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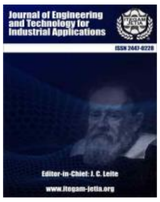

RESEARCH ARTICLE OPEN ACCESS

# AN INNOVATIVE DANDELION OPTIMIZED NETWORK CONTROL (DONC) BASED EFFECTIVE ENERGY MANAGEMENT SYSTEM FOR ELECTRIC SHIPS

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**ABSTRACT**

Energy Management System (EMS) plays a vital role in an international marine shipboard, due to their increased energy demand. The main purpose of this research work is to develop a new energy management system for satisfying the load demand of ship board applications. For accomplishing this objective, an advanced controlling mechanism, named as, Dandelion Optimized Network Control (DONC) is developed in this work. Also, the hybridized energy source including the fuel cell and battery storage are used in this design, where the fuel cell is main source of energy, and the battery storage is used as the supplementary storage device. Moreover, two different converter topologies such as interleaved zeta converter for fuel cell and bi-directional converter for battery storage are implemented in this study. The main purpose of using these converters are to effectively boost the output voltage of hybridized energy sources with reduced ripple current and distortions. The proposed DONC integrates the functions of DO technique as well as FNN for predicting the output power of fuel cell. During this process, the Fictitious Neural Network (FNN) technique obtains the input parameters of load demand power and battery SoC, and produces the predicted power of fuel cell for an effective energy management in electric ship board. In this mechanism, the weight value of FNN is optimally computed with the use of DO algorithm. The key benefits of the proposed DONC are increased efficiency, proper energy management according to the load demand, and reliable for ship applications. During simulation analysis, the load demand and fuel cell power are estimated with the normal, high, and low battery SoC states. The findings indicate that the proposed DONC can effectively manage and control the energy need of electric ship with the hybridized energy system.

## I. INTRODUCTION

Global trade is largely fueled by international shipping, notably maritime merchandise transportation [1, 2]. In fact, ocean transport accounts for a sizable portion of global trade in terms of both capacity (80%) as well as value (70%). The continuous expansion of international trade and ocean transport activities have been projected as contributing to the rise in CO2 levels globally in the future. Shipping is responsible for a sizeable share of the world's greenhouse gas (GHG) emissions, particularly $CO_2$. Electrical energy is an invisible, universal item that is frequently available worldwide at an affordable cost, and it is currently regarded as a basic need for consumers [3-5]. Electricity must typically be converted into other kinds of power because storing energy is not an easy operation. When needed, the electricity can be converted into chemical, biological, mechanical heat, and other forms. The ultimate consumption up to 2040 is expected to see a 40% increase in electricity demand. Industrial electric motors are responsible for more than thirty percent of the rise in electricity demand. The main causes of the rise in power demand are the gain in income, the release of smart linked technologies onto the market, and the installation of new cooling systems. Similar to how demand for electricity fluctuates during the day, so does its price. Electric utilities used multiple pricey power generating plants during the period of peak load [6-8]. To accommodate demand, the plants run alongside the base load power unit. It also refers to the choice of fuels made in light of analyses of economic dispatch for various electric power plants. In this situation, an adequate energy storage system (ESS) is always needed to handle the abrupt fluctuations in load.

In all-electric systems, an intelligent system is a recent development. The inclusion of numerous non-homogeneous energy sources in the framework encourages the widespread usage of renewable energy. Moreover, AI improves efficiency and fixes the non-optimality problem. An appropriate control and management approach for the traction system can be provided by the proposed ship hybrid power systems [9]. An important fuel cell and battery hybridized energy management strategy controls the flow of electricity between various energy sources [10]. A key component of the smart control method is adapting the hybrid system electrical power to variations in load power and battery state of charge (SoC). The fuel cell and battery storage are the vital components of the proposed energy management system used for ship applications [11, 12]. Typically, the flow of power among different energy sources can be effectively managed and controlled with the use of energy management system. Moreover, controlling the distribution of hybrid system power to changes in load power and battery SoC is a crucial component of the automated control scheme. The main contributions of this research work are given below:

- A new AI based energy management technique, named as, Dandelion Optimized Network Control (DONC) is developed for shipboard.
- The advanced converter circuits such as interleaved Zeta and Bi-directional are used to improve the voltage gain with high efficiency.
- In this study, a hybridized sources including fuel cell and battery storage have been used for satisfying the need of electrical ship.
- An extensive simulation analysis is carried out in this study for examining the performance and results of the proposed framework.

The following units make up the remaining sections of this paper: Section 2 presents the thorough literature assessment on various energy management techniques. The block diagram, descriptions, and general description of the proposed work are all provided in Section 3. In Section 4, numerous measures are used to validate the simulation analysis and compare the outcomes of the suggested methodology. Finally, Section 5 summarizes the entire study together with the conclusions and suggested next steps.

## II. RELATED WORKS

Chen, et al [13] developed a hybrid energy storage system by optimizing the size and frequency of battery and super capacitor. For this purpose, a multi-objective optimization algorithm has been deployed for improving energy management with ensured power quality and components' life. This study indicates that a variety of energy management strategies are implemented in the previous works for improving energy efficiency. The methods are typically applied in accordance with the fact that these strategies may effectively control the power allocation in real-time. However, the effectiveness of these solutions mainly depends on subject-matter expertise and knowledge of engineering. In this design, the fuel cell stack is used as the main power source, which helps to satisfy the energy demand of ship. Here, both the passive and fully active topologies are used for an effective energy management of ship load. Wu, et al [14] deployed a reinforcement learning strategy for reducing the high cost consumption of hybridized energy sources. In this work, hybrid fuel cell and battery storage systems are used for satisfying the energy demand of ships. Here, the Markov Decision Process (MDP) based mathematical framework is deployed to solve the sequential decision-making problems. According to the availability of power and demand, the current system status is updated in this model. The suggested methodology considers the input of historical voyage power profile, and energy management solution to the future voyage is delivered as output for solving the energy management problem. In addition, this study considers some other parameter such as power demand, battery state of charge, power level of fuel cell, shore power availability, and power change fraction for reducing the cost.

Iris, et al [15] investigated the recent operational strategies, and technologies for improving the environment performance with better energy management. In this study, the different types of load applications including smart grid and micro-grid have been considered for analysis. Letafat, et al [5] utilized an improved Sine Cosine Algorithm (SCA) to optimize the energy management problem for ferry boat applications. Here, the non-linearity of fuel cell efficiency and operational limitations of fuel cells are taken into account for minimizing the operation cost of ferry ship. In addition, the authors concentrated on the simultaneous energy management and component sizing in the hybridized system. Nuchturee, et al [16] conducted a comprehensive review for maximizing the energy efficiency of maritime transportation. Moreover, an intelligent power management framework has been developed for optimally splitting power among different sources. In addition, several parameters used for validating the energy efficiency of ship management are investigated in this study, which includes ship energy efficiency management plan, energy efficiency operational indicator, and reference line. Furthermore, the distinct characteristics of various energy storage devices are analyzed in this paper that comprises the followings: power density, energy density, capacity, response time, efficiency and cycle life. The common drawbacks of the previous energy storage systems are requirement of high temperature, short life cycle, low reliability, and high environmental impact.

Fang, et al [17] provided a detailed overview about green maritime transportation with an economic and environmental benefits. Typically, seaport micro-grid is one of the newest technology for seaport management, which helps to improve the energy penetration and storage capacity. The study indicated that an active synchronization is the best way for connecting electric ship with seaport micro-grid. Han, et al [18] investigated about the voltage restoration and stabilization techniques in a hierarchical systems. Here, the Takagi-Sugeno and Lyapunov-Krasovskii models are implemented for minimizing the complexity of distributed energy systems. Moreover, the control and stability techniques are categorized into the types of primary control, upper control, and stability. The authors indicated that an optimization techniques play a major role in enhancing the current sharing performance of droop control. Yuan, et al [19] introduced a multi-energy hybrid power system with better reliability and efficiency for large-scale ship applications. Here, the different types of propulsion modes have been discussed in this study, which includes mechanical propulsion, electric propulsion, and hybrid propulsion mode. With additional working modes and significantly less fuel use, a hybrid series-parallel power system combines the benefits of both series and parallel designs, allowing for more flexible energy flow regulation and consumption optimization. A suitable control method is necessary due to the system's very complex structure and high cost. Hoang, et al [20] deployed a critical strategy to determine the best pathway for port to ship with reduced carbon emissions. One of the initiatives to ensure that the global shipping sector has a more sustainable and low-carbon future is to reduce the reliance of marine vessels on fossil fuels. This is accomplished by introducing ship propulsion systems that use alternate and cleaner fuels. Elberry, et al [21] investigated about the major issues and challenges in the electricity based storage systems. In this study, the energy storage systems are investigated and compared based on their storage time, size and cost. Nuchturee, et al [22] studied the recent developments in the field of electric propulsion for ship applications. The authors also discussed about the recent challenges and opportunities for an intelligent energy management. Khan, et al [23] presented a new study for examining the different types of energy storage techniques with the current status and trends. Table 1 shows the characteristic analysis of the different types of technologies used for ship energy management with their pros and cons.

Table 1: Characteristic analysis on RES in ships.

| Reference | Technology used | Pros | Cons |
|---|---|---|---|
| [24] | Energy storage systems | Increased stability and reliability; | Lower lifetime and high cost consumption; |
| [25] | Solar-PV systems | Maximized energy efficiency, and requires low initial cost; | Requires frequent maintenance and limited lifetime; |
| [26] | Wind | Increased efficiency; | Increased capital cost, and fast degrading; |
| [27] | Ocean based energy generation | Suitable for multi-application domain, and maximized energy efficiency; | Ineffective technology development, and low reliability; |
| [28] | Geothermal | Maximized energy efficiency; | High-cost consumption, and low level of expertise; |
| [29] | Alternative fuels | Requires low cost and circular economy; | Low level of expertise and knowledge; |
| [31] | Power | Power quality problem | Always growing and becoming more sophisticated. |

Source: Authors, (2023).

## III. PROPOSED METHODOLOGY

This section provides the complete explanation for the proposed energy management system using hybridized sources for ship. The main contribution of this work is to effectively manage and control the power system of electric ship with the use of artificial intelligence algorithm. In order to control the energy consumption of electric ships, this article proposes an intelligent DONC model. Determining the proposed model's effectiveness at maintaining a constant DC bus voltage is the major goal of this investigation. These studies emphasize the EMS while focusing on the process of power decisions in hybrid power systems. The proposed design is a hybrid power model that includes a fuel cell as the main DC power source and a battery bank and supercapacitor as the energy storage system. The proposed block diagram is shown in Fig 1, which comprises the following components:

- Fuel cell modeling
- Battery storage modelling
- Interleaved Zeta converter
- Bi-directional converter
- Dandelion Optimized Network Control (DONC)

The battery and the output power of the fuel cell are regulated by a controller using the DC/DC converters that are connected to them in the control circuit block. According to the energy conservation strategy being employed, this control system has been set up accordingly. In order to allow DC/DC converters to adhere to the energy management system-determined DC bus voltage level, they need an output voltage reference and a minimal input/output current reference. This work aims to develop a new energy management system by using a hybridized energy sources with advanced controlling technique. In this framework, the electrical energy is obtained from the fuel cell and battery systems for satisfying the demand of ships. Then, the voltage regulation is performed with the use of interleaved zeta and bi-directional converters, which helps to improve the voltage gain. Moreover, the novel Dandelion Optimized Network Controller (DONC) is implemented to effectively perform energy management. Finally, the harmonic suppression is carried out with the use of inverter circuit, and the output is fed to the ship load.

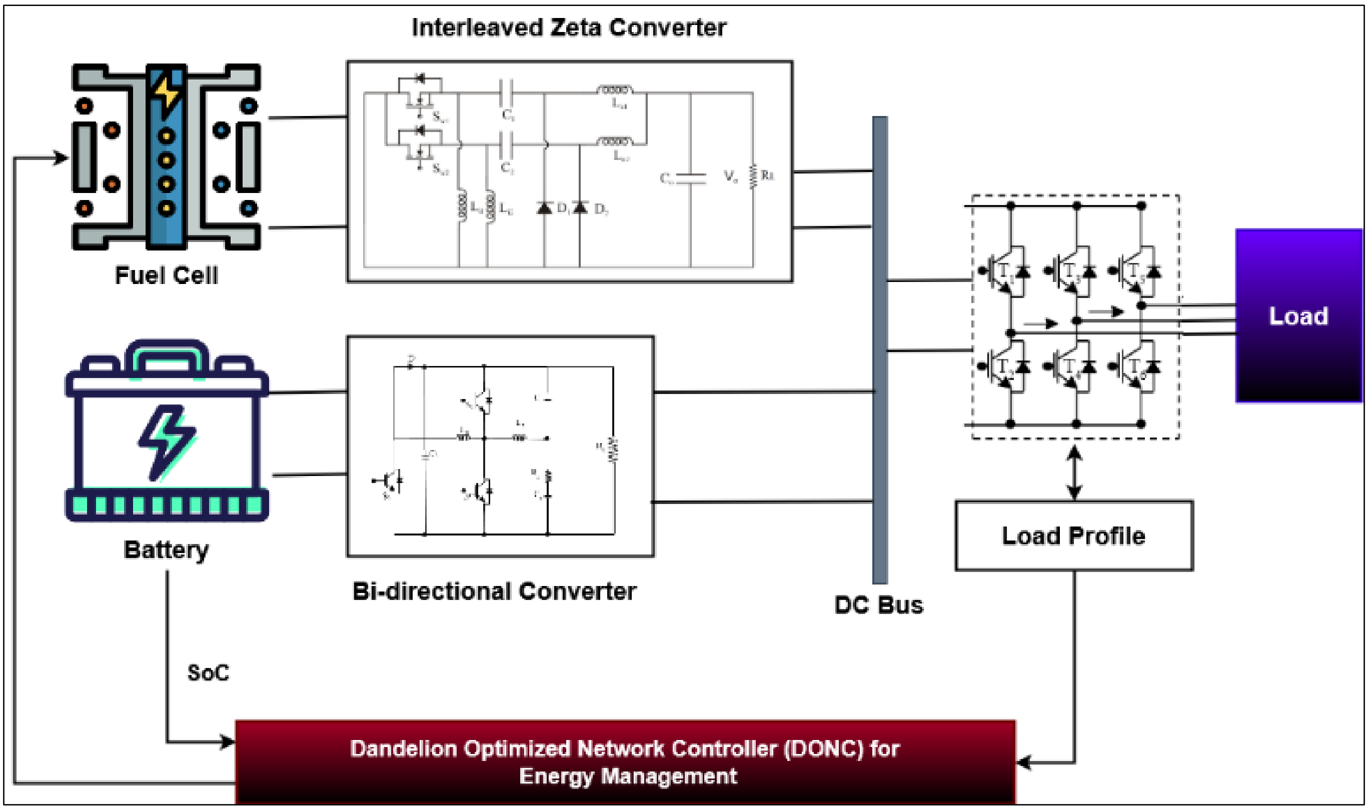

Figure 1: Block diagram of the proposed ship controlling system.
Source: Authors, (2023).

### III.1 HYBRID ENERGY SYSTEM

In hybrid systems, the required amount of power for the load is provided by at least two energy sources. Typically, the system is coupled with one or more renewable energy sources, a system for storing energy, or a fuel system that runs on fossil fuels or hydrogen [30]. One of the main issues is the stochastic existence of wind and photovoltaic (PV) energy resources. When wind is readily usable, it is typically ignored since it is frequently uncorrelated with load patterns. Additionally, solar energy may only be used throughout the daytime. In order to ensure cost-effectiveness, scientific, and design goals, it is necessary to optimize the hybrid system components with the fewest significant random variables. Hybrid systems are anticipated to use an optimization method that coordinates with the (EMS) to determine which source provides the load with the required amount of power or the amount of power should be provided for every point of reference to reduce the use of fuel while preserving stability of the system. The supercapacitor power is not taken into consideration in the optimization problem because the battery converter controls the DC-bus voltage. The supercapacitors are discharged or recharged with the identical energy from the battery device during each cycle, which balancing the load power between the fuel cell and the battery.

$$\mathrm{Pow_L = Pow_{FC} + Pow_B} \qquad (1)$$

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

Where, $\mathrm{Pow_L}$ is the load power, $\mathrm{Pow_{FC}}$ denotes the fuel cell power, $\mathrm{Pow_B}$ represents the battery power, $\mathrm{N_{FC}}$ indicates the number of fuel cells, $\mathrm{N_B}$ represents the number of battery storage systems, and $\varphi_1$ and $\varphi_2$ are the penalty coefficients.

### III.2 INTERLEAVED ZETA CONVERTER

In the proposed framework, an interleaved Zeta converter has been used to regulate the output voltage of fuel cells. The output voltage of the Zeta converter is not inverting. To achieve high efficiency along with excellent control of the voltage to its load, a single-stage dc-dc power converter is used. Compared to the traditional Zeta converter, this converter has a larger duty-ratio range and a greater voltage of supply variance. High efficiency, a lower voltage ripple, reduced distortion, and controllable voltage of the output are only a few of the operating benefits of the Interleaved Zeta converter. The electromagnetic interference will also be lessened as a consequence of the continuous input current and smaller filter component sizes. The circuit model of an interleaved zeta-converter is shown in Fig 2, and its mode of operations from mode 1 to mode 4 are represented in Fig 3 (a) to (d) respectively.

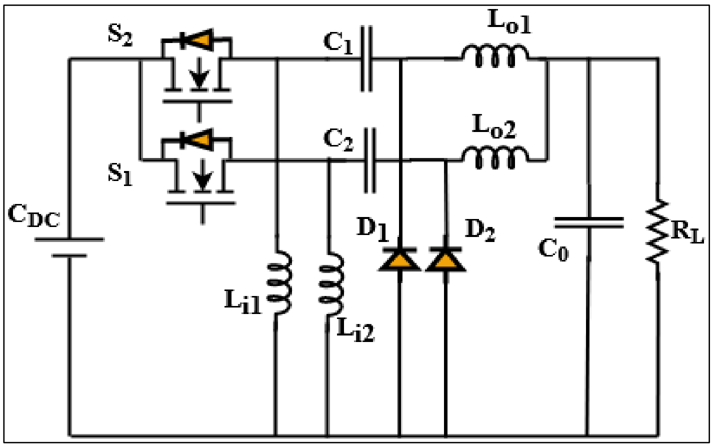

Figure 2: Circuit model of interleaved Zeta converter.
Source: Authors, (2023).

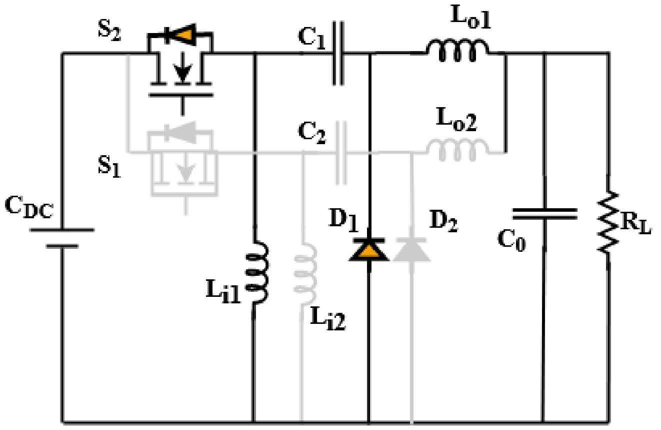

Figure 3 (a): Converter mode 1.

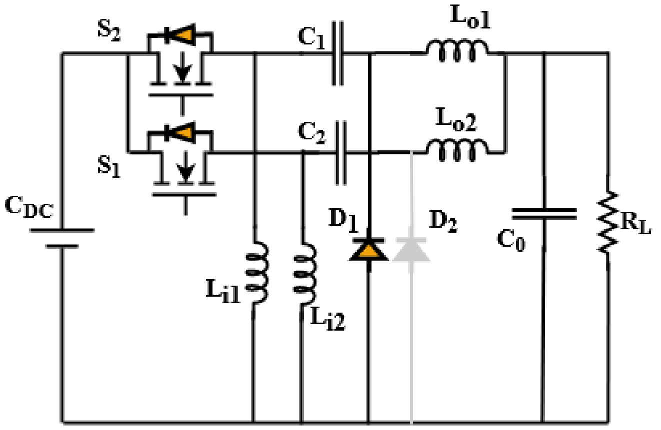

Figure 3 (b): Converter mode 2.

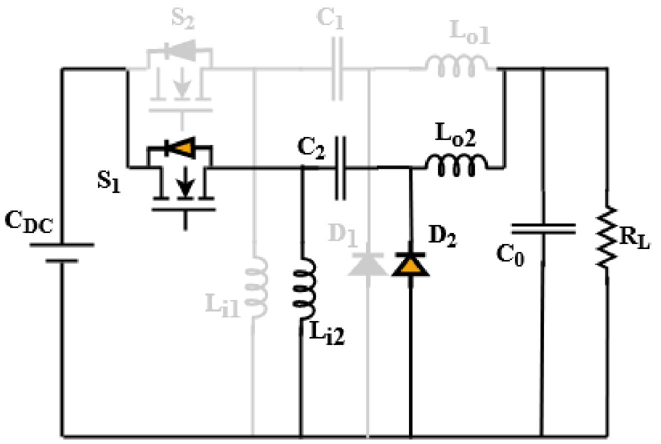

Figure 3 (c): Converter mode 3.

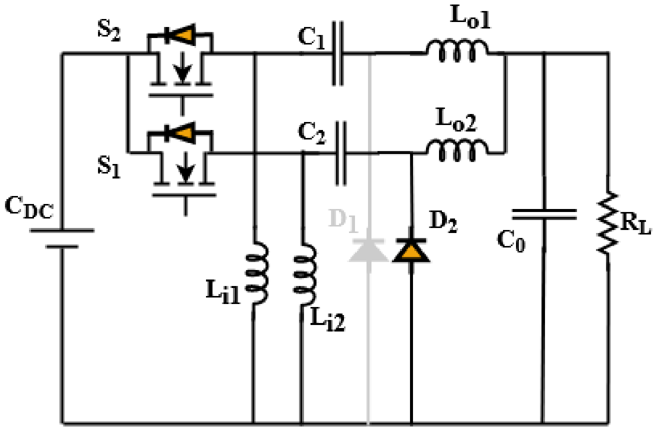

Figure 3 (d): Converter mode 4.

Figure 3: Converter mode 1, 2, 3 and 4.
Source: Authors, (2023).

### III.3 BI-DIRECTIONAL CONVERTER

The bi-directional DC-DC converter is used in this instance to charge the batteries and provide increased power to the ship board. Fig 4 depicts the suggested bidirectional converter's schematic diagram, which has 3 switches, 4 capacitors, and 2 inductors that are used to raise the load's current. With a smaller circuit size and less power loss, this converter design achieves higher efficiency. The inductors' and capacitors' charging and discharging periods have a big impact on how well this converter functions. Here, modes 0 and 1 of the bidirectional converter equivalent circuit can be used. During mode 0, the voltage and current of the converter is estimated by using the following equations:

$$V_{L1} = V_{FC} - V_{R_S} \tag{3}$$

$$V_{L2} = V_{FC} - V_{C1} \tag{4}$$

$$i_{c1} = i_{c4} = I_{FC} - I_{R_S} \tag{5}$$

$$V_{c4} = i_{L2} - \frac{V_{R2}}{R_L} \tag{6}$$

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

$$V_{L1} = V_{FC} - V_{c1} - V_{L2} \tag{7}$$

$$V_{L2} = -V_B + V_{C4} \tag{8}$$

$$i_{c1} = \frac{I_{L1} - I_{L2}}{2} \tag{9}$$

$$i_{c4} = i_{L2} - \frac{V_{R2}}{R_1} \tag{10}$$

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).

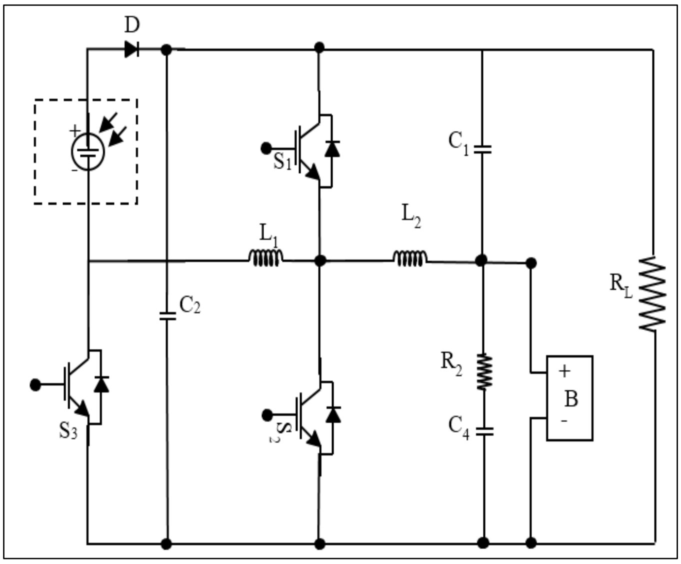

Figure 4: Bi-directional converter circuit model.
Source: Authors, (2023).

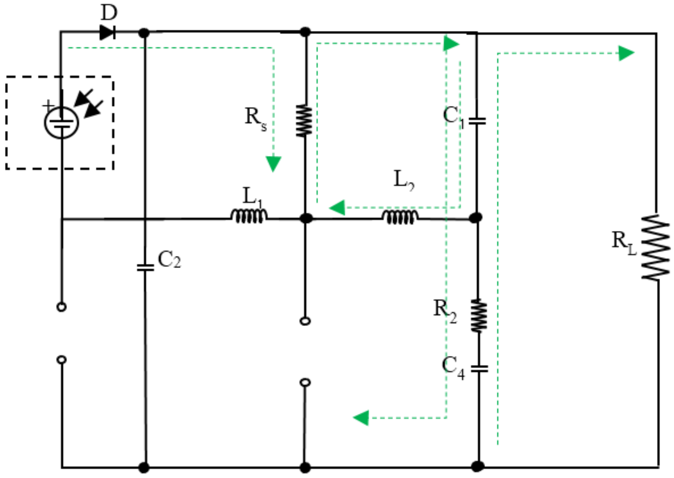

Figure 5 (a): Converter Mode 0.

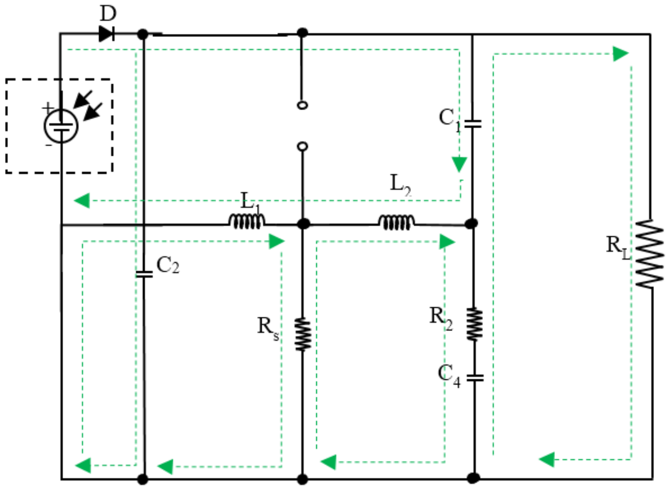

Figure 5 (b): Converter Mode 1.

Figure 5: Converter Mode 0 and 1.
Source: Authors, (2023).

## III.4 DANDELION OPTIMIZED NETWORK CONTROLLER (DONC)

In order to ensure an effective energy management for electric ship applications, an advanced Dandelion Optimized Network Controller (DONC) is used in this study. In the previous works, several AI based controlling mechanisms are applied for an effective energy management, but they facing issues with high computational complexity, larger computational time, and slow processing speed. Therefore, this research work aims to develop a new controlling algorithm by integrating the functions Dandelion Optimization (DO) technique with a Fictitious Neural Network (FNN). In this technique, the output power of load and battery SoC are considered as the input parameters, and the predicted output power of fuel cell is produced as the output. The FNN is an advanced neural network model, which is used to solve the complex prediction problems with suitable solutions. In this work, it is used to predict the output power of the fuel cell for an effective energy management of ship board. It comprises the layers of input, hidden and output, where the input layer gets parameters of output power of load and battery SoC, and the output layer produces the predicted power of fuel cell as the output. During this process, the weight value is optimally computed with the use of DOA. The DO algorithm models the three phases of the dandelion seed's journey from one location to another dependent on the direction of the wind. The seeds rise in a spiral pattern during the first phase of development, which is aided by bright conditions and drag force. Additionally, the dandelion seeds scatter locally when it rains. This variation in height results in two distinct possibilities for the search, namely a randomly settle at various spots while being influenced by the wind and weather, eventually growing into new dandelions. It works based on the iterative process similar to other optimization techniques. Prior to starting the optimization process, the DO algorithm entails setting up the dandelion seeds and figuring out their fitness function. Moreover, it includes the following stages:

1. Parameter initialization
2. Rising phase
3. Descending phase
4. Landing phase
5. Best optimal solution

By using these operations, it provides the best optimal solution as the output, which is used to compute the weight value of FNN. According to this, the FNN technique predicts the output power of fuel cell for an efficient energy management.

## IV. RESULTS AND DISCUSSION

This section provides the simulation results of the proposed energy management system used for shipboard applications. In this study, the MATLAB/Simulink tool has been used to test the results of the proposed energy management system. The simulation parameters are given in Table 1. The fuel cell system is made to handle load demands between 0 and 10 kW. Under interrupted and continuous peak demand scenarios, the storage system's supercapacitors and batteries are intended to make up for the fuel cell's sluggish dynamic response.

Table 1: Energy management simulation parameters.

| **Parameters** | **Specifications** |
|---|---|
| Fuel cell | 10 kW |
| Battery power for charging mode | -1.2 kW |
| Battery power for discharging mode | 4 kW |
| Battery SoC | 40% to 100% |
| DC Voltage | 280 V |

Source: Authors, (2023).

Fig 6 shows the load power and fuel cell power with respect to varying time in terms of seconds. Here, the load power denotes the actual demand of load, and the fuel cell power represents the energy generated by the fuel cell. The findings reveal that the load demand is higher than the energy generated by the fuel cell. Here, the battery is used as the supplementary storage that satisfies the remaining required energy of load. Consequently, the battery current is estimated with respect to varying time in terms of seconds as shown in Fig 7. Consequently, the load power and fuel cell power, and the battery current for normal SoC are represented in Fig 8 and Fig 9 respectively.

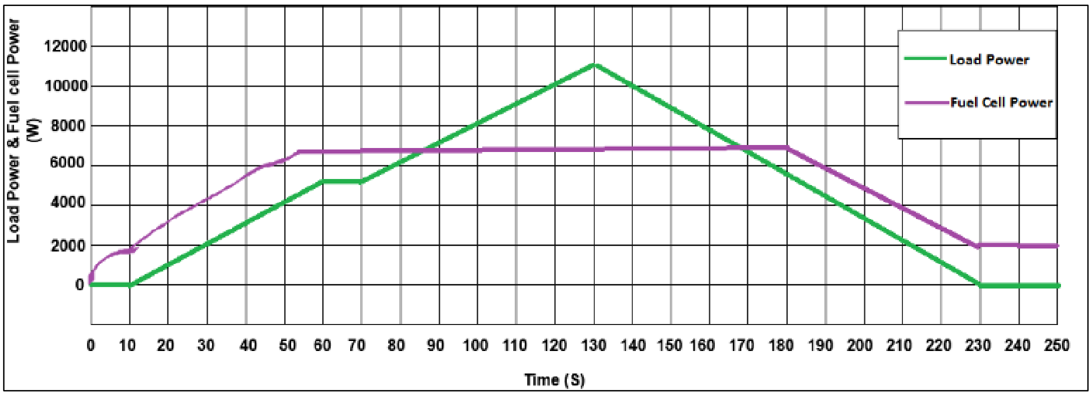

Figure 6: Load power and fuel cell power for high SoC.
Source: Authors, (2023).

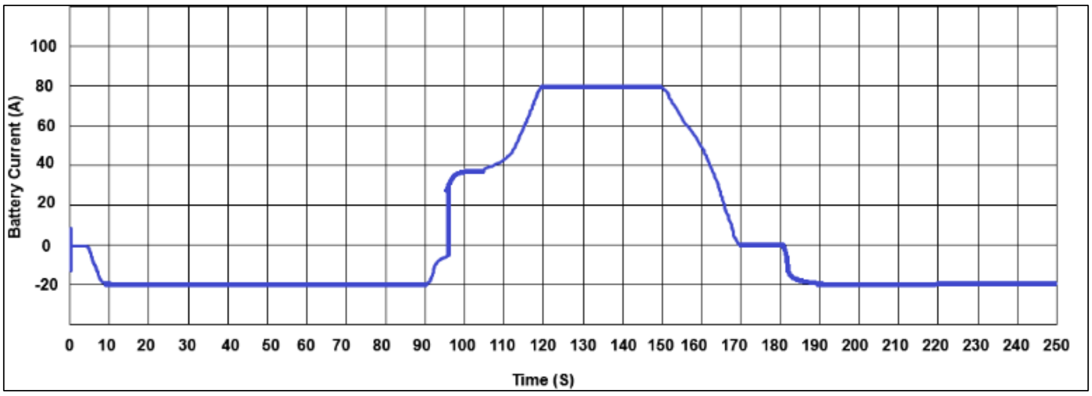

Figure 7: Battery current for high SoC.
Source: Authors, (2023).

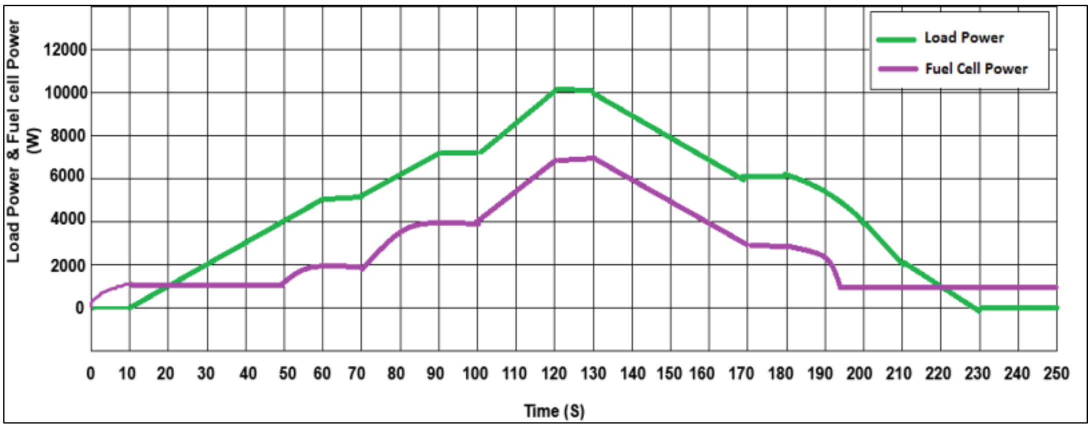

Figure 8: Load power and fuel cell power for normal SoC.
Source: Authors, (2023).

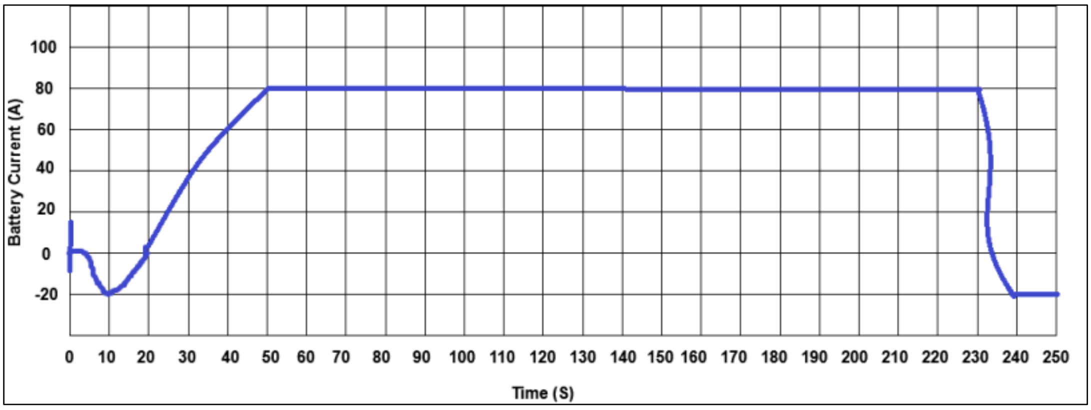

Figure 9: Battery current for normal SoC.
Source: Authors, (2023).

Fig 10 shows the fuel cell power with high SoC of battery storage. Due to the high battery storage capacity in this mode, the EMS must draw power from the battery to lower the charge mode from high to regular SoC since the fuel cell cannot provide as much power as the load requires to supply the load. The results indicate that the output power of fuel cell is lower than the load demand, and the required remaining power is taken from the battery.

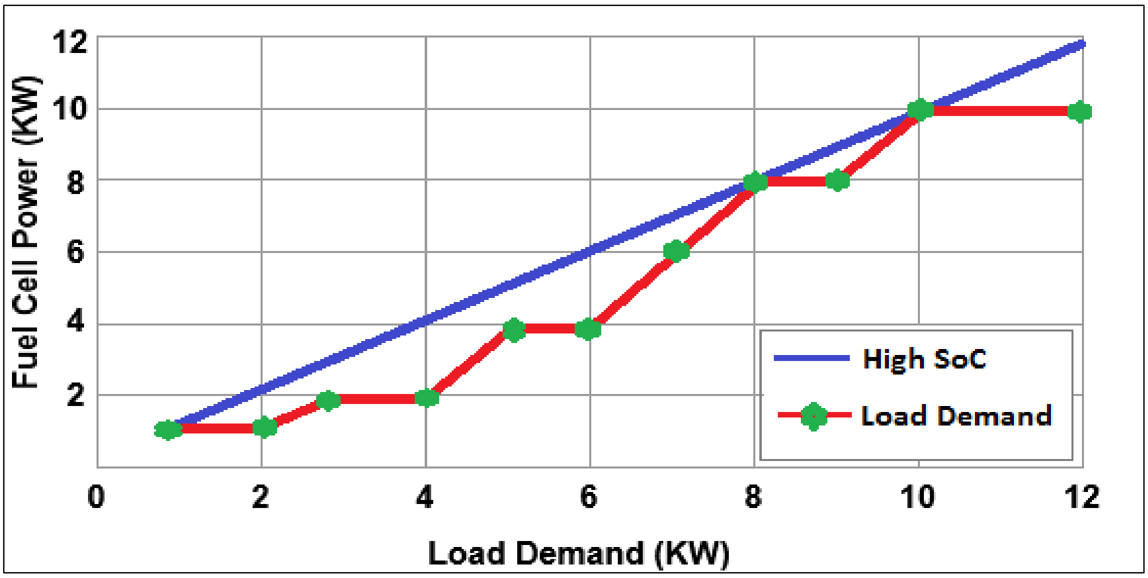

Figure 10: Fuel cell power Vs High SoC.
Source: Authors, (2023).

Similarly, Fig 11 shows the fuel cell power with respect to normal SoC of battery. In this mode, the ideal operation mode of battery efficiency and health of batteries is the SoC from 65% to 85%. In order to maintain the battery's condition of charge, the EMS tray only keeps up with the load demand. According to the waveforms, it is identified that the two waveforms are identical, which denotes that the load demand is equal to the output power of fuel cell.

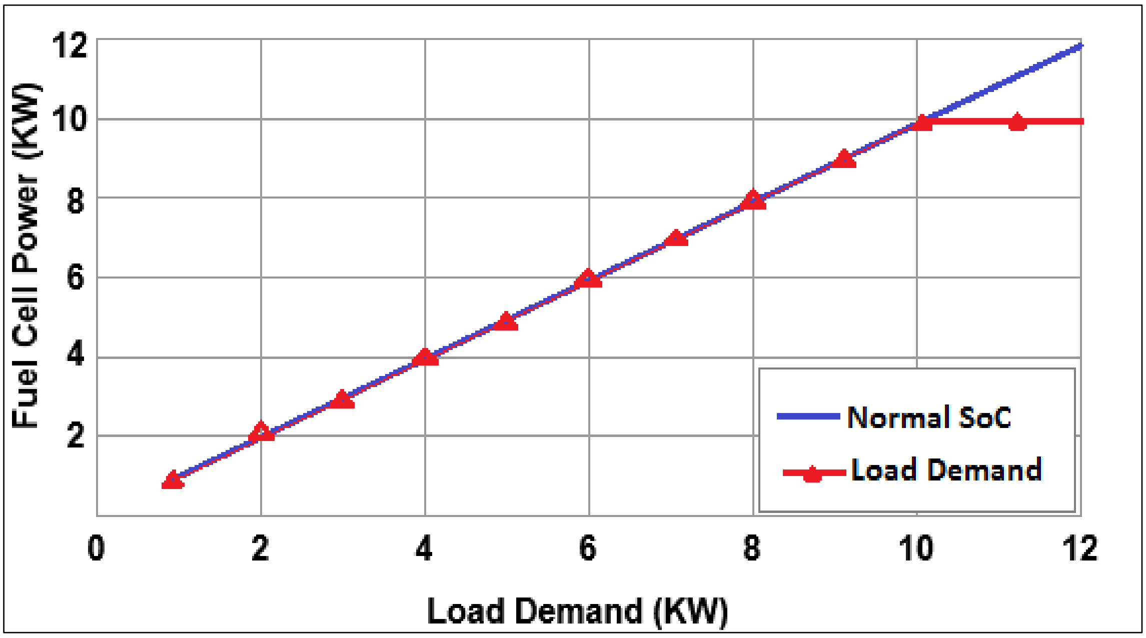

Figure 11: Fuel cell power Vs Normal SoC.
Source: Authors, (2023).

Fig 12 shows the fuel cell power with low SoC of battery. A low battery SoC shows that there is insufficient energy in the battery. This is because the EMS modifies the fuel cell to generate additional power than the load demand in order to serve the load and recharge the battery. The estimated waveforms indicate that the output power of fuel cell is higher than the load demand, and residual energy is used for charging battery.

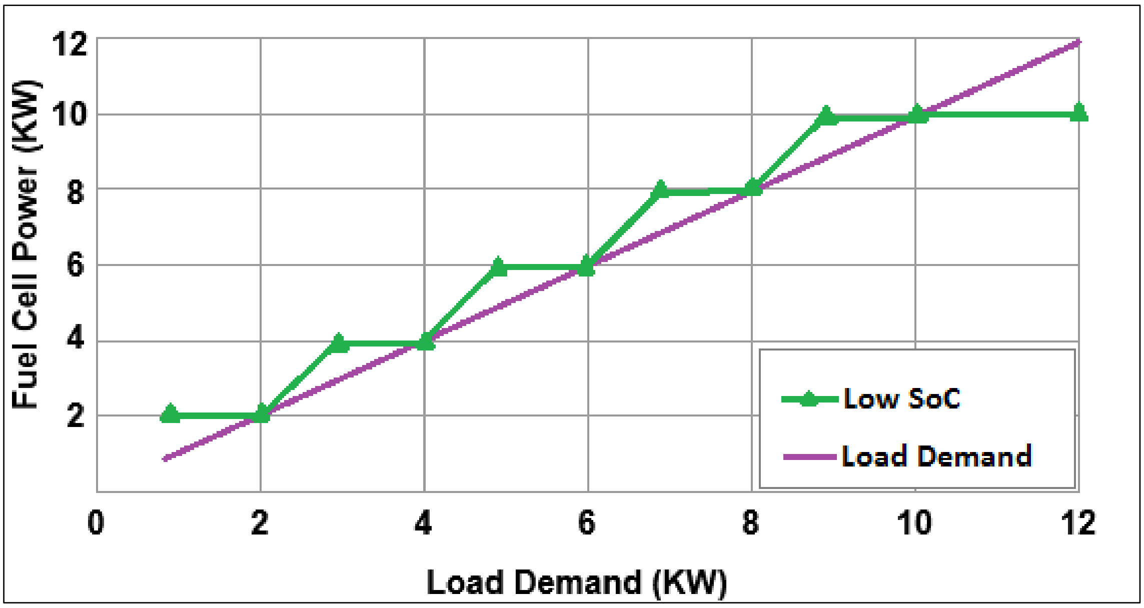

Figure 12: Fuel cell power Vs Low SoC.
Source: Authors, (2023).

## V. CONCLUSION

This research's major goal is to create a new energy management system to meet the load requirements of ship board applications. In this work, an innovative controlling mechanism called DONC is devised to achieve this goal. In this design, the fuel cell serves as the primary source of energy while the battery storage serves as an additional storage device. This is known as a hybridized energy source. Additionally, two distinct converter topologies, including a bi-directional converter for battery storage and an interleaved zeta converter for fuel cells, are used in this work. These converters are primarily used to efficiently increase the output voltage of hybridized energy sources while minimizing ripple current and distortions. The suggested DONC blends the DO techniques and FNN's functionalities for forecasting fuel cell output power. In order to manage energy effectively on an electric ship board, the FNN technique collects the input parameters of load demand power and battery SoC during this process. With the help of the DO algorithm, the weight value of the FNN is ideally determined in this manner. Increased efficiency, effective energy management in accordance with load demand, and dependability for ship applications are the main advantages of the proposed DONC. In the simulation analysis, the normal, high, and low battery SoC states are used to determine the load demand and fuel cell power. The results show that the suggested DONC can efficiently monitor and control the energy requirements of electric ships using a hybridized energy system. The current study can be expanded in the future to include other renewable energy sources like solar panels and diesel generators for the control of electric ship energy.

## VI. DECLARATION STATEMENT

**Conflict of Interest:** The authors declare that they have no conflict of interest.
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