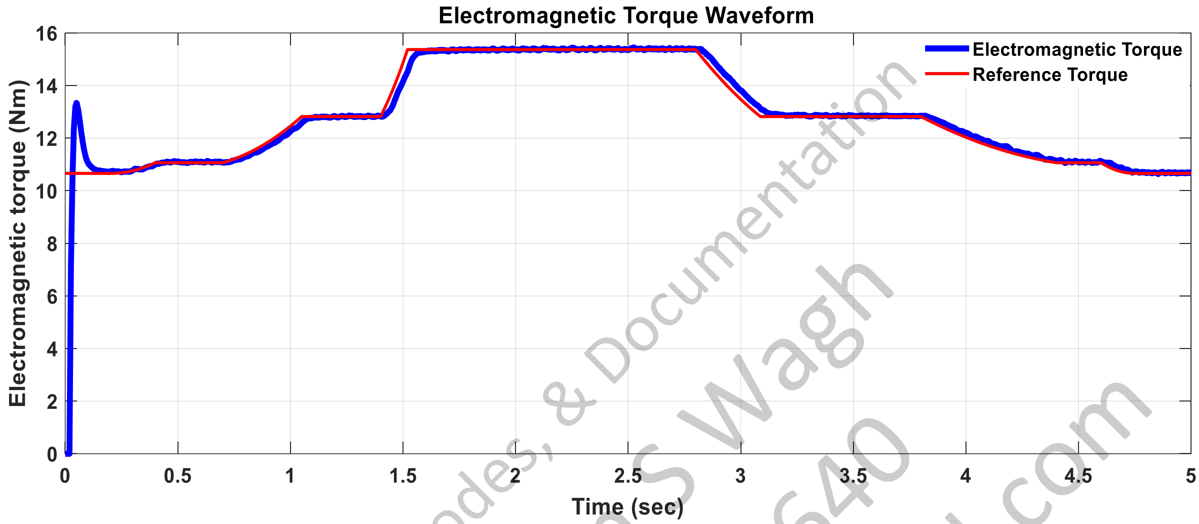

Fig. 20. Electromagnetic Torque Waveform.

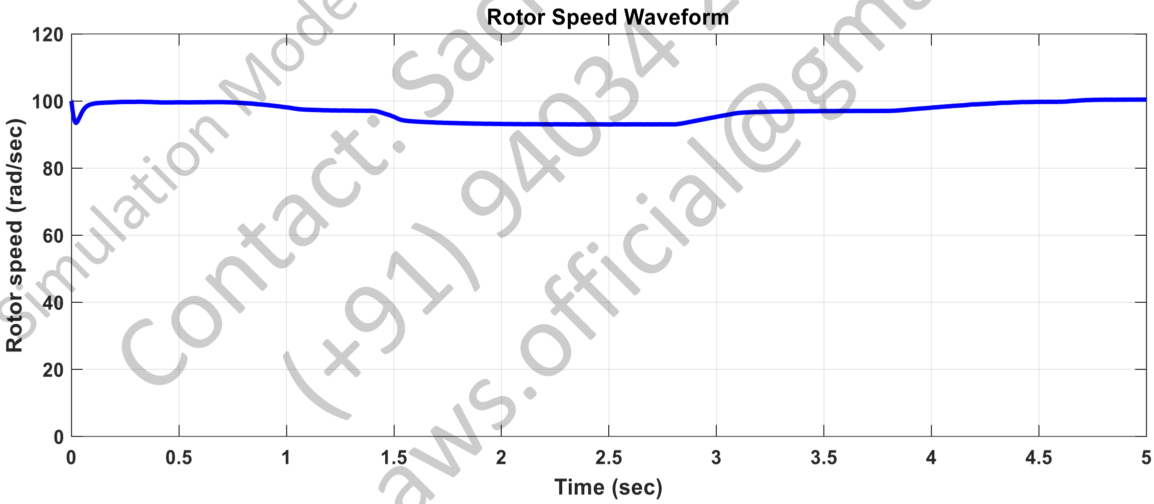

Fig. 21. Rotor Speed Torque Waveform.

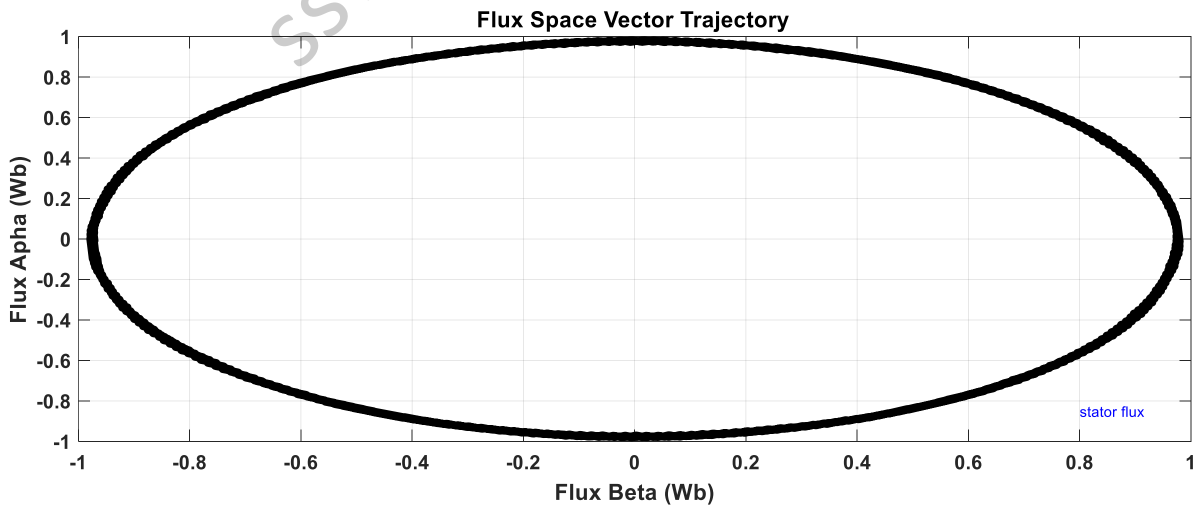

Fig. 22. Trajectory of Stator Flux.

6. Improvement of The Management Strategy

Fig. 23. The Proposed System with An Additional Switch.

Fig. 24. The Energy Management Algorithm.

Fig. 6.11 Energy management and control strategy of the proposed system.

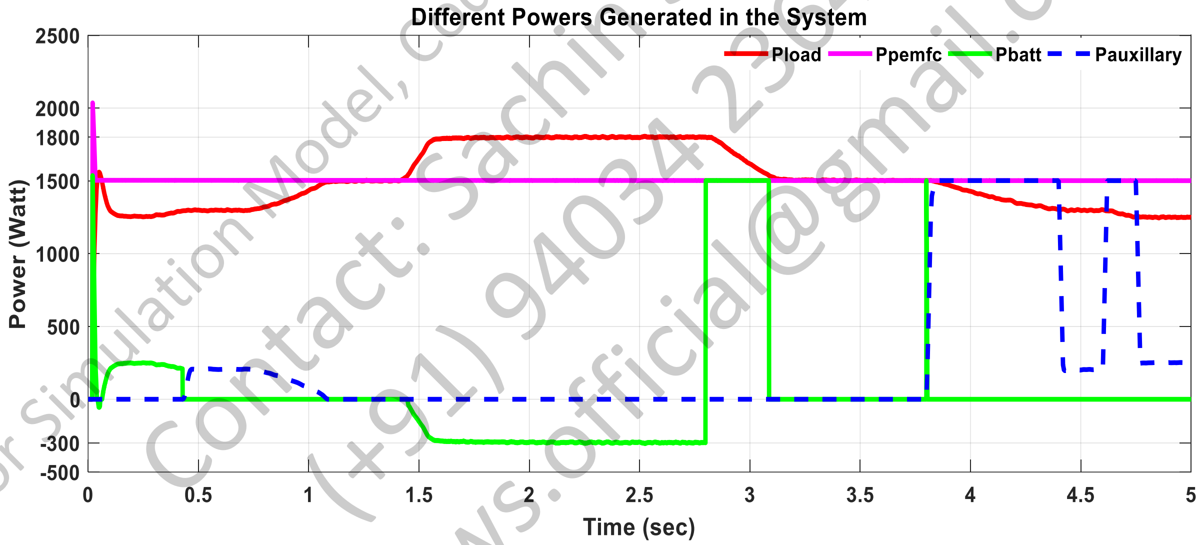

Fig. 25. Powers Generated in The Modified Proposed System.

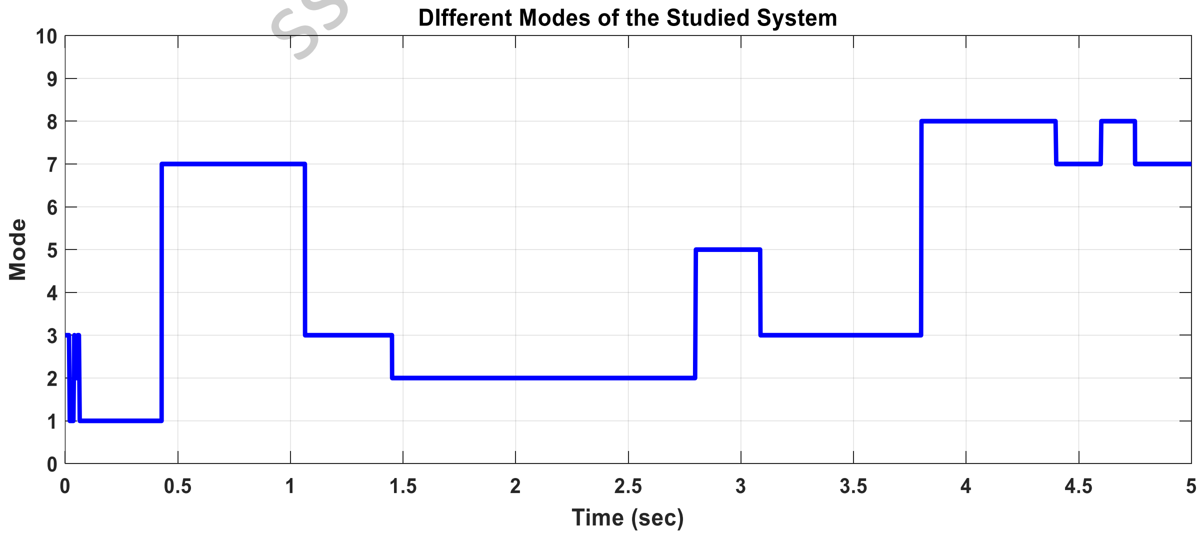

Fig. 26. Different Modes of The Modified Proposed System.

Conclusion

This research investigates a hybrid energy storage system comprising Proton Exchange Membrane Fuel Cells (PEMFCs) and batteries to meet the dynamic and often unpredictable power demands of electric vehicles (EVs). Recognizing the limitations of fuel cells in handling peak load conditions and their relatively slow transient response, the integration of a battery bank was proposed as a complementary energy source. The resulting hybrid system, designed to supply a 3 kW EV powertrain, is modelled mathematically and simulated using MATLAB/Simulink to assess its real-time performance under various operating conditions.

A key contribution of this study is the development and implementation of two distinct Power Management Control (PMC) strategies aimed at optimizing energy utilization, ensuring operational continuity, and minimizing losses. The first strategy adopts a power-balancing approach, designed primarily to illustrate energy flow between the fuel cells and battery storage. This method ensures that the energy demand from the EV is met by appropriately dividing the load between the two sources based on instantaneous power requirements. However, this approach, while effective for basic load-sharing, does not capitalize on periods when the fuel cell generates excess energy.

To address this gap, a second, more advanced energy management strategy is introduced. This enhanced strategy incorporates four controlled switching elements that dynamically manage power distribution not only between the main sources but also toward an auxiliary energy storage channel. The fourth switch, in particular, is dedicated to capturing and storing surplus energy generated during low-demand phases, thereby preventing energy waste and improving overall system efficiency. This predictive and recovery-oriented control logic allows the system to adapt to fluctuations in load demand and energy generation, significantly improving energy conservation and battery life.

The control logic behind both strategies is carefully designed to balance system performance, efficiency, and reliability. The algorithms intelligently coordinate the roles of the fuel cell and the battery in real-time: the fuel cell primarily handles the base load due to its high efficiency at steady-state operation, while the battery supplements short term high power demands and absorbs regenerative or excess energy.

Simulation results validate the effectiveness of the proposed strategies. The hybrid system consistently delivers uninterrupted power to the EV, demonstrating improved energy utilization, reduced stress on individual components, and an extended system lifespan. Moreover, the incorporation of energy recovery mechanisms reflects a forward-thinking approach to energy management critical in future EV architectures where efficiency and sustainability are paramount.

In conclusion, this work not only reinforces the technical viability of PEMFC-battery hybrid systems for electric vehicles but also underscores the importance of smart energy management in maximizing their potential. By introducing advanced control strategies capable of real-time power optimization and energy recovery, this research lays a foundational framework for future developments in electric mobility. The proposed methodology paves the way for more intelligent, adaptive, and efficient EV energy systems, with promising applications in both consumer and commercial electric transportation sectors.