Emerging Trends in Digital Transformation

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INVESTIGATION OF DUAL ENERGY STORAGE SYSTEMS FOR HYBRID ELECTRIC MOBILITY

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ABSTRACT: This project optimises dual energy storage system (DESS) design, control, and performance to increase hybrid electric mobility vehicle economy, durability, and power output. The top energy sources are batteries and supercapacitors. High power density systems using high energy density devices increase regenerative braking, minimize primary storage component stress, and manage changing load requirements. Innovative energy management systems determine storage unit power distribution under different driving conditions. HEVs with dual energy storage systems are more dependable, efficient, and viable in many conditions, according to simulations and trials. This car may be used in future hybrid electric autos.

Keywords:*Dual Energy Storage System (DESS), Hybrid Electric Vehicles (HEVs), Battery–Supercapacitor Integration, Energy Management Strategy (EMS), Power Density,*

I. INTRODUCTION

Environmental degradation and climate change are worldwide challenges. Rapid industrialization, overuse of conventional fuels, and urbanization have damaged the ecosystem. Secure and alternative energy must be prioritized. Eco-friendly and efficient technologies are prominent now. Reasons include rising fossil fuel prices and shifting mobility habits.

Climate change has prompted many international meetings and accords to address environmental issues. Major agreement is Kyoto Protocol. Lowering greenhouse gas emissions minimizes industry and auto pollution. Many governments have severe restrictions to reduce toxic gas and other pollution from petroleum-powered cars. CO2 is one.

The hybrid electric vehicle (HEV) industry has evolved as a greener transportation option. Electric and hybrid vehicle technologies are popular because they reduce fuel use, energy waste, and carbon emissions.

Traditional energy sources are declining, oil prices are rising, and carbon emissions are rising. Some of the world's largest issues. Indian villages, companies, and transportation are increasing rapidly, making this difficult. Electric grids and internal combustion engine cars emit the most carbon.

As people care more about the environment and business, transportation must adopt EVs. The switch from gas to electric vehicles can help future generations live more sustainably. Electric vehicles conserve natural resources and reduce pollution.

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DC-DC Converter

VSIs transfer battery energy to motors in electric and hybrid automobiles. Cutting the number of cells in series lowers battery voltage, improving efficiency and cost. PMSMs benefit from a high-voltage DC bus for motor efficiency and power output.

The inverter and batteries are connected with a reversible DC/DC converter for different voltages. This dual-way converter instantly switches DC voltage to run the motor and recharge the battery.

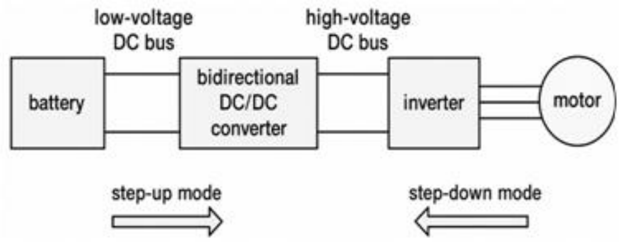

Figure1 DC-DC converter in an electric vehicle

II. LITERATURE SURVEY

Sharma, R. K. (2025): R. K. Sharma (2025) examined dual energy storage hybrid electric mobility systems. DESS uses lithium-ion batteries and supercapacitors. Complex energy management systems improve power distribution, battery stress, and fuel efficiency. Dynamic travel improved system reliability and battery life, according to modeling.

Chen, L. (2024): Chen (2024) optimizes hybrid electric vehicle management with DESS. This paper optimizes supercapacitors and batteries' real-time power balance using adaptive energy management. Improve regenerative braking and reduce energy losses to boost fuel efficiency and vehicle longevity.

Martinez, J. P. (2023): In 2023, J. P. Martinez explores hybrid energy storage system architecture and component sizes. The correct battery and supercapacitor size improves performance and lowers costs, according to paper. The paper indicated hybrid electric vehicles accelerate and handle loads better.

Kumar, S. (2022): Kumar (2022) examines hybrid electric car energy storage solutions using numerous data sources. Optimizing and rule-based methodologies proved that intelligent solutions help users save energy and battery life. Monitoring system state of charge (SOC) optimizes performance, research finds.

Garcia, M. (2021): Garcia studied supercapacitors' peak power regulation in hybrid energy storage systems in 2021. Supercapacitors reduce heat stress, boost system lifespan, and reduce battery burden, according to the paper. Batteries can run more efficiently and break less, according to experiments.

Adeyemi, T. (2020): Dual energy storage devices improve hybrid electric car economy and sustainability, according to Adeyemi (2020). Devices with high power and energy densities can withstand more loads, says research. DESS optimises movement, minimizes emissions, and saves energy.

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III. METHODOLOGY

Bidirectional DC to DC converter

Both energy storage system batteries are connected to the driving inverter's DB bus by a two-way DC/DC converter.

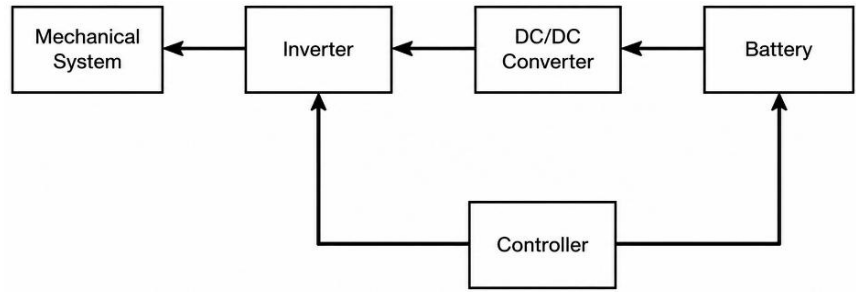

Figure 2 Block Diagram of DC to DC Convertor

Basic components of Fuzzy Controller

The key fuzzy driver components are:

Fuzzy logic is affected by language variables. Other methods use complex numerical values, whereas fuzzy logic control does not. Monitor models with easy math. With merely mathematical logic, it's a superb control mechanism. One of the easiest and most effective ways to maintain vegetation.

Fuzzy logic control begins with fuzzy series. Fuzzy theory associates components by degrees. When all else fails, fuzzy sets can be compared to classical sets. The Fuzzy Logic Controller (FLC) is employed when system accuracy is low and mathematical analysis is too expensive or time-consuming. There are three key components:

- Fuzzification, fuzzy rule engine implementation,
- Structure.
- Clarified text.

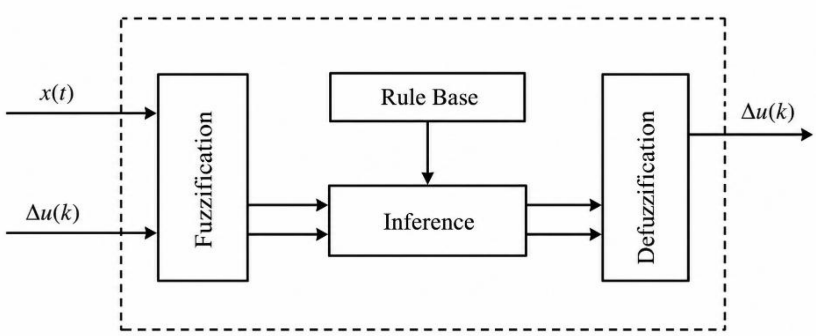

Figure 3 Internal Block Diagram of Fuzzy Control

IV. RESULTS AND DISCUSSION

The approach entails managing the vehicle's power and voltage and assessing its electrical needs. Global management should optimize source use for driver and lane power. Fuel cell stacks in FCV/HEV power systems manage DC-bus voltage with DC-DC converters. The reference current matches boost converter currents (iL1 or iL2) to modify system frequency, not transformer output voltage, which is monitored in each mode. The converter control framework's motor fuel, power, and voltage monitoring system activates BDC mode for

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variable power demands (Pdem) and dual source voltages (VES1, VES2). A proportional-integral (PI) system or more complex method can control active switches (S, Q1–Q4). You can also select current references (iL1, refer or iL2, déf).

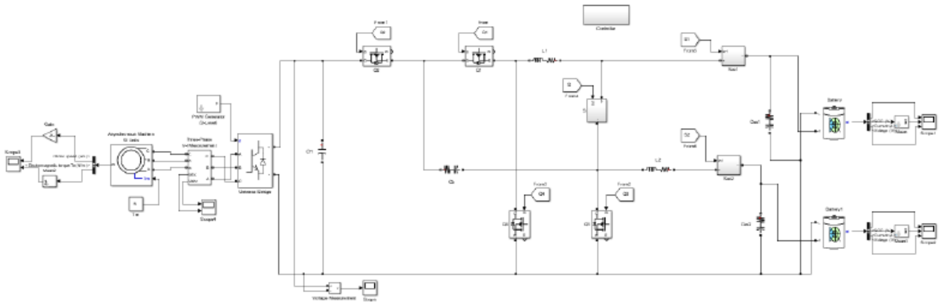

Figure 4 Proposed bidirectional converter

For circuit modification, the recommended converter has four MOSFETs and three reversible switches. The generator or mobility modes adjust to battery charge as the induction machine runs.

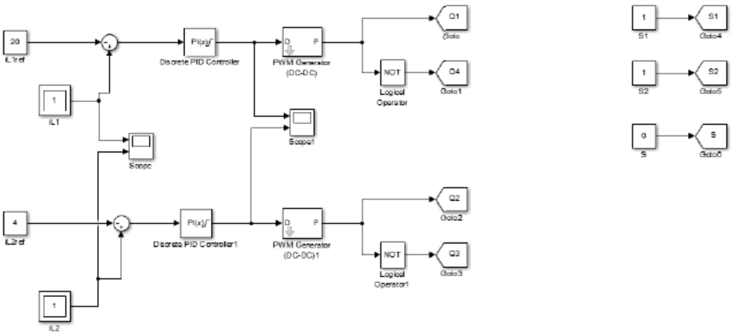

Figure 5 Proposed control structure

Mode A shows controller. Mode controls switches Q1, Q2, Q3, and Q4. S1 and S2 are active in mode A, but not S. Q1Q4 and Q2Q3 were consecutive shifts. PI controllers set duty cycles by comparing real values to setpoints. Below are graphs of device operation in various modes.

A fuzzy controller with 49 rules, two input variables, and one output variable replaces the PI controller.

Both error E and error change dE are input membership variables for the fuzzy controller. Fuzzy function yields one. Seven membership functions for each variable make up the "mamdani" function, which humans are exploring. The following are wavelet-shaped input membership functions.

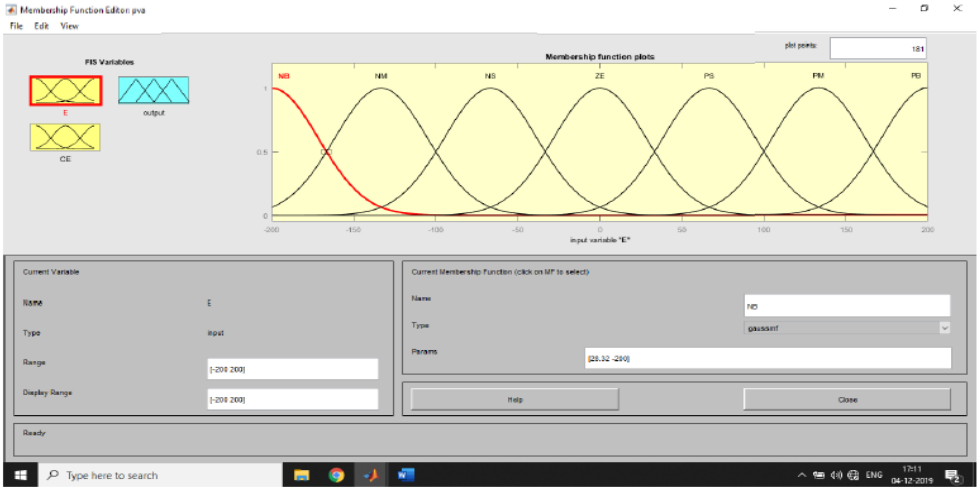

Figure 6 Error input membership function

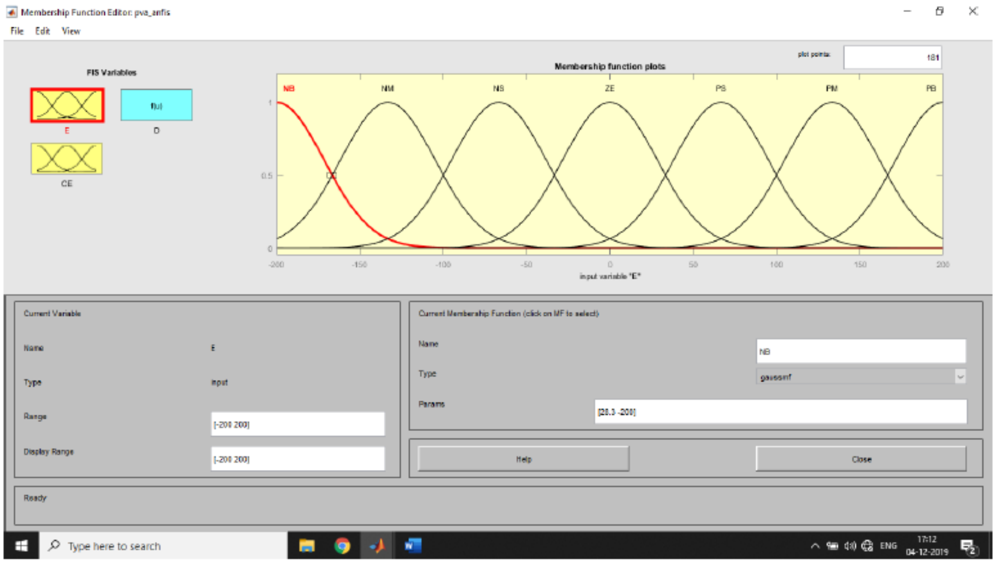

Figure 7 Change in error input membership function

The output membership functions are of triangular format.

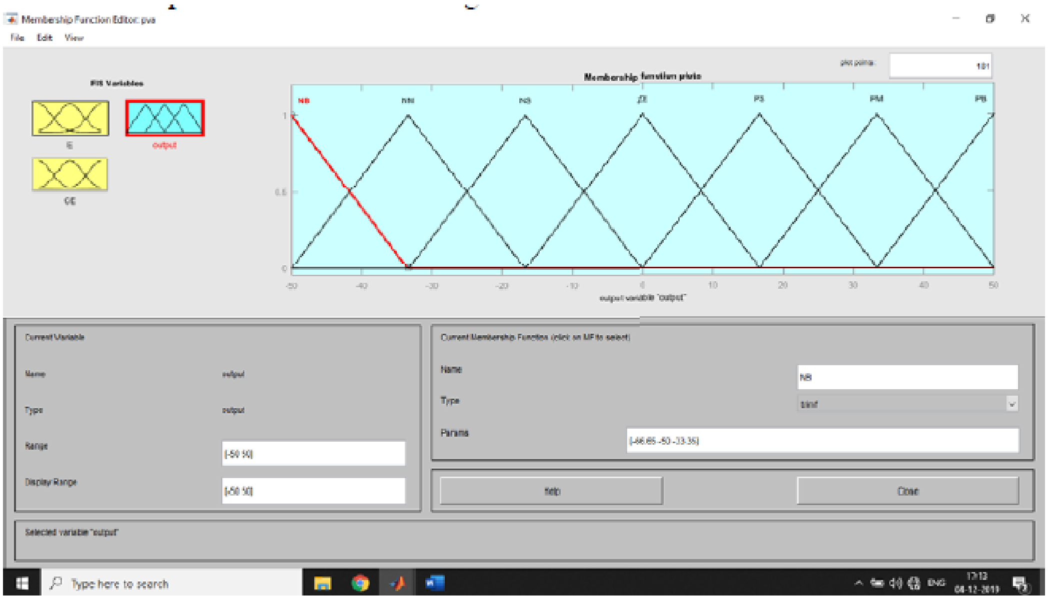

Figure 8 Output membership functions

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Many programs can duplicate your findings. Example: Matlab. Researchers can access files online. They sometimes need minimal effort. In the application, Mfiles can be used as virtual paper for writing.

V. CONCLUSION

DESS-based hybrid electric mobility systems improve vehicle performance, efficiency, and lifetime by combining batteries' high energy density with supercapacitors' high power density and rapid responsiveness. This hybridization enhances energy management reliability and efficiency in dynamic driving situations like regenerative braking and acceleration. Additionally, it minimizes storage component stress. DESS's benefits are maximized by advanced control and optimization technologies that distribute electricity uniformly and extend system longevity. New research and technology reveal that dual energy storage systems can provide environmentally friendly, high-performance, and efficient hybrid electric mobility despite cost, system complexity, and integration.

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