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A Smart and Effective Energy Management System for Shipboard Applications using a Stochastic Fractal Search Network (SFSN) Controlling Model

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Abstract: The use of all-electric ships is a recent emerging technology due to the growing effects of ship pollution on the environment and the preventive legislation that are tightening every day. Fuel cells are a promising technology, making it an intriguing decision for marine vessels to use them as their primary energy source. The primary goal of this research effort is to facilitate the development of a new energy management system to meet the load requirements of ship board applications. In this work, a sophisticated controlling mechanism called Stochastic Fractal Search Network (SFSN) has been developed to achieve the aforementioned objective. In this hybridized system, the fuel cell serves as the primary source of energy while the battery storage serves as a supplementary storage device. Additionally, this work implements two distinct converter topologies, including a non-isolated high gain interleaved converter for fuel cells and a bi-directional converter for battery storage. These converters are primarily used for effectively raising the output voltage of hybridized energy sources while minimizing ripple switching stress, voltage loss, and distortions. The proposed SFSN combines Deep Neural Network (DNN) and Stochastic Fractal Search (SFS) optimization techniques to anticipate the fuel cell's output power. In order to control energy effectively on an electric ship board, the DNN technique collects the input parameters of load demand power and battery SoC during this process. With the help of the SFS algorithm, the bias and weight values of the DNN are optimally computed in this approach. The proposed SFSN's main advantages are improved efficiency, efficient utilization of energy in accordance with load requirements, and dependability for ship applications. In the simulation analysis, the normal, high, and low battery SoC states are used to determine the load demand and fuel cell power. Also, some other measures including fitness, converter's voltage gain and efficiency are also validated and compared in this assessment. According to the results, the suggested SFSN can efficiently monitor and control the energy requirements of electric ships with a hybridized energy system.

Keywords: *Hybrid Renewable Energy Sources, Fuel Cell, Battery Storage, Non-Isolated High Gain Converter, Inverter, Bi-Directional Converter, Shipboard, Stochastic Fractal Search Network (SFSN) Controller, and Energy Management System (EMS).*

1. Introduction

The use of renewable energy generation and energy storage in ship transportation is being encouraged by recent advances in electrical utilities [1, 2]. The usage of renewable energy sources (RES) for the production of electricity is under pressure from greenpeace. A lot of developing nations prioritize RES as a technique for electricity generation. Recent research has shown a strong interest in reducing the harmful environmental effects of shipping and increasing ship energy efficiency. Like many other industries, the shipping sector [3-5] is under intense pressure to lessen its harmful effects on the environment. By 2050, CO2 emissions are expected to rise by 50–250% if no action is taken. About 15% of the world's carbon emissions are already caused by shipping. However, advances in energy management and advancements in power and motor technology can dramatically lower greenhouse gas emissions. The International Maritime Organization's (IMO) implementation [6] of stricter environmental laws to regulate ship emissions has increased the concern. In order to help ships comply with the new international standards, the IMO has established a measure to reduce the energy efficiency design index (EEDI) called hybrid electricity and engine opinions. Fuel cells can be utilized in hybrid propulsion systems as the primary power source to make them more environmentally friendly. The proton exchange membrane fuel cell (PEMFC) offers several benefits comparing to other RES, which encourage its use in the transportation industry, including zero emissions, rapid startup, efficient operation, high power density, minimal operating temperatures, stable fluid, and minimal disturbance [7, 8]. In order to increase the fuel cell system's efficiency and dynamics, a battery system is typically employed as a source of energy technology to hybridize the fuel cell motor system in applications related to transportation. An energy management strategy (EMS), which will enhance the system's electrical integration, is necessary given the

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coexistence of the fuel cell and battery systems. To correctly divide the power that is required between the fuel cell and battery systems, the development of an appropriate EMS [9, 10] is a fundamental problem. The hybrid system's dynamic behavior, consumption of fuel, efficiency of the system, component weight, and lifespan are all influenced by the EMS. While the majority of studies [11-13] on EMS focus on hydrogen consumption, which is certainly significant, this paper focuses more on the reduction of energy consumption, and the energy used to recharge the battery. This is done in an effort to increase the ship's energy efficiency.

Electric power systems have seen the development of several artificial intelligence (AI) [14, 15] applications throughout the past decades. In contemporary electrical power systems, artificial intelligence approaches are important. The complexity of power system performance, forecasting loads, security, and management when connected to the grid is a result of the expansion of different power generation technologies as well as the inherent uncertainties of RES. Power flow between power sources is controlled by an important fuel cell and battery hybrid system termed as EMS [16]. Adjusting the flow of hybrid system power to variations in load power and battery state of charge (SoC) is a crucial component of a smart control system. In the existing studies, several AI based controlling algorithms are developed for an effective EMS in ship applications, in which the Fuzzy Logic Controller (FLC) [17, 18], Artificial Neural Network (ANN) [19, 20], and Adaptive Neuro-Fuzzy Inference System (ANFIS) [21] are the most frequently used controlling methods. Due to the lack of system models or when the models are difficult theoretically, the FL approach is more reliable than expert systems in power system control. The ANNs mimic the little arithmetic nodes joined in a highly complicated layer architecture of the human neural system. In all-electric systems, an intelligent system is a recent development. With the inclusion of many non-homogeneous energy sources in the design, the widespread adoption of renewable energy has been promoted. Specifically, the AI improves efficiency and fixes the non-optimality problem in the power system applications. The ANFIS [22] is a fuzzy inference system that employs a hybrid learning algorithm during training to replicate the behavior of the human brain. Due to ANFIS's capacity for learning and generalization, it may be described as a computational representation of the human neural system.

In the proposed work, an effective EMS using hybridized fuel cell and battery sources is developed for an electric ship applications. The contributions behind this research work are given below:

- Stochastic Fractal Search Network (SFSN), an innovative AI-based energy management system, has been developed for shipboard application.
- For enhancing the voltage gain with high efficiency, innovative converter circuits including non-isolated high gain interleaved and bi-directional circuits are implemented in this study.
- Moreover, a hybridized source that combines battery storage and fuel cells has been used to meet the ship's electrical demands.
- Also, a thorough simulation analysis is carried out to evaluate the effectiveness and outcomes of the proposed model.

The remaining sections of this document are divided into the following units: The comprehensive literature review on various energy management approaches used in electric ship applications is presented in Section 2. Section 3 contains the block diagram, descriptions, and overall explanation of the proposed work. Numerous metrics are employed in Section 4 to compare the results of the stipulated methodology and evaluate the simulation study. Section 5 concludes the overall works by summarizing the entire investigation, along with its findings and recommended future actions.

2. Related Works

This section examines a few of the controlling methods applied to shipboard energy management and control applications. *Hou, et al* [23] implemented an adaptive model predictive controlling mechanism to accurately predict and estimate the load for ship energy management. To perfectly synchronize generator sets, hybrid energy storage system and motor driving, an integrated EMS is developed in this study. The integrated method improves the system performance by using MPCs and, it enables the designers to carefully coordinate many shipboard network components while working within limits. *Rafiei, et al* [24] developed a hybrid zero-emission energy management system for ferry boat applications. The main purpose of this research article is to develop an energy management system with increased performance and lower cost. Moreover, it incorporates the fuel cell, battery and col-ironing systems for supplying the required power to the ferry boat. In this study, the Sine-cosine optimization algorithm is implemented to optimize the performance and efficiency of the entire energy management system. *Chen, et al* [25] introduced a new hybridized energy storage system for shipboard applications. The primary characteristic of the technique is the employment of a deterministic rule-based approach to control the power supply under various operating circumstances. Frequency-based power allocation, which is efficient and intriguing due to its resilience and good performance in real time, is one of the most straightforward rule-based systems. Fuel cell and hybrid energy storage system power flow is controlled by the suggested EMS, which is dependent on load demand and the condition of the fuel cell, power source, and super capacitor. Support vector machine (SVM) controlling model, low-pass filters, and SoC control are all included in the strategy.

Zhang, et al [26] introduced a new sizing method using a hybridized energy system for satisfying the demand of electrical ships. In this study, the different types of energy management strategies are investigated as listed in below:

- Deterministic models
- Fuzzy logic
- Global optimization techniques
- Real time optimization models

Due to the unique characteristics of the ship, the development of the energy storage system must initially evaluate the broad characteristics and characteristics of the envisioned ship. In this study, the topology of the energy management system is established initially; and the scope of the energy management system is chosen grabbing power constraints, electricity constraints, etc. into consideration. *Hou, et al* [27] conducted a sensitivity analysis to validate and examine the efficiency energy management system used in the shipboard applications. Here, an adaptive MPC is used to resolve the power fluctuation problems in order to improve the efficiency and reduce the cost of the energy management system. *Wu et al* [28] applied a reinforcement learning to lower the high cost consumption of hybridized energy sources. In this study, the energy needs of ships are satisfied using hybrid fuel cell and battery storage systems. Here, the sequential decision-making issues are resolved using a mathematical framework based on the Markov Decision Process (MDP). This model updates the current system status based on power availability and demand. The suggested methodology takes into account the past trip power profile as an input, and delivers an energy management solution for the upcoming journey as an output to address the energy management issue.

For large-scale ship applications, *Yuan et al* [29] presented a multi-energy hybrid power system with greater reliability and efficiency. In this study, various propulsion modes—mechanical propulsion, electric propulsion, and hybrid propulsion mode—have been discussed. A hybrid series-parallel power system incorporates the advantages of parallel as well as series systems, resulting in more flexible energy flow management and fuel consumption optimization. It also uses much less fuel. Due to the system's expensive cost and extremely complex construction, a proper control approach is required. A thorough analysis of green maritime transportation with advantages for the economy and the environment was provided by Fang et al [30]. Typically, the newest technology for managing seaports is the seaport micro-grid, which enhances energy penetration and storage capability. According to the study, the optimal method for tying an electric ship to a seaport micro-grid is an active synchronization.

Edrington, et al [31] designed a new distributed energy management system for 4-zone ship power system. In order to successfully coordinate the distributed energy storage and guarantee that the impact on the generators is reduced to a minimum, a higher-level controlling layer is needed. In order to meet load demand while reducing ramp rate violations, the Energy Management layer must keep the distributed energy storage in the proper state of charge. *Yang, et al* [32] applied a particle swarm optimization (PSO) technique for performing energy management in electrical ships. The research object for this article is to develop an EMS for a solar-diesel hybrid ship with 5000 vehicle places. After testing the ship, experimental data were collected, a multi-objective optimization model relating to the ship's fuel efficiency and diesel generator efficiency was put together, and a partial swarm optimization technique was utilized to solve a multi-objective issue.

3. Proposed Methodology

The proposed energy management system for ships that uses hybridized sources is explained in detail in this section. The key contribution of this paper is the use of an advanced artificial intelligence algorithm to efficiently manage and control an electric ship's power system. This article suggests an innovative controlling model, referred to as, Stochastic Fractal Search Network (SFSN) to manage the energy consumption of electric ships. This investigation's main objective is to determine how well the suggested model maintains a consistent DC bus voltage. These investigations emphasize the EMS while concentrating on how hybrid power systems make power decisions. A fuel cell serves as the primary DC power source in the suggested design, and a battery bank and supercapacitor serve as the energy storage system. The block diagram of the proposed EMS design is depicted in Fig 1, which comprises the following modules:

- Fuel cell and battery system modeling
- Non-Isolated high gain interleaved converter for fuel cell
- Bi-directional converter for battery storage
- 3-phase inverter circuit

- Stochastic Fractal Search Network (SFSN) controller for EMS
- Output to electric ship

By using the DC-DC converters, the controller controls the battery and the fuel cell's output power. This control system has been configured in line with the energy conservation plan in operation. DC-DC converters require an output voltage reference and a minimal input/output current reference in order to maintain the DC bus voltage level set by the energy management system. By combining advanced controlling techniques with hybridized energy sources, this work seeks to design and develop a novel energy management system for electrical ships. In this design, the battery and fuel cell systems provide the electrical energy needed to power ships. After that, a non-isolated high gain interleaved converter is used to regulate the voltage, which helps to raise the fuel cell's output voltage while lowering switching stress, loss, and increasing efficiency. Additionally, the smart SFSN is used in conjunction with these cutting-edge converter designs to efficiently control and predict energy. Finally, a three phase inverter circuit is used to perform harmonic suppression, and the desired output is delivered to the ship load.

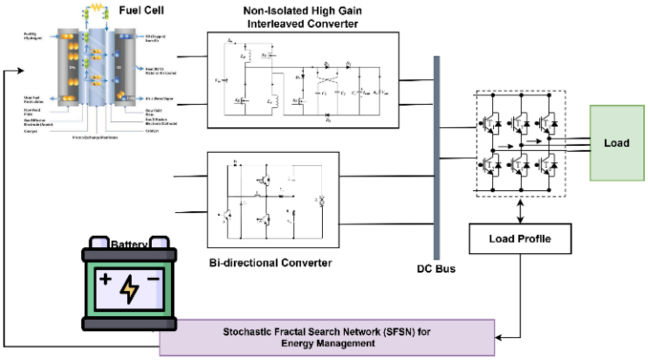


Fig 1. Proposed design block diagram

3.1 Hybrid Energy System

In the case of hybrid systems, the load that requires the necessary amount of power is supplied by a minimum of two distinct sources of energy. A fuel system that uses fossil fuels or hydrogen, a system for storing energy, or any combination of these are usually connected with the system. The existence of wind and photovoltaic (PV) energy resources is one of the primary problems. Since, the wind is generally unrelated to load patterns even when it is readily useable, it is typically neglected. Furthermore, solar energy can only be used during the day. Hence, it is highly essential to optimize the hybrid system components with the fewest significant random variables in order to ensure affordability, and design goals. In order to reduce fuel consumption while maintaining system stability, hybrid systems will probably employ an optimization method that works together with the EMS to determine which source will supply the load at a sufficient quantity of power. Since the battery converter regulates the DC-bus voltage, the supercapacitor power is not taken into account in the optimization problem. At each cycle, the supercapacitors get the same amount of energy from the battery device to be discharged or recharged, balancing the load power between the fuel cell and the battery.

$$Pow_L = Pow_{FC} + Pow_B \tag{1}$$

$$Pow_{FC} = minimum\ (N_{FC} + \varphi_1 N_B + \varphi_2 N_{SC}) \tag{2}$$

Where, Pow_L is the load power, Pow_{FC} denotes the fuel cell power, Pow_B represents the battery power, N_{FC} indicates the number of fuel cells, N_B represents the number of battery storage systems, and φ_1 and φ_2 are the penalty coefficients.

3.2 Non-Isolated High Gain Interleaved Converter

Typically, the RES-based energy generation systems provide a small amount output voltages, necessitating the use of efficient DC-DC converters with higher voltage gain abilities. For voltage improvement and boosting, standard DC-DC converters were used in the past, but the traditional DC-DC boost converters continue to operate under high switching stress, which is identical to the output voltage. To accommodate the higher switching stress, switches must have larger power ratings, which eventually results in greater conduction losses. Higher duty ratios also cause strong voltage spikes, and transmission losses, when used to obtain high voltage gain. Depending on the requirements of the application, many DC-DC converter topologies with high gain capabilities are now available. Two further groups, referred to as isolated and non-isolated converter topologies, include high-gain DC-DC converters. The isolated converter designs suffer from serious drawbacks, such as heating effect, excessive voltage ripples on the switches, leakage inductive power, and increased cost. Hence, the non-isolated converter model is adopted in this study for obtaining higher voltage gain, since they are more compact and economical because galvanic isolation is not necessary. The circuit model of the proposed Non-isolated high gain interleaved converter is shown in Fig 2. This converter design comprises 3 switching elements (S1 to S3), 4 diodes (D1 to D4), 2 inductors (I1 and I2), and 3 capacitors (C1 to C3). Here, the switches S1 and S2 could be operated with the duty cycle of DS_x and S3 is operated with the duty cycle of DS_y.

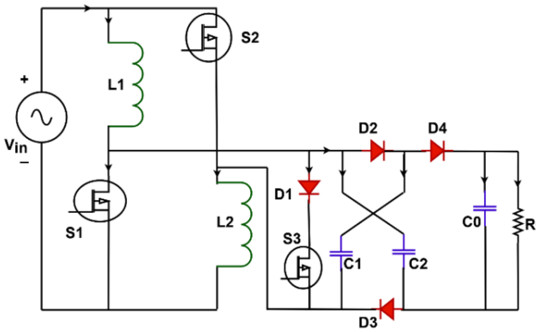
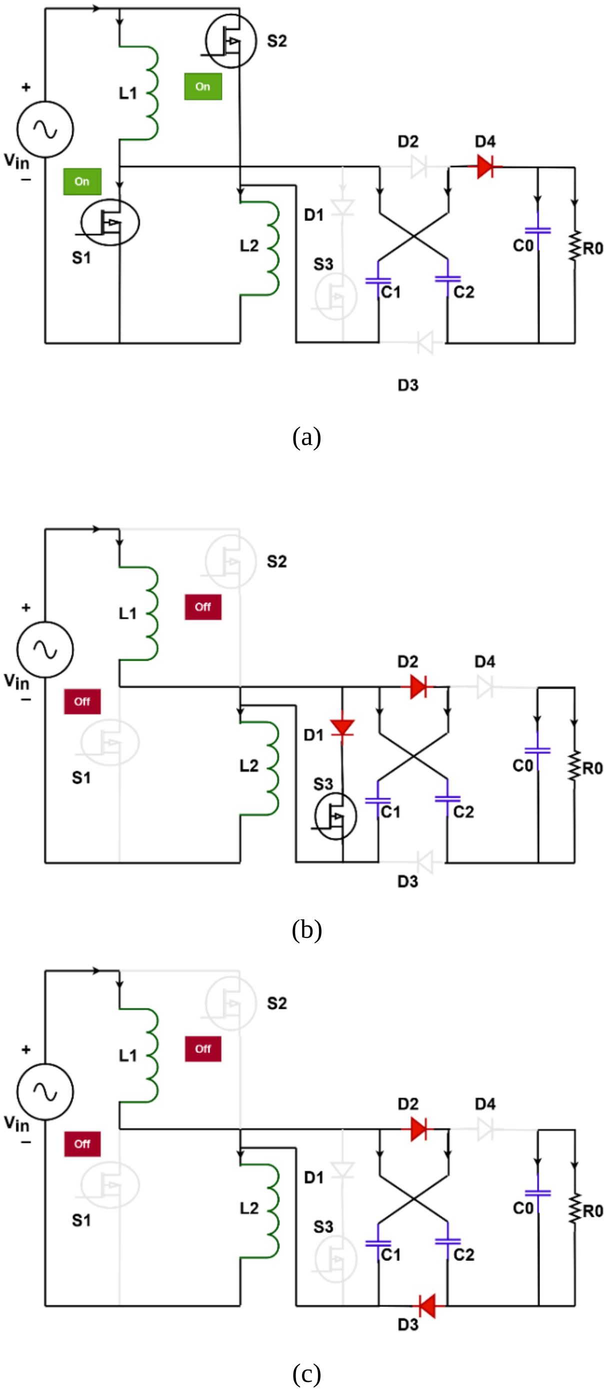


Fig 2. Circuit model of Non-isolated high gain interleaved converter



(a)

(b)

(c)

Fig 3. Modes of operations (a). Mode 1, (b). Mode 2 and (c). Mode 3

In this design, the output voltage across the inductors is estimated by using the following equations:

$$VL_1 = L_1 \frac{diL_1}{dt} \quad (3)$$

$$VL_2 = L_2 \frac{diL_2}{dt} \quad (4)$$

$$VL_1 = VL_2 = V_{in} \quad (5)$$

$$\frac{V_{out}}{V_{in}} = \frac{2(DS_x+1)}{(1-DS_x-DS_y)} \quad (6)$$

$$\begin{cases} V_{S1} = V_{S2} = \frac{V_{in}+V_{out}}{4} \\ V_{S3} = \frac{V_{out}}{2} \end{cases} \quad (7)$$

$$\begin{cases} V_{D1} = V_{in} \\ V_{D2} = V_{D3} = V_{D4} = \frac{V_{in}+V_{out}}{2} \end{cases} \quad (8)$$

By using equ (7) and (8), the voltage stress among switching components and diodes are estimated.

$$L_1 = L_2 = \frac{V_{in} \times D1}{\Delta iL \times S_f} \quad (9)$$

$$C_O = \frac{P_O}{V_O \times \Delta V_C \times S_f} \quad (10)$$

Where, VL_1 and VL_2 indicates the voltage across the inductors, V_{out} is the output voltage, V_{in} denotes the input voltage, P_O represents the output power, C_O is the capacitor output voltage, S_f is the switching frequency, and V_C is the capacitor voltage. By using this converter design, the overall output voltage and conversion efficiency have been highly improved, which supports to deliver the maximum energy to the ship from the fuel cells.

3.3 Bi-directional Converter

In this case, the bi-directional DC-DC converter is being used to enhance the power on board the ship and charge the batteries. Fig. 4 shows the schematic diagram of the proposed bidirectional converter, which uses 3 switches, 4 capacitors, and 2 inductors to increase the load's current. This converter design achieves improved efficiency with a lower circuit size and less power loss. This converter's performance is heavily influenced by the lengths of time that the inductors and capacitors are charged and discharged. The bidirectional converter equivalent circuit's modes 0 and 1 can be applied in this situation. The following equations are used to determine the converter's voltage and current in mode 0:

$$V_{L1} = V_{FC} - V_{R_S} \quad (11)$$

$$V_{L2} = V_{FC} - V_{C1} \quad (12)$$

$$i_{c1} = i_{c4} = I_{FC} - I_{R_S} \quad (13)$$

$$V_{c4} = i_{L2} - \frac{V_{R2}}{R_L} \quad (14)$$

Similarly, the voltage and current during mode 1 state are estimated by using the following equations:

$$V_{L1} = V_{FC} - V_{c1} - V_{L2} \tag{15}$$

$$V_{L2} = -V_B + V_{C4} \tag{16}$$

$$i_{c1} = \frac{I_{L1} - I_{L2}}{2} \tag{17}$$

$$i_{c4} = i_{L2} - \frac{V_{R2}}{R_1} \tag{18}$$

Where, V_{L1} and V_{L2} represents the voltage of inductors, V_{c1} and V_{c2} are the voltage of capacitors, I_{L1} and I_{L2} represents the inductors' current, R_1 and R_2 are the resistors, R_L is the resistive load, and R_S is the series resistance. The circuit model of converters' operating modes are presented in Fig 5 (a) and (b).

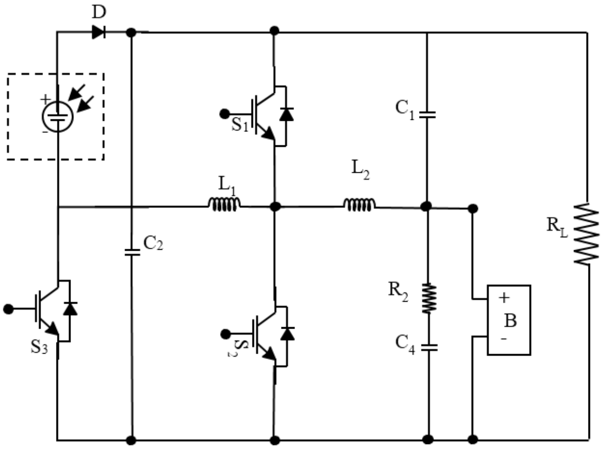


Fig 4. Bi-directional converter circuit model

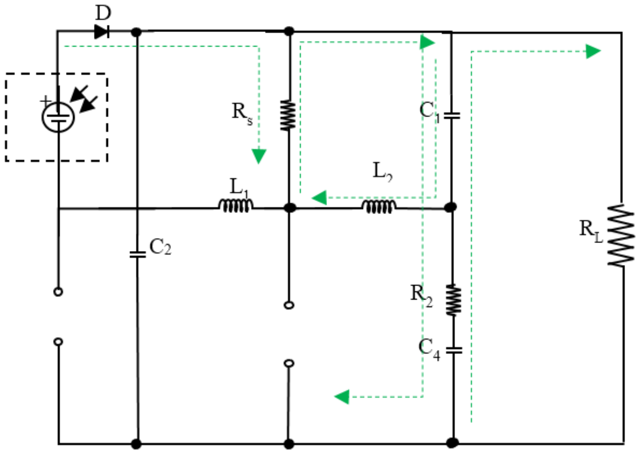


Fig 5 (a). Converter Mode 0

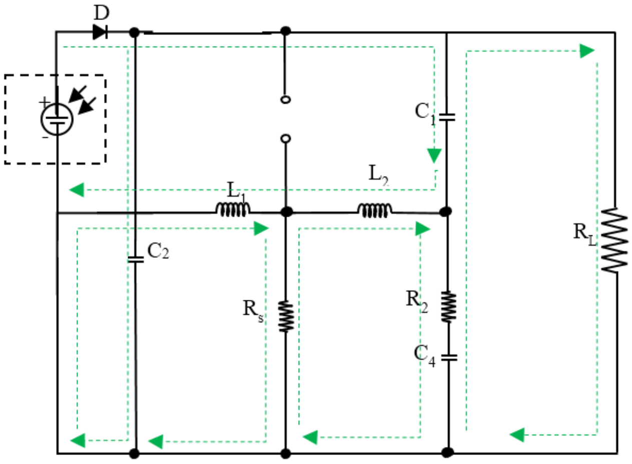


Fig 5 (b). Converter Mode 1

3.4 Stochastic Fractal Search Network (SFSN) Controller

The main contribution of this paper is to perform an effective energy management with the use of hybridized power sources, which is accomplished with the use of SFSN controller. In the earlier studies, several AI based controlling algorithms are developed for performing an effective energy management in electrical ships. Yet, they struggles with the major problems of high complexity in the circuit design, lower efficiency, and high cost. Therefore, the proposed work aims to develop a smart and novel controlling algorithm based on AI for EMS in ship. In this method, the expected output power of the fuel cell is generated as the output while the output power of the load and battery SoC are taken into consideration as the input parameters. The Deep Neural Network (DNN) is an advanced neural network model that can be utilized to tackle challenging prediction issues effectively. In this study, it is utilized to forecast the fuel cell's output power for efficient shipboard energy management. It consists of input, hidden, and output layers. The input layer obtains parameters for the load and battery SoC's output power, while the output layer generates the projected fuel cell power as the output. In this technique, the bias and weight value computations are optimally performed with the use of Stochastic Fractal Search (SFS) optimization algorithm. The goal of parameter estimation is to choose the model variables' ideal values in order to make the model as closely match the outcomes of the experimental data as possible. An objective function that can measure how well the model matches the experimental data is crucial from the perspective of optimization. It is one of the population-based meta-heuristic method, imitates growth in nature. There are two key processes in it, called updating and diffusion, respectively. The first phase, known as the exploitation phase, uses Gaussian random walks in order to find a better solution for every choice near its current location. The second phase, known as the exploration phase, generates an attempt solution for each current solution based on where alternatives are located in the current population. The optimization stages involved in this technique are given below:

- Fitness computation for each solution
- Diffusion process
- Exploitation phase
- Exploration phase
- Reduce the size of population
- Find best optimal solution

The obtained best solution is used to estimate the weight and bias values of the DNN, which helps to accurately predict the energy level of fuel cell. With the use of SFSN controlling model, the overall performance and energy efficiency level of proposed system is highly improved.

4. Results and Discussion

The proposed energy management system's simulation findings for shipboard applications are illustrated in this section. The MATLAB/Simulink tool has been utilized in this work to test the performance of the proposed energy management system developed using SFSN controlling model. The fuel cell system can accommodate load needs of 0 to 10 kW, whereas the supercapacitors and batteries of the storage system are designed to compensate the slow dynamic response of the fuel cell under discontinuous and continuous peak demand situations. The simulation parameter settings are shown in Table 1.

Table 1. Energy management simulation parameters

Parameters	***Specifications***
Fuel cell	10 kW
Duty cycle ratio (D1)	50%
Duty cycle ratio (D1)	35%
Switching frequency	50 kHz
Inductors L1 and L2	360μH
Capacitors C1 to C3	100 μH
Battery power for charging mode	-1.2 kW
Battery power for discharging mode	4 kW
Battery SoC	40% to 100%
DC Voltage	280 V

In Fig. 6, the power of the load and the fuel cell are depicted in relation to changing time (s). Here, the fuel cell power refers to the energy produced by the fuel cell, while the load power indicates the real demand of the load. The results show that the energy produced by the fuel cell is insufficient to meet the load demand. In this case, the battery serves as an additional energy source to meet the load's residual energy requirements. As a result, the battery current is calculated in terms of seconds with respect to changing time, as illustrated in Fig 7.

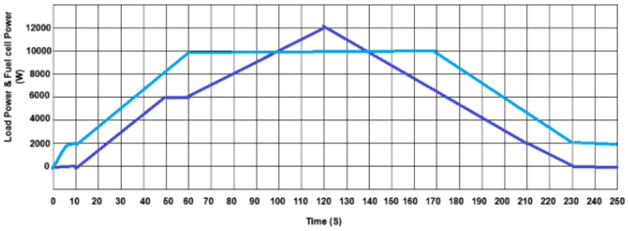


Fig 6. Load power and fuel cell power for high SoC

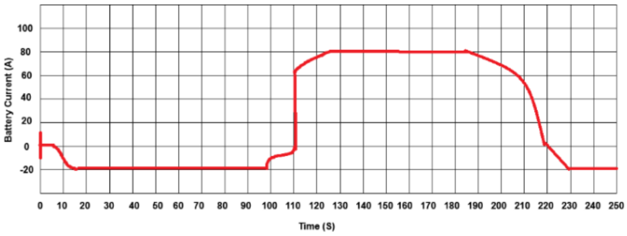


Fig 7. Battery current for high SoC

As a result, Figs. 8 and 9 show, respectively, the load power, fuel cell power, and battery current for a typical SoC. Similarly, the load power and fuel cell power, and the battery current for normal SoC are illustrated in Fig 8 and Fig 9 respectively. By using the proposed SFSN controlling strategy, the output energy of fuel cell is predicted, which helps to satisfy the energy demand of ship load.

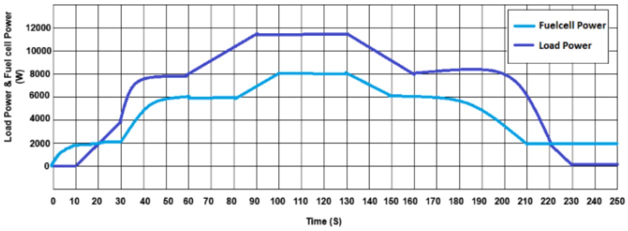


Fig 8. Load power and fuel cell power for normal SoC

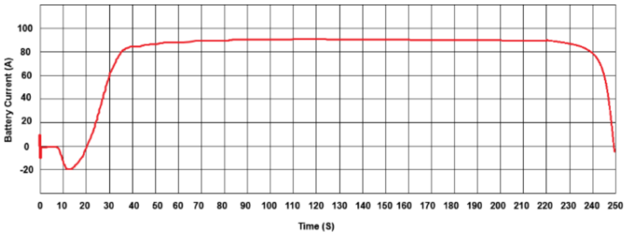


Fig 9. Battery current for normal SoC

Fuel cell power with a high SoC of battery storage is shown in Fig 10. Since the fuel cell cannot provide as much power as the load demands to supply the load, the EMS must pull power from the battery to lower the charge mode from high to normal SoC due to the high battery storage capacity in this mode. The findings show that the fuel cell's output power is less than the load requirement, and the remaining power is drawn from the battery. Similarly, Fig. 11 illustrates the fuel cell's power with respect to a battery's typical SoC. The SoC between 65% and 85% is the optimal operating mode for maintaining battery health and efficiency in this mode. The EMS tray only meets the load demand in order to keep the battery's state of charge constant. The waveforms show that the two waveforms are identical, indicating that the load demand and fuel cell output power are both equal.

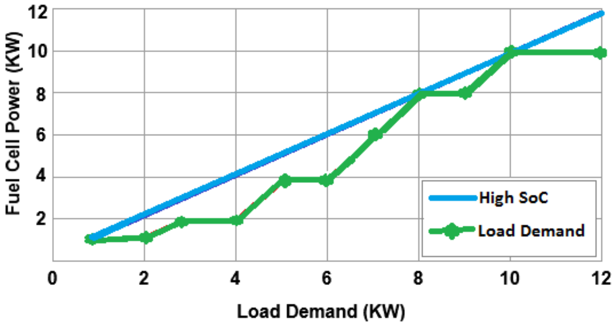


Fig 10. Fuel cell power Vs High SoC

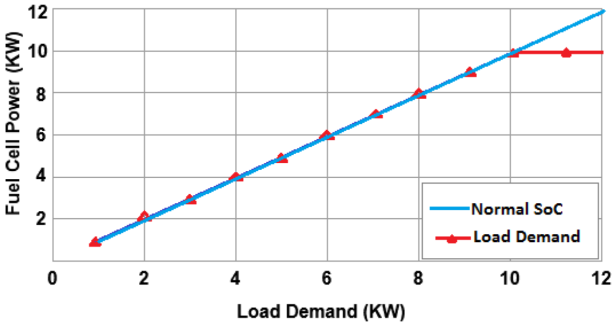


Fig 11. Fuel cell power Vs High SoC

The average fitness value, best score obtained, and radar graph analysis are validated in this study to verify the effectiveness of the SFS optimization technique applied. As seen in Fig. 12, a few common optimization strategies are included for comparison, including Gray Wolf Optimization (GWO), Differential Evolution (DE), Butterfly Optimization Algorithm (BOA), and Harris Hawks Optimization (HHO). The acquired findings show that the suggested SFS technique, which is far superior to the other algorithms, achieves the best fitness value with less iterations. As a result, as shown in Fig. 13, the best score calculated using SFS is validated both before and after improvement. To validate and examine the best, worst, mean, time, and accuracy of the suggested optimization approach, as illustrated in Fig. 14, the radar graph analysis is also carried out. Overall, the findings show that by locating the best optimal solution for the specified problem, the suggested SFS offers an enhanced optimization performance. This method is employed in this work to significantly improve the prediction performance of the SFSN regulating method.

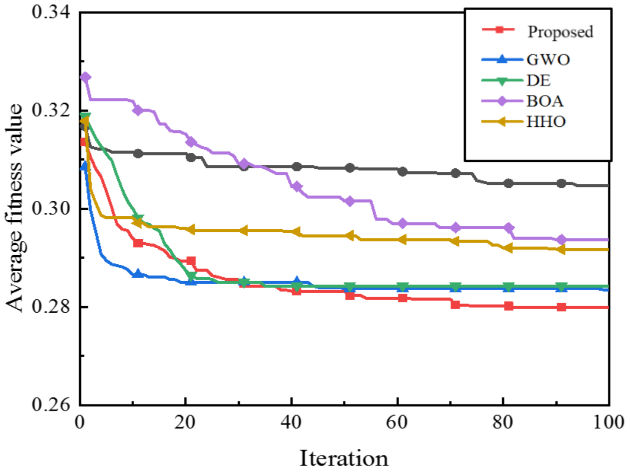


Fig 12. Fitness comparison

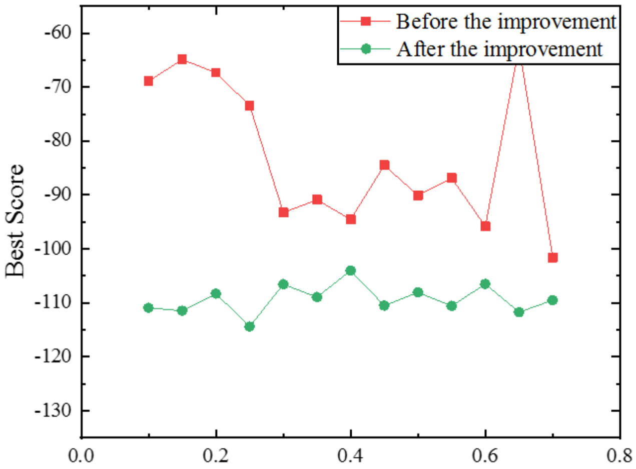


Fig 13. Best score obtained

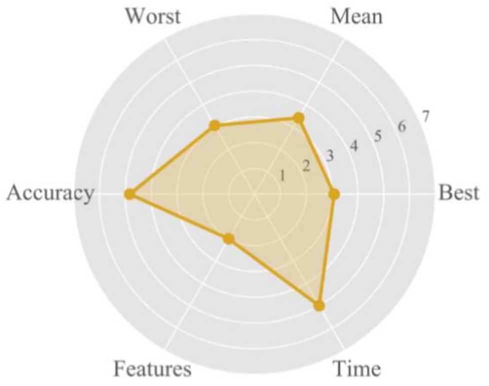


Fig 14. Radar analysis

As illustrated in Figs. 15 and 16, the suggested non-isolated high gain converter's voltage gain and efficiency are validated and contrasted with those of traditional converter designs. Based on the results, it can be seen that the suggested converter design outperforms previous converter models in terms of voltage gain and efficiency. The proposed converter model's overall performance efficiency is increased as a result of the decreased switching stress and voltage loss.

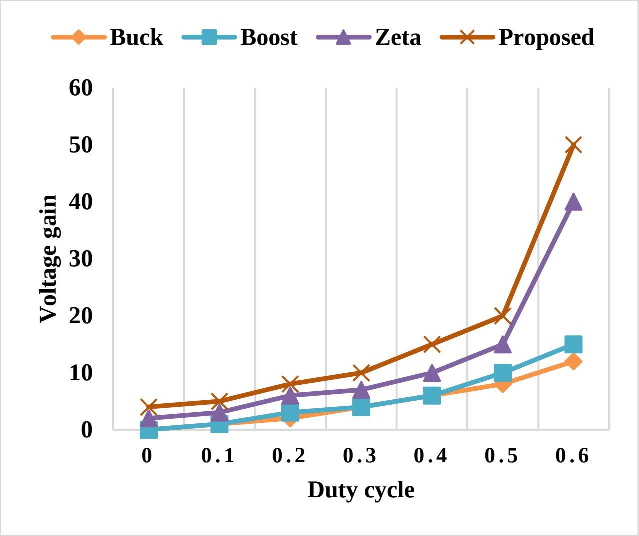


Fig 15. Comparative analysis based on voltage gain

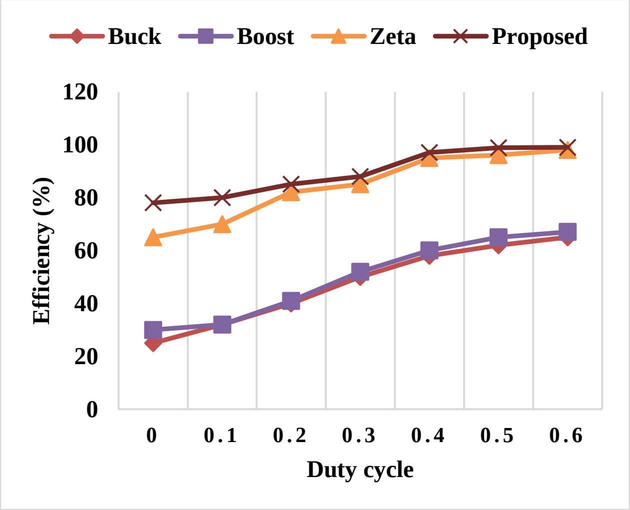


Fig 16. Comparison based on efficiency

5. Conclusion

The need for evaluation of all-electric, zero-emission marine vessel systems has grown as a result of the growing environmental effects of ship pollution and the imposed preventive legislation in this regard, which are becoming tighter every day. This paper evaluated the viability and difficulties of utilizing a hybrid energy system with zero emissions in an electrical ship. A hybrid system based on fuel cells and batteries is needed to achieve an effective energy system with high quality and sufficient volume and weight. The main objective of this research endeavor is to develop a smart energy management system that can handle the load requirements of ship board applications. To accomplish the aforementioned goal, a complex regulating mechanism known as the SFSN has been developed in this work. In this hybridized system, the battery storage acts as an additional storage device besides to the fuel cell as the main energy source. Also, this work incorporates two different converter topologies, including a bi-directional converter for battery storage and a non-isolated high gain interleaved converter for fuel cells. In order to successfully increase the output voltage of hybridized energy sources while reducing ripple switching stress, voltage loss, and distortions, these converters are typically used. The DNN technique gathers the input parameters of load demand power and battery SoC during this operation to efficiently control energy on an electric ship board. The bias and weight values of the DNN are ideally determined in this method using the SFS algorithm. The key benefits of the proposed SFSN are increased efficiency, effective energy use in accordance with load requirements, and dependability for ship applications. The normal, high, and low battery SoC states are employed in the simulation analysis for determining the load demand and fuel cell power. In this evaluation, other metrics like fitness, converter voltage gain, and efficiency are also validated and contrasted. The findings show that the proposed SFSN achieves 99% efficiency in monitoring and controlling the energy requirements of electric ships with a hybridized energy system.

References

[1] A. Fan, Y. Li, H. Liu, L. Yang, Z. Tian, Y. Li, *et al.*, "Development trend and hotspot analysis of ship energy management," *Journal of Cleaner Production*, p. 135899, 2023.

[2] F. Mylonopoulos, H. Polinder, and A. Coraddu, "A Comprehensive Review of Modeling and Optimization Methods for Ship Energy Systems," *IEEE Access*, 2023.

[3] L. P. Van, K. Do Chi, and T. N. Duc, "Review of hydrogen technologies based microgrid: Energy management systems, challenges and future recommendations," *International Journal of Hydrogen Energy*, 2023.

[4] X. Peng, H. Chen, and C. Guan, "Energy Management Optimization of Fuel Cell Hybrid Ship Based on Particle Swarm Optimization Algorithm," *Energies*, vol. 16, p. 1373, 2023.

[5] V. Tummakuri, T. R. Chelliah, and U. Ramesh, "Energy Management and Charging Portfolio Analysis for Future Battery Powered Harbor Vessels," *IEEE Transactions on Industry Applications*, 2023.

[6] M. Tadros, M. Ventura, and C. Guedes Soares, "Review of the decision support methods used in optimizing ship hulls towards improving energy efficiency," *Journal of Marine Science and Engineering,* vol. 11, p. 835, 2023.

[7] M. H. Dewan and R. Godina, "Effective Training of Seafarers on Energy Efficient Operations of Ships in the Maritime Industry," *Procedia Computer Science,* vol. 217, pp. 1688-1698, 2023.

[8] T. Johansen, S. Blindheim, T. R. Torben, I. B. Utne, T. A. Johansen, and A. J. Sørensen, "Development and testing of a risk-based control system for autonomous ships," *Reliability Engineering & System Safety,* vol. 234, p. 109195, 2023.

[9] R. Yan, H. Mo, S. Wang, and D. Yang, "Analysis and prediction of ship energy efficiency based on the MRV system," *Maritime Policy & Management,* vol. 50, pp. 117-139, 2023.

[10] N. L. Trivyza, A. Rentizelas, G. Theotokatos, and E. Boulougouris, "Decision support methods for sustainable ship energy systems: A state-of-the-art review," *Energy,* vol. 239, p. 122288, 2022.

[11] T. Lei, C. Hui, and Y. Xiangguo, "A Review of Control Strategies for Hybrid Ships Energy Management System," in *International Conference on Marine Equipment & Technology and Sustainable Development*, 2023, pp. 791-807.

[12] J. Barreiro, S. Zaragoza, and V. Diaz-Casas, "Review of ship energy efficiency," *Ocean Engineering,* vol. 257, p. 111594, 2022.

[13] Z.-H. Zhao, "Improved fuzzy logic control-based energy management strategy for hybrid power system of FC/PV/battery/SC on tourist ship," *International Journal of Hydrogen Energy,* vol. 47, pp. 9719-9734, 2022.

[14] A. Al-Othman, M. Tawalbeh, R. Martis, S. Dhou, M. Orhan, M. Qasim, *et al.*, "Artificial intelligence and numerical models in hybrid renewable energy systems with fuel cells: Advances and prospects," *Energy Conversion and Management,* vol. 253, p. 115154, 2022.

[15] N. N. A. Bakar, N. Bazmohammadi, H. Çimen, T. Uyanik, J. C. Vasquez, and J. M. Guerrero, "Data-driven ship berthing forecasting for cold ironing in maritime transportation," *Applied Energy,* vol. 326, p. 119947, 2022.

[16] E. Mohammadi, M. Alizadeh, M. Asgarimoghaddam, X. Wang, and M. G. Simões, "A review on application of artificial intelligence techniques in microgrids," *IEEE Journal of Emerging and Selected Topics in Industrial Electronics,* 2022.

[17] A. Atoui, M. Seghir Boucherit, K. Benmansour, S. Barkat, A. Djerioui, and A. Houari, "Unified fuzzy logic controller and power management for an isolated residential hybrid PV/diesel/battery energy system," *Clean Energy,* vol. 6, pp. 671-681, 2022.

[18] A. Elgammal and T. Ramlal, "An Optimal Fuzzy Logic Sliding Mode Voltage Regulation DC-grid System for Hybrid Electric Ships with FC-Battery Energy Storage System," *European Journal of Energy Research,* vol. 3, pp. 21-27, 2023.

[19] K. Wang, J. Wang, L. Huang, Y. Yuan, G. Wu, H. Xing, *et al.*, "A comprehensive review on the prediction of ship energy consumption and pollution gas emissions," *Ocean Engineering,* vol. 266, p. 112826, 2022.

[20] P. Rajesh, F. H. Shajin, and G. Kannayeram, "A novel intelligent technique for energy management in smart home using internet of things," *Applied Soft Computing,* vol. 128, p. 109442, 2022.

[21] M. Gaber, A. Khamis, and D. Zydek, "Proposed Intelligent Energy Management Systems for Hybrid Electric Traction System," in *International Conference On Systems Engineering*, 2023, pp. 274-283.

[22] K. Suruli and V. Ila, "Energy Management Strategy Using ANFIS Approach for Hybrid Power System," *Tehnički vjesnik,* vol. 27, pp. 567-575, 2020.

[23] J. Hou, J. Sun, and H. Hofmann, "Adaptive model predictive control with propulsion load estimation and prediction for all-electric ship energy management," *Energy,* vol. 150, pp. 877-889, 2018.

[24] M. Rafiei, J. Boudjadar, and M.-H. Khooban, "Energy management of a zero-emission ferry boat with a fuel-cell-based hybrid energy system: Feasibility assessment," *IEEE Transactions on Industrial Electronics,* vol. 68, pp. 1739-1748, 2020.

[25] H. Chen, Z. Zhang, C. Guan, and H. Gao, "Optimization of sizing and frequency control in battery/supercapacitor hybrid energy storage system for fuel cell ship," *Energy,* vol. 197, p. 117285, 2020.

[26] Z. Zhang, C. Guan, and Z. Liu, "Real-time optimization energy management strategy for fuel cell hybrid ships considering power sources degradation," *IEEE Access,* vol. 8, pp. 87046-87059, 2020.

[27] J. Hou, Z. Song, H. Hofmann, and J. Sun, "Adaptive model predictive control for hybrid energy storage energy management in all-electric ship microgrids,"

Energy Conversion and Management, vol. 198, p. 111929, 2019.

[28] P. Wu, J. Partridge, and R. Bucknall, "Cost-effective reinforcement learning energy management for plug-in hybrid fuel cell and battery ships," *Applied Energy*, vol. 275, p. 115258, 2020.

[29] Y. Yuan, J. Wang, X. Yan, B. Shen, and T. Long, "A review of multi-energy hybrid power system for ships," *Renewable and Sustainable Energy Reviews*, vol. 132, p. 110081, 2020.

[30] S. Fang, Y. Wang, B. Gou, and Y. Xu, "Toward future green maritime transportation: An overview of seaport microgrids and all-electric ships," *IEEE Transactions on Vehicular Technology*, vol. 69, pp. 207-219, 2019.

[31] C. S. Edrington, G. Ozkan, B. Papari, D. E. Gonsoulin, D. Perkins, T. V. Vu, *et al.*, "Distributed energy management for ship power systems with distributed energy storage," *Journal of Marine Engineering & Technology*, vol. 19, pp. 31-44, 2020.

[32] R. Yang, Y. Yuan, R. Ying, B. Shen, and T. Long, "A novel energy management strategy for a ship's hybrid solar energy generation system using a particle swarm optimization algorithm," Energies, vol. 13, p. 1380, 2020

[33] Salman Al-Nuaimi, M. A. ., & Abdu Ibrahim, A. . (2023). Analyzing and Detecting the De-Authentication Attack by Creating an Automated Scanner using Scapy. International Journal on Recent and Innovation Trends in Computing and Communication, 11(2), 131–137. https://doi.org/10.17762/ijritcc.v11i2.6137

[34] Chang Lee, Deep Learning for Speech Recognition in Intelligent Assistants , Machine Learning Applications Conference Proceedings, Vol 1 2021.