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Empowering telecommunication towers employing improved war strategy optimization method

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In the field of telecommunication towers, specifically focusing on Base Transceiver Station (BTS) units, this research presents a revolutionary power supply system that is characterized by optimization and environmental cleanliness. The primary goal is to develop a reliable and continuous energy supply for these isolated units. In order to accomplish this objective, the use of PEMFCs (Proton Exchange Membrane Fuel Cells) is utilized. To provide a constant and controlled voltage of output from the PEMFC to the BTS, a proportional-integral (PI) controller based on improved war strategy optimization is used. The purpose of this controller is to improve the efficacy of the model and efficiently adjust to different operating situations. By conducting a comparison study with other methodologies, the suggested system showcases its advantages in terms of both efficiency and dependability. The research results presented in this study provide a substantial and noteworthy addition to the domain of sustainable energy solutions for communications infrastructure. Through the use of PEMFCs and the integration of modern control algorithms, the suggested system presents a very favorable method for supplying power to telecommunication towers. This approach not only enhances the operational efficiency of these towers but also contributes to the reduction of their environmental footprint.

In accordance with the experiences, there is a high need for energy in people's lives. Fossil fuels cannot be known as good sources due to the environmental problems and some others. For this reason, it has led us to use renewable and sustainable energy resources[1]. As it is agreed by all people, electricity is known as one of the most necessary energies which is of utmost importance among all. It can be used for various functions which facilitates life of humankind[2].

The external factors have affected the growth of Fuel Cell in the 21st century. The efficacy of other strategies was not sufficient, for this reason the fuel cells were known as means in order to generate power. Perhaps, it is vital to mention that one of the branches of renewable energy is the Fuel cell. Moreover, the Fuel Cell is a significantly efficient energy strategy that changes chemical fuel energy into energy of electricity, which comprises Anode, Cathode, and Electrolyte[3]. With the passage of time, the efficacy of other strategies enhanced sharply; as a result, the interest of people toward using the fuel cells diminished[4]. However, as the fuel cells enhanced their efficiency, people tended to use it again. Some main kinds of fuel cells are presented in this study, namely the PEFC (Polymer-Electrolyte Fuel Cell), AFC (the Alkaline Fuel Cell), MCFC (the Molten-Carbonate Fuel Cell), SOFC (the Solid-Oxide Fuel Cell), PEFC (the Phosphoric-Acid Fuel Cell), and PEMFC (Proton Exchange Membrane Fuel Cell), which has been known as one the best Fuel Cells[5].

In light of the aforementioned factors, PEMFC can be considered as one of the efficient members of the FCs. The PEMFCs have been known as energy conversion procedures for stationary uses and mobile because of the zero emission and significant energy efficacy[6]. The PEMFC functions as a stable electrolyte, facilitating ion transfer and preventing fuel from infusing among electrodes. In addition, its effectiveness significantly impacts the fuel cell's longevity and efficacy[7]. The process of fuel cells involves an oxidation reaction that breaks down hydrogen into H^+ and electrons. Then, Oxygen is integrated with electrons and hydrogen ions through a decrease reaction at the cathode[8]. In order for both reactions to happen constantly, the electrons generated from the Hydrogen must move from an external circuit to the cathode[9]. One of the applications that the PEMFCs can be employed is in Base Transceiver Station (BTS) technology.

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A BTS is a stationary radio transceiver that facilitates communication in a mobile network[10]. Its primary function is to link mobile devices to the network by transmitting and receiving radio signals[11]. The BTS then converts these signals into digital form and relays them to other terminals within the network or the Internet[12]. Moreover, a BTS is a tool that helps wireless communication between a network and User Equipment (UE). UE refers to devices such as computers with wireless, mobile phones, antennas, or internet connectivity. The network can be any wireless communication technology, including CDMA, GSM, WiMAX, and Wi-Fi[13].

When it comes to the telecom industry, particularly BTS, systems working with hybrid renewable energy are able to play a critical role in ensuring a constant supply of power[14]. By combining different energy sources, these systems can provide an uninterrupted and reliable power output[1]. Implementing a system like this can decrease operational expenditures and alleviate environmental concerns for BTS, which currently rely heavily on diesel generators with battery backup[15].

In today's world, there is a great demand for telecommunication services, especially in remote areas where communication is vital for development and progress[16]. However, providing electricity to stations of telecommunication like Base Transceiver Station units that are usually located at altitudes that are high and have limited accessibility, can be a challenging task[17]. To overcome this problem, medium and low-pressure electricity networks have been developed in cities and villages[18]. However, the transmission of electricity to remote BTS units is still difficult due to their unique location and the high costs associated with providing electricity[19]. In this regard, there are some studies of other researchers in Base Transceiver Station with other techniques in the literature which will be mentioned in the following[20].

Related works

Thomas et al.[21] proposed that a single sediment MFC (Microbial Fuel Cell) could power WSN (Wireless Sensor Network) nodes, allowing for the collection and transmission of sensor data to sinks. The PowWow platform combined modular and opened hardware model with software that is open-source and had a low memory footprint and utilized a programming which was event-driven. Additionally, the platform had energy harvesting capabilities and could adjust the radio data conveyance manner based on the electricity which had been provided by the sediment-MFC. The study found that the Microbial Fuel Cell could successfully influence the WSN with constant performance within an extensive period, and signals at high rate released from a basis to receptor linked a PC. Notably, the sediment- Microbial Fuel Cell was easy to generate and manage without needing any artificial catalysts or membrane.

Kaur et al.[22] proposed a straightforward system of electric energy conversion in order to prepare towers of telecommunication. This was conducted to decrease maintenance and operation expenditure of companies. The telecommunications industry was expanding rapidly and reaching remote rural areas that might not have reliable access to electricity. To ensure uninterrupted service, telecom towers were increasingly relying on backup power sources such as battery banks and diesel generators for their base transceiver stations. Using backup power too much led to higher operating costs, less dependable energy became a danger to the environment. A proposal emerged for using PEMFC as a clean energy basis for Base Transceiver Stations, along with a smart interfacing unit. This development could greatly reduce the need for capacity of battery banks, compared with previous solutions. Additionally, an interfacing unit which was intelligent was suggested, which utilized an electronic boost converter of power for conditioning power. The unit was equipped with a genetic algorithm-assisted controller and a simple closed loop for optimal performance. A controller assisted by a genetic algorithm proposed to maintain precise regulation of voltage in the BTS's DC distribution. Additionally, it ensured the reliable operation of the BTS, despite changes in load disparity of telecom and fluctuations in the voltage of output in the PEMFC. The proposed system was successfully implemented and the results demonstrated its feasibility in ensuring telecom towers' reliable operation.

Ma et al.[23] proposed that it was really feasible and cost-effective to utilize systems of fuel cell power in telecommunication towers. In fact, the purpose was to supply power and grid services for cell towers in conditions of emergency. It was important to explore the potential benefits of integrating reliable and energy-efficient fuel cell technology with the power grid to improve economic advantages. If some information was exchanged between backup systems and the power grid, they could enhance their abilities and provide some extra profits for grid services. It was notable they differed based on the time and situation. Configurations of system and the grid service profits prepared some opportunities in order to extend backup fuel cell uses in response to grid needs. In fact, the primary goal of the research was to discover the ways, in which fuel cells could decrease costs of system, environmental damages, and their reliance on fossil fuels.

Jansen et al.[24] proposed that an extensive MATLAB/Simulink model for a pioneering energy storage solution was developed that utilized solid hydrogen at a low pressure. The system was seamlessly integrated with battery energy storage and solar Photovoltaic (PV), and took into consideration the varying damages of the power conditioning equipment. For semi-empirical parameterization of the metal-hydride and fuel cell models, Levenburg-Marquardt least square algorithm was utilized. The simulations were conducted by the use of the load data of the telecom tower which was experimentally achieved. According to the data, the efficacy of the electricity system decreased, in turn, from 21.05 to 17.43% in a Solar/Battery system and the hybridized system that was considered the most economical system. The system included a10kW/40 kWh Li-Ion battery, a Regenerative Hydrogen Fuel Cell, and a 16.2 kW Solar PV. When comparing to a Diesel Genset that was 73.40 ¢/kWh, the system had a Levelized energy expenditure of 17.16 ¢/kWh. Additionally, an Internal Return Rate and a Net Present Value of the system were, in turn, 15.15% and $109,236.

Xie et al.[25] suggested a clean and optimized design built on the PEMFC (Proton Exchange Membrane Fuel Cell). The purpose of that research was to gain a steady system of source for the towers of telecommunication. In order to supply a safe energy for the Telecommunication system, an optimized measured output voltage was presented from the PEMFC to the BTS. An optimized PI controller was presented called Courtship Learning-

based Water Strider Algorithm (CLWSA). The achievements of the study were compared with other strategies to show the excellence of the strategy with others.

Study gap and motivation
As can be observed from the literature, during the recent years, telecommunication towers have utilized a variety of techniques to power their systems. However, there has been a noticeable lack of extensive research conducted on optimizing PEMFC to enhance the reliability of BTS power supply, and the other techniques did not have that great efficiency in their performance. This gap in knowledge has inspired this study to propose an innovative and improved system that surpasses the limitations of current methods. This proposed system offers a more efficient and sustainable solution for powering telecommunication towers, which could potentially transform the way these towers operate and improve their performance.

Therefore, this research focuses on finding the best power supply method for BTS units that can reduce electricity costs while maintaining reliable communication services. This will not only benefit the telecommunication industry but also contribute to the overall development of remote areas.

Paper orientation
The primary objective of this study is to generate an efficient and eco-friendly power supply mechanism for telecommunication towers, with a specific focus on BTS units. The suggested model is built on the innovative technology of PEMFCs, coupled with a newly metaheuristic algorithm, called improved War Strategy optimization algorithm. The integration of these two elements results in a range of benefits, such as improved reliability, significant cost savings, and a positive impact on the environment. By implementing this system, the telecommunication industry can enhance its services and contribute towards a more sustainable future. This paper presents a groundbreaking method to challenge the pressing issues surrounding power supply for BTS units, which have long posed a challenge for telecommunication infrastructure. By introducing this novel approach, we can pave the way for further advancements in sustainable energy solutions and ensure that our telecommunication systems are equipped with reliable, long-lasting power solutions. This development marks an important step towards a more sustainable and efficient future for the telecommunications industry.

Configuration of the BTS
The configuration of a BTS (Base Transceiver Station) power system plays a crucial role in ensuring reliable and uninterrupted power supply[26]. This section provides a comprehensive explanation of the BTS power system configuration, which consists of various components working together to meet the power requirements of the Base Transceiver Station unit[27]. The major configuration of this system has been illustrated by Fig. (1).

The following sections will cover each building block of this configuration in depth and describe their specific functions and how they connect to each other, as Well as how they work with the power supply of the Base Transceiver Station. These components are crucial for the effective, reliable, and sustainable delivery of power. Now that we have an overview of the elements, lets dive deep into the specifics of each of these and understand how do they optimize the process of making BTS operating.

Inverter
The inverter has a key role in the power system of the BTS, as it transforms Direct Current (DC) power obtained from the basis into Alternating Current (AC) power that is suitable for the operation of BTS equipment. The device functions as an intermediary between the alternating current loads and direct current power source,
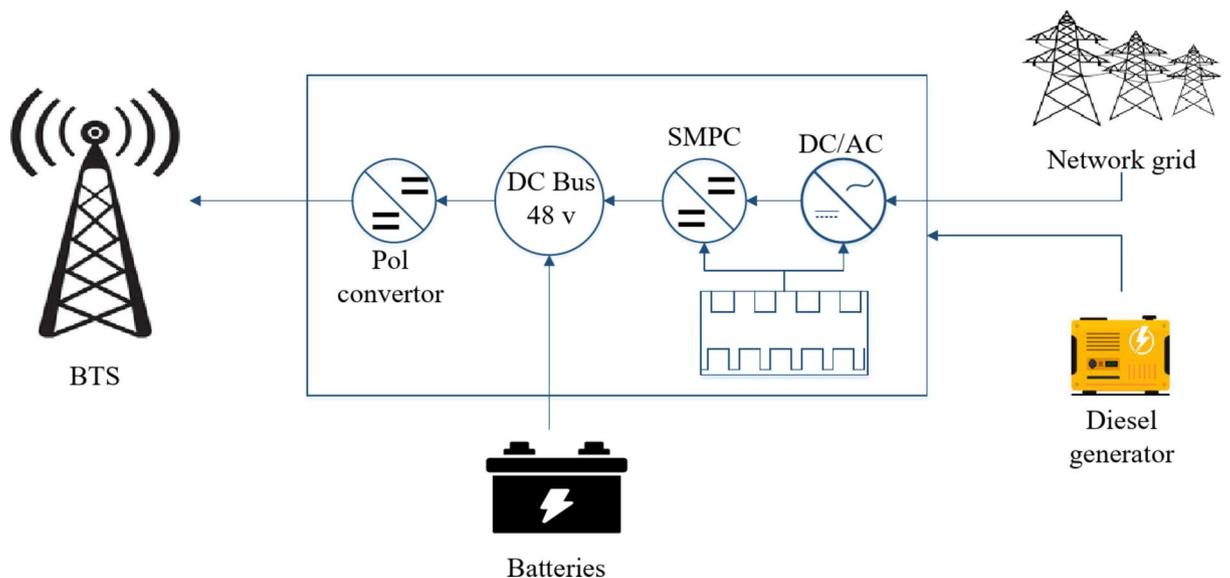

Fig. 1. Major configuration of a Base Transceiver Station.

facilitating the optimal usage of the available power. The primary goal of the inverter is to transform DC power derived from the network grid or backup system into AC power, which is crucial for the operation of various components including transmitters, receivers, signal processing units, cooling systems, and other auxiliary devices.

The inverter is responsible for voltage control, which guarantees a consistent AC voltage output that is within the allowable range as defined by BTS equipment. Ensuring the integrity and optimal performance of sensitive electrical components inside the BTS is crucial. The use of an inverter inside the BTS plays a significant role in maintaining optimal power quality. This is achieved by effectively addressing several possible problems including as voltage sags, surges, harmonics, and transient disturbances.

Additionally, it guarantees dependable functionality via the provision of consistent and steady AC power. Inverters have the capability to seamlessly include backup power sources, such as diesel generators or battery banks, therefore guaranteeing continued operation in the event of power outages or grid problems. Contemporary inverters have been engineered with a primary focus on achieving optimal efficiency, therefore mitigating power losses incurred during the conversion of DC to AC. This design objective serves to curtail energy consumption, diminish operational expenses, and alleviate the ecological repercussions associated with the BTS system.

The combination of grid connectivity and smart grid technology facilitates the exchange of electricity in both directions between the BTS system and the electrical grid. This enables the implementation of various functionalities like load shifting, reduction of peak demand, and provision of grid support services. Inverter-based systems have the capability to inject surplus power back into the grid, so making a valuable contribution to the general stability and resilience of the grid. The mathematical formula for the output of an inverter in this situation can be represented as follows:

$$V_{out} = V_{in} \times \eta_{inv} \tag{1}$$

Where, V_{out} represents the voltage of output in the inverter, known as the AC voltage has been supplied to the BTS equipment, V_{in} denotes the input voltage to the inverter, typically the DC voltage from the power source, and η_{inv} represents the efficiency of the inverter, expressed as a decimal or percentage.

A PWM (Pulse Width Modulation) controller has been utilized to regulate the voltage of output and frequency of the inverter. This controller enables precise control over the power supply and ensures that the AC output matches the BTS power requirements accurately.

Switch-mode power and point of loads converters

The utilization of a Switch-Mode Power Converter (SMPC) in research endeavors has several benefits, including enhanced efficiency, reduced physical footprint, and adaptable functionality. These converters find extensive use in many applications, including power supply for electronic devices, renewable energy systems, electric vehicles, and telecommunications equipment such as Base Transceiver Stations (BTS). In this exposition, an overview of Secure Multi-Party Computations (SMPCs) will be presented, along with a concise depiction of fundamental mathematical equations pertaining to their functioning.

A Switch-Mode Power Converter employs high-frequency switching methodologies to have a control and maintain the output voltage or current. The system functions by the fast alternation of input power, resulting in the conversion of this power into discrete energy pulses. Subsequently, the aforementioned pulses undergo filtration and averaging processes in order to provide a continuous and consistent output voltage or current. Switched-mode power converters (SMPCs) often include energy semiconductor devices, such IGBTs (Insulated-gate Bipolar Transistors), MOSFETs (Metal-Oxide-Semiconductor Field-effect Transistors), or diodes, in conjunction with control circuitry.

The Switch-Mode Power Converter (SMPC) is used for the purpose of regulating and managing the voltage and current magnitudes that are provided to the Base Transceiver Station (BTS). The converter is tasked with the responsibility of ensuring a consistent and regulated power source to the BTS unit, irrespective of any variations in the incoming voltage.

The average voltage of output in an SMPC is able to be calculated using the following formulation, assuming ideal conditions:

$$V_{out} = D \times V_{in} \tag{2}$$

where, V_{in} describes the input voltage of the SMPC, and D is the cycle of duty that represents the fraction of time that during that time, the switch is closed and is achieved as follows:

$$D = \frac{T_{ON}}{T} \tag{3}$$

In contrast, Point of Loads (POLs) converters are used for the purpose of distributing power to several components inside the Base Transceiver Station (BTS). The converters mentioned are responsible for receiving the regulated power generated by the SMPC converter and then transforming it to the precise voltage levels necessary for various loads, including transmitters, receivers, signal processing units, and cooling systems.

The condition-space representation of a boost converter, encompasses two circumstances, the current through the voltage and the inductor across the capacitor can be considered as follows:

$$\dot{x} = \begin{bmatrix} a & b \\ c & d \end{bmatrix} x + \begin{bmatrix} e \\ f \end{bmatrix} V_{in} \tag{4}$$

Device	Parameter	Value
BTS Load distribution	Transceiver	160 W
	Heat exchanger load	360 W
	Equipment load of Microwave	100 W
	Base Transceiver station load (Transceiver + microwave)	2380 w, 50 A
	Load/Transceiver	12
	BTS number at the site	1
	Voltage of battery	48 V
Boost Converter	Voltage of input	26–39 V
	Voltage of output	48 V
	f_s	10 kHz
	Inductance	0.01 mH
	Resistance	1.2 Ω
	Conductance	21.6 mF

Table 1. Settings for the employed parts of the load distribution base transceiver station and the boost converter[22].

Form	Load		Power
	DC	AC	
2×2×2	1.20 kW	1.9 kW	3.09 kW
4×4×4	2.08 kW	2.5 kW	4.50 kW
6×6×6	2.88 kW	3.8 kW	6.40 kW

Table 2. Power requirements of different BTS at telecommunication tower sites.

$$y = \begin{bmatrix} g & h \end{bmatrix} x$$

The model is represented by activating the device, i.e.,

$$a = \frac{-r_L}{L}, b = c = f = g = 0, d = \frac{-1}{C(R + r_C)}, e = \frac{1}{L}, h = \frac{R}{R + r_C} \tag{5}$$

And by deactivating the device, the model is turned into:

$$a = \frac{r_L + \frac{R r_C}{R + r_C}}{L}, b = -c = \frac{-R}{C(R + r_C)}, d = \frac{-1}{C(R + r_C)}, \quad e = \frac{1}{L}, f = 0, g = \frac{R r_C}{R + r_C}, h = \frac{R}{R + r_C} \tag{6}$$

These equations can be gathered as follows:

$$a = \frac{r_L}{L} D + \frac{r_L + \frac{R r_C}{R + r_C}}{L}(1 - D), b = -c = \frac{-R}{C(R + r_C)}(1 - D), d = \frac{-1}{C(R + r_C)}, \quad e = \frac{1}{L}, f = 0, g = (1 - D)\frac{R r_C}{R + r_C}, h = \frac{R}{R + r_C} \tag{7}$$

where, DT_S specifies the activated and $(1-D) T_S$ shows the deactivated states.

Table 1 provides the settings for the employed parts of the load distribution Base Transceiver station and the boost converter.

Distribution system

The DC bus functions as the primary power distribution infrastructure for the whole of the BTS system. It serves as an intermediary connection between the power supply, such as the electrical grid or the backup diesel generator, and the many components of the Base Transceiver Station (BTS). The DC bus system is designed to optimize power transmission efficiency and reduce losses in the process of distributing electrical power. Table 2 presents the power requirements of different BTS at telecommunication tower sites.

The network grid functions as the principal power source for the Base Transceiver Station (BTS), ensuring a consistent and dependable supply of electrical power. Nevertheless, in order to guarantee continuous functioning in the event of grid failures or outages, a contingency system consisting of a diesel generator is included. The backup generator functions as a supplementary power solution, guaranteeing uninterrupted power provision in times of unforeseen circumstances.

The BTS distribution system functions at a voltage level of 48 V DC, according to the established industry standard for BTS equipment voltage requirements. The aforementioned setup enables effective power usage,

voltage management, and backup capabilities, hence guaranteeing a dependable and uninterrupted power supply for the BTS unit.

Through meticulous design and strategic optimization of the BTS power system, it is feasible to augment the overall performance, efficiency, and dependability of telecommunication towers, while concurrently mitigating their environmental impact.

In recent years, the many benefits shown by PEMFCs have positioned them as a viable option to Distributed Generators (DGs). Hence, this work presents the introduction of a PEMFC-based feeding setup for the BTS. This system's primary configuration can be seen by Fig. (2).

The use of a PEMFC with a power output of 3000 W is seen in Fig. (2). This fuel cell is employed to provide clean electricity to the BTS via the intake of hydrogen and oxygen. One notable feature of the PEMFC technology is its little need for ongoing maintenance and testing.

The voltage produced by a PEMFC is influenced by factors such as humidity, ambient pressure, temperature, load changes, and environmental conditions. The variation is either above or below the output voltage, which falls between[15,30] %. This enables the interface device to interconnect to remain at a constant 48 V DC bus. The suggested optimization controller has been utilized to efficiently regulate the output voltage of a boost converter in a DC/DC mode. The transmission of signal traffic has been adjusted through load alterations and voltage oscillations of the PEMFC in the Base Transceiver Station situated on the telecommunication tower.

Proton exchange membrane fuel cell

The PEMFC is a fuel cell that changes chemical energy stored in hydrogen fuel to energy of electricity through an electrochemical process. It operates based on redox reactions involving hydrogen and oxygen. The PEMFC requires a supply of pure hydrogen gas (H2), which can be obtained from sources like natural gas, methanol, or water electrolysis[28]. The gas of hydrogen has been fragmented into negatively charged electrons at the anode, where a catalyst usually platinum is used, and positively charged hydrogen ions (protons). The PEM divides cathode and the anode sides, allowing only positively charged protons to pass through.

The cathode receives oxygen gas (O2) from the air, which combines with electrons from protons and the external circuit to make up water (H2O). The reaction occurs on the cathode surface with the help of a catalyst. PEMFCs are used in various sectors, including telecommunications, transportation, portable power devices, and stationary power generation[29]. They prepare a sustainable and reliable basis of electrical energy, especially for off-grid or isolated locations where it is hard to have access to conventional sources of power.

PEMFCs provide significant energy efficiency and environmental benefits when used in Base Transceiver Stations (BTS). These systems achieve a high electrical efficiency of up to 60%, effectively converting a substantial amount of the electricity content in fuel to usable energy of electricity. This results in reduced energy waste and lower operating costs. PEMFCs function without combustion, generating water vapor and heat as byproducts, thereby decreasing greenhouse gas emissions and minimizing the environmental impact of telecommunication tower sites. Silent operation enables their use in noise-sensitive environments, while their modular and scalable design facilitates easy scalability. PEMFCs exhibit rapid start-up capabilities, rendering them suitable for remote deployment. This is due to their ability to operate using on-site generated hydrogen fuel via electrolysis. The equation for the terminal voltage (V_T) of a single FC has been expressed in the following:

$$V_T = E_N - V_\Omega - V_{con} - V_{act} \qquad (8)$$

where, V_Ω reflects the Ohmic over-potential caused by resistances during proton conduction, V_{con} indicates the concentration over-potential resulting from reactant concentration, V_{act} stands for the activation over-potential, and E_N represents the Nerst voltage that is the thermodynamic potential of the cell and can be obtained by the following equation:
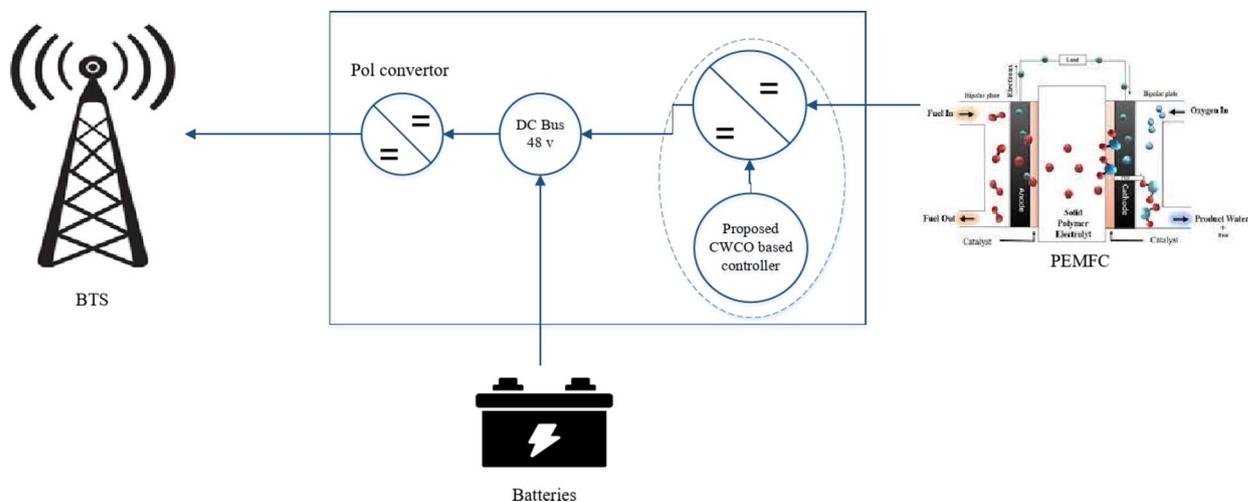

Fig. 2. Primary configuration of the suggested BTS model.

$$E_N = 1.229 - 8.5 \times 10^{-4} (T_{PEM} - 298.15) + 4.31 \times 10^{-5} \times T_{PEM} \times [ln(P_{H_2}) + 0.5 \times ln(P_{O_2})] \quad (9)$$

where, T_{PEM} represents the operating temperature of the cell in degrees Celsius, while P_{O_2} and P_{H_2} represent, in turn, the pressures, which are partial in hydrogen and oxygen in atmospheres. These values can be specified as follows:

$$P_{H_2} = \frac{1}{2} \times R_{ha} \times P_{H_2O} \left[\frac{1}{\frac{R_{ha} \times P_{H_2O}}{P_a} \times e^{\frac{1.635 I_{PEM}/A}{T^{1.334} I_{PEM}}}} - 1 \right] \quad (10)$$

$$P_{O_2} = R_{hc} \times P_{H_2O} \left[\frac{1}{\frac{R_{hc} \times P_{H_2O}}{P_c} \times e^{\frac{1.635 I_{PEM}/A}{T_{PEM}^{1.334} I_{PEM}}}} - 1 \right] \quad (11)$$

In this study, the variable I_{PEM} represents the fuel cell's performing flow. The variable A represents the active section in the membrane. The variables P_c and P_a represent the inputted pressures, which are partial for the negative and positive sides. The variables R_{ha} and R_{hc} illustrate the electrodes' dependent humidity. The variable P_{H_2O} explains the fullness pressure of vapor in the cell and can be obtained according to reference[27].

$$P_{H_2O} = \exp\left(-2.18 + 0.0295 \times (T_{PEM} - 273.15) - 9.18 \times 10^{-5} T_c^2 + 1.4 \times 10^{-7} T_c^3\right) \quad (12)$$

The activation over-potential can be determined using the formula as follows:

$$V_{act} = -[\gamma_1 + \gamma_2 \times T_{PEM} + \gamma_3 \times T_{PEM} \times \ln(C_{O_2}) + \gamma_4 \times T_{PEM} \times \ln(I_{PEM})] \quad (13)$$

where, the empirical coefficients are considered by γ_i, and:

$$\gamma_2 = 4.3 \times 10^{-5} \ln(C_{H_2}) + 2.1 \times 10^{-4} \ln(A) + 2.9 \times 10^{-3} \quad (14)$$

where, the fullness of hydrogen and oxygen in the catalytic border in the side, which is negative (mol/cm^3) can be achieved by C_{H_2} and C_{O_2} which are formulated as follows:

$$C_{H_2} = \frac{P_{H_2}}{1.1 \times 10^6} \times e^{\frac{-77}{T_{FC}}} \quad (15)$$

$$C_{O_2} = \frac{P_{O_2}}{5.1 \times 10^6} \times e^{\frac{498}{T_{FC}}} \quad (16)$$

and the loss of Ohmic voltage has been obtained in accordance with the following equation:

$$V_\Omega = (R_m + R_c) \times I_{FC} \quad (17)$$

where,

$$R_m = \frac{\rho_m \times l}{S} \quad (18)$$

Such that, S and   defines, in turn, the membrane surface (cm^2) and the thickness of membrane, and ρ_m defines the resistivity of membrane which is achieved by the following:

$$\rho_m = \frac{181.6 \left[1 + 0.062 \left(\frac{T_{FC}}{303}\right)^2 \times \left(\frac{I_{FC}}{S}\right)^{2.5} + 0.03 \left(\frac{I_{FC}}{S}\right)\right]}{\left[\lambda - 0.063 - 3 \left(\frac{I_{FC}}{S}\right)\right] \times e^{\frac{T_{FC} - 303}{T_{FC}}}} \quad (19)$$

In this context, λ represents the control parameter, Rm denotes the resistance of membrane, and R_c determines the resistance of connection. The focus over-potential has been determined using the subsequent equation:

$$V_{cons} = -\beta \times ln\left(J_{max} - \frac{J}{J_{max}}\right) \quad (20)$$

β represents a coefficient, while J represents the standard flow density and Jmax represents the highest flow density. This study employs a 178 μm wide Nafion 117 membrane to evaluate the variables of the model, which are stack. Table 3 displays the operational conditions of the studied PEMFC system.

Variables	Value	Unit	Variables	Value	-
λ	23	-	J_{max}	1.5	mA/cm^2
B	0.015	v	γ_1	-0.950	-
P_{H_2}	1	atm	γ_2	0.002	-
P_{O_2}	1	atm	γ_3	7.5×10^{-5}	-
A	50.6	cm^2	γ_4	-1.93×10^{-4}	-
R_c	0.0003	Ω	T	69.85	$^\circ C$
J	1.2	mA/cm^2	l	177	μm

Table 3. Operational conditions of the investigated PEMFC system.

Improved war strategy optimization
Background
Olden empires owned an army to battle themselves from assaults by extra authorities. The military of the empire encompasses numerous armies namely, elephants, chariots, infantry, and to name but a few. Throughout the battle, each kingdom plans a scheme that is famous as "Vyuha" to assault the contrasting military to succeed in the war and thus demonstrate their power[30]. A Vyuha is an outline or organization of numerous military groups utilized to overcome the contrasting empire throughout a fight. the monarch and leaders of every unit are going to manage their militaries in a particular outline to guarantee that their military reaches the proposed goals and attains the aim.

The fighting tactic was framed in light of the task's purposes, menaces, problems, and perspectives. Warfare tactic is a constant dynamic procedure in which equipped militaries merely manage and battle the opposition. This tactic could adjust to altering situations as warfare develops. The situations of the monarch and leader own a continuous influence on the military fighter's situation. The banners on top of the monarch's and military leader's wagons signify their position, which is noticeable to total fighters. Militaries in the group are accomplished to track a tactic on the basis of the noises of a tabor or extra-musical tool. Whenever one of the armed leaders passes away, the tactic has been changed and every additional leader needs to acquire how to reestablish and carry on the warfare tactic's formation. The Monarch's goal is to overcome the contrasting monarch/commander, while the military fighter's foremost objective is to assault the contrasting group and growth in rank.

Mathematical model of the war strategy
In each repetition, total fighters own the same chance to be either Monarch or Leader reliant on their Battling Power (objective function). Both the Monarch and the Leader perform the role of commanders in the Warfare field. The motion of the Monarch and the Leader in the Warfare field would lead the remains fighters. There is a probability for either the Monarch or the Leader to confront a stiff struggle from the enemy's fighter (Local Optima) who has sufficient power to trick the commanders. To evade this situation, fighters in warfare would be led not only by the Monarch's or Leader's situation but also by their collective motion strategies.

Attack strategy
There are 2 warfare tactics. In 1st model, each fighter renews his situation on the basis of the situations of the Monarch and the Leader. This renewing appliance of the assault model is illustrated in Fig. 1. The monarch catches a useful situation to launch an enormous assault on the enemy. Overall, the fighter with the utmost assault power or capability is considered in the role of the monarch. Total fighters would own a similar weight and rank at the warfare's commencement. If the fighter effectively performs the tactic, his rank increases. Though, as the warfare develops, the ranks and weights of total fighters would be renewed on the basis of the tactic's achievement. when the warfare reaches its end, the situation of the Monarch, Military leader, and fighters keep on so near as they reach the goal.

$$Z_i(t+1) = Z_i(t) + 2 \times \rho \times (L - M) + rand \times (W_i \times M - Z_i(t)) \tag{21}$$

where $Z_i(t+1)$, Z_i, L, M, and W_i are the novel situation, the former situation, the leader's situation, the monarch's situation, and the weight, respectively. The colored circles around the fighter in Fig. 1 signify locus points of $(W_i \times M - Z_i(t))$ on the basis of the Monarch situation. If W_i is more than 1, then the situation of $(W_i \times M - Z_i(t))$ is over the monarch situation and therefore the renewal situation of the fighter is over the leader situation. If W_i is less than 1, then the situation of $(W_i \times M - Z_i(t))$ is in between the monarch's situation and the fighter's present situation. The renewal situation of the fighter is near in comparison with the former example. If $W_i = 0$, then the updated position of the soldier goes so near to the leader situation that denotes the finishing phase of the warfare.

Rank and weight updating
The situation renews of every search agent is dependent on the communication of the situation of the Monarch, the Leader, and each fighter's rank. Every fighter's rank is dependent on his achievement history in the warfare field administered which would consequently impact the weighing influence W_i. Every fighter's rank reveals how near the fighter as a search agent is to the goal as a value of fitness. It is not worthy the weighting factors in additional competitive processes namely PSO, GSA, WOA, and GWO would differ linearly while in the present

suggested WSO process, the weight (Wi) fluctuates as a factor of α exponentially. If the assault power (fitness) in the novel situation (S_n) is less than that of the former situation (S_f) the fighter earnings the former situation.

$$Z_i\,(t+1) = Z_i\,(t+1) \times (S_n \geq S_f) + Z_i\,(t) \times (S_n < S_f) \tag{22}$$

If the fighter renews the situation effectively, the fighter's rank (Ri) would be progressed

$$R_i = (R_i + 1) \times (S_n \geq S_f) + R_i \times (S_n < S_f) \tag{23}$$

On the Basis of the rank, the novel weight is considered as:

$$W_i = W_i \left(1 - \frac{R_i}{\max\_rep}\right)^a \tag{24}$$

Defense strategy

The 2nd tactic situation renew is on the basis of the situations of the Monarch, the military leader, and a stochastic fighter. While the weight and ranking renewing stay similar.

$$Z_i(t+1) = Z_i\,(t) + 2 \times \rho \times (M - Z_{rand}(t)) + rand \times W_i \times (L - Z_i(t)) \tag{25}$$

This warfare tactic discovers further search space in comparison with the former tactic since it contains the stochastic fighter's situation. For big amounts of W_i, fighters take big paces and renew their situation. For min amounts of W_i, fighters take min paces whilst renewing the situation.

Replacement/Relocation of weak soldiers

For each repetition, recognize the feeble fighters making the worst fitness. several replacement methods are tested. The simplest method is substituting the feeble fighter with a stochastic fighter as determined in the next Equation.

$$Z_{\,w}(t + 1) = Lb + rand \times (Ub - Lb) \tag{26}$$

The 2nd method is changing the place of the feeble fighter near the average total military in a warfare field which is defined by the following formula. This method enhances the method's convergence manner.

$$Z_{\,w}(t + 1) = -(1 - randn) \times (Z_{\,w}\,(t) - \text{median}\,(Z)) + K \tag{27}$$

Salient features of the proposed algorithm

(1) The suggested process attains the best equilibrium between exploitation and exploration.
(2) Every result (fighter) owns a distinctive weight on the basis of his rank.
(3) The weight of each fighter is renewed if the fighter effectively enhances his fitness at the renewing pace. Therefore, the weight renewing purely relies on the subdivision situation connected to Monarch's and leader's situation.
(4) The weights would differ nonlinearly. The weights fluctuate in huge amounts throughout the initial repetitions and fluctuate in minor amounts throughout the last iterations. This makes quicker convergence to the global optimum amount.
(5) The situation renewing procedure consist of 2 phases. This enhances the exploration aptitude for the global optimum result.
(6) The suggested process is not complex and needs a smaller amount of computational load.

Exploration and exploitation

Exploration using for global optima and exploitation using for convergence are the 2 foremost standards for any bio-inspired optimization processes. The best interaction between these two events would cause the process stronger and more effective. The protection tactic signifies exploration whilst the assault tactic signifies exploitation. The additional foremost features which impact the exploitation and exploration ability of the suggested process are:

(1) Initially, the variable 'rand' could take any amount stochastically that is ranging between '0' and '1'. This 'rand' variable determines whether the fighter's motion is to be exploration-oriented or exploitation oriented.
(2) Then, the factor $\rho\,r$ assistances the operator by providing the flexibility to select an amount that is dependent on the cost value. Based on the experiments achieved on diverse trial functions, it is deduced that a minimum amount of $\rho\,r$ is between 0 and 0.5 which suits the greatest unimodal functions, and the amounts between 0.5 and 1 outfit the greatest multimodal functions.
(3) Penultimately, the search agent's motion in the orientation of $Xrand$ makes the process more explorative to pursue the noticeable regions in the search space so as to set at the global optima.
(4) Finally, Wi impacts the search agent's orientation on the greatest probable situation. Wi leads the search agents to go globally and perform exploration and as the search procedure develops and arrives at the last step, it would cause the search agents to be exploitative. The weights allocated to each fighter are adaptive

and alter from repetition to repetition. The fighter with a huge fitness value would own a smaller amount of weight and the fighter with a smaller amount of fitness would own a huge weight. At the beginning of the fighting, every fighter takes large steps, and their weight varies in large steps. when the warfare reaches its final, the fighters take minor paces to touch the goal, and the weight fluctuates in minor paces. Since the tactic is selected on a random basis, the fighters go in a random orientation and do not accurately pursue the monarch. This advances the process's exploration proficiency. The objective region is recognized by military groups when warfare reaches the end (noticeable search space). Military groups border the objective as well as the Monarch and Leader are so near to the objective. Therefore, the entire group goes in minor paces and joins to the objective situation. Consequently, it can be said that the process owns the exploitation aspect too.

Improved war strategy optimization

In this section, the "War Strategy Optimization" algorithm is being modified in order to enhance its performance and effectiveness in solving optimization problems. By incorporating specific modifications, we aim to improve the algorithm's convergence speed, exploration-exploitation balance, and overall solution quality.

a) OBL (Opposition-Based Learning):

OBL is a strategy where both the original solutions and their corresponding opposite solutions are considered during the optimization process. For improving the War Strategy Optimization algorithm, two modifications are used: Opposition-Based Learning (OBL) and Sine Map Chaos Theory. The OBL can be applied as follows: During the initialization stage, a set of initial solutions is generated randomly. For each solution, its corresponding opposite solution is also generated by considering the negation or reversal of decision variables.

The optimization process then involves evaluating the fitness of both the original and opposite solutions, allowing for a more comprehensive search in the solution space.

For each candidate, the method creates a complement value. The complement value is calculated by taking into account a random candidate, Z_w, and is shown below:

$$Z_w^C = Z_w^{max} + Z_w^{min} - Z_w \tag{28}$$

where, Z_w^C signifies the opposite position of Z_w, and Z_w^{min} and Z_w^{max}, in turn, illustrate solution's the minimum and maximum boundaries. Herein, 50% of the initial candidates have been updated by OBL.

b) Sine Map Chaos Theory:

The Sine map chaos theory is utilized to inject chaotic behavior into the optimization process of the "War Strategy Optimization" algorithm. This can be done as follows:

A sine map chaotic sequence is generated based on a chaotic parameter and the current iteration. This chaotic sequence is then used to perturb the solutions' position within the process of optimization. The Sine map functions as a unimodal map that may be expressed using the following formulation:

$$r_{i+1} = \frac{\alpha}{4} \times \sin\left(\pi \, r_i\right), \tag{29}$$

Here, $\alpha = 4$[31], and r is a constant in the range between 0 and 1.

This equation is then used for relocation as follows:

$$Z_w\left(t + 1\right) = -\left(1 - r_i\right) \times \left(Z_w\left(t\right) - median\left(Z\right)\right) + K \tag{30}$$

As in bio-inspired algorithms, the algorithm uses a unique dynamic weighting mechanism to assign each search agent a weight based on its performance, ensuring that agents with higher performance influence the search more, balancing exploration and exploitation[32]. The first phase of its two-phase update strategy thoroughly explores the solution space, while the second phase intensifies the search around promising areas to optimise exploitation and prevent stagnation in local optima[33]. IWSO uses nonlinear weight modifications, which vary more during beginning iterations and stabilize at the end, quickening convergence to the global optimum[34]. Sine Map Chaos Theory enhances the resilience of searches and the diversity of solutions by enabling the algorithm to unpredictably break free from local optima, thereby facilitating exploration of the global search space[35]. Opposition-Based Learning (OBL) contributes to global search effectiveness by taking into account both existing and contrasting solutions, which has proven beneficial in numerous optimization scenarios[36].

Verification of the IWSO algorithm

To verify the suggested algorithm, we conducted experiments on a computer configuration with the following specifications:

Processor: Intel Core i7-10700 K.

RAM: 16GB DDR4.

Graphics Card: NVIDIA GeForce RTX 3070.

Storage: 1 TB SSD.

Operating System: Windows 10.

The validation process involved testing the improved War Strategy Optimization algorithm on CEC-BC-2017 test suite functions and comparing its results with five different state-of-the-art algorithms, including African vultures optimization algorithm (AVOA)[37], Dwarf Mongoose Optimization Algorithm (DMO)[38], Tunicate Swarm Algorithm (TSA)[39], Owl Search Algorithm (OSA)[40], and Pigeon-inspired Optimization Algorithm (PIO)[41]. Table 4 provides the information for the parameter setting of the studied algorithms.

Each algorithm was run 15 times on all test functions to ensure reliable and statistically significant results.

Algorithm	Parameter	Value
AVOA	L_1	0.8
	L_2	0.2
	w	2
	P_1	0.5
	P_2	0.5
	P_3	0.4
DMO	Number of babysitters	3
	Number of alpha groups	197
	Number of scouts	197
	Peep value	2
TSA	Number of search agents	80
	P_{min}	1
	P_{max}	4
	Number of generations	200
OSA	T_{dead}	18
	$|P|$	10
	Acc_{low}	0.2
	Acc_{high}	1
PIO	Number of pigeons	200
	Space dimension	20
	Map and compass factor	0.2
	Operation limit (compass and map)	150
	Landmark operation limit	200
	Inertia factor (w)	1
	Self-assurance factor (c_1)	1.2
	Swarm assurance factor (c_2)	1.2

Table 4. The information for the parameter setting of the studied algorithms.

The benchmark functions used in the validation process were selected to represent a wide range of optimization problem types. The functions are commonly utilized to assess the efficacy of optimization algorithms.

The five modern methods chosen for contrast were selected based on their popularity and effectiveness in solving optimization problems. These methods represent a diverse range of metaheuristic algorithms, comprising (PSO) Particle Swarm Optimization, Genetic algorithms, (ACO) Ant Colony Optimization, differential evolution, and simulated annealing.

By comparing the results of the modified War Strategy Optimization algorithm with these state-of-the-art methods, we can assess its performance, efficiency, and effectiveness in solving the benchmark functions. The comparison will be based on various metrics, including the Best, Mean, and standard deviation (StD) values of the scrutinized functions. The validation section aims to provide empirical evidence of the proposed algorithm's capabilities and its potential advantages over existing methods.

The findings depicted in Table 5 compare the performance of the suggested IWSO algorithm with five other state-of-the-art algorithms (AVOA, DMO, TSA, OSA, and PIO) on various benchmark functions (F1 to F12). The comparison is based on three metrics: Best, Mean, and standard deviation (Std) values of the scrutinized functions.

Upon analyzing the results, it is evident the suggested IWSO consistently performs better than the others across multiple cost functions. In terms of the best values that represents each algorithm found the Best solution, the IWSO algorithm achieves significantly lower values compared to the other methods. This indicates that the IWSO algorithm is capable of finding more optimal solutions for the given benchmark functions.

Furthermore, when considering the Mean values, which represent the average solution quality obtained by each algorithm, the IWSO algorithm consistently achieves lower values compared to the other methods. This demonstrates that the IWSO algorithm not only excels in finding good solutions but also maintains a high level of consistency in its performance. Additionally, examining the standard deviation (StD) values provides insights into the stability and robustness of each algorithm. The IWSO algorithm exhibits relatively higher StD values compared to some of the other methods. While this may indicate slightly higher variability in its results, it also suggests that the IWSO algorithm explores a wider range of solutions, potentially leading to the discovery of more diverse and superior solutions.

Overall, the results of the comparison clearly indicate that the suggested IWSO algorithm performs better than the other modern strategies regarding quality of solution, consistency, and exploration capabilities. Its ability to consistently find better solutions, as evidenced by the lower Best and Mean values, showcases its effectiveness in solving the benchmark functions. Moreover, the slightly higher StD values suggest that the IWSO algorithm explores a larger search space, leading to the discovery of diverse and potentially superior

Function	Indicator	AVOA	DMO	TSA	OSA	PIO	IWSO
F1	Best	2.63	114.19	1.73	67.90	1.91	1.85
	Mean	12.81	319.34	15.84	196.33	13.07	9.02
	Std	12.48	153.52	9.74	106.02	8.14	11.83
F2	Best	7.23	3.87	5.78	2.08	5.15	0.08
	Mean	71.39	51.56	75.68	40.82	42.97	0.00
	Std	54.70	52.31	50.07	29.89	45.80	0.33
F3	Best	2.63	49.18	0.02	43.04	0.01	0.01
	Mean	11.80	40.70	0.04	23.68	0.04	0.03
	Std	8.25	10.38	0.01	8.97	0.01	0.01
F4	Best	9.33	7.09	0.11	5.01	0.07	0.13
	Mean	10.63	5.35	0.27	4.67	0.17	0.25
	Std	2.83	1.48	0.15	0.81	0.14	0.06
F5	Best	0.16	3.78	0.00	2.65	0.00	0.00
	Mean	1.62	7.62	0.01	7.06	0.00	0.01
	Std	1.40	1.93	0.00	1.89	0.00	0.00
F6	Best	2.28	0.15	0.00	0.13	0.00	0.00
	Mean	1.09	0.98	0.00	0.75	0.00	0.00
	Std	1.59	1.89	0.00	1.71	0.00	0.00
F7	Best	0.72	0.71	0.55	0.58	0.31	0.57
	Mean	1.74	1.11	1.51	0.71	1.32	0.89
	Std	0.24	0.27	0.18	0.14	0.11	0.18
F8	Best	13.82	8.67	9.79	7.45	8.41	9.80
	Mean	18.51	17.77	20.93	16.05	10.54	10.05
	Std	6.65	4.25	5.49	3.27	4.68	5.45
F9	Best	0.16	10.05	0.00	6.03	0.00	0.00
	Mean	2.13	35.82	0.00	34.63	0.00	0.00
	Std	1.94	24.65	0.00	24.25	0.00	0.00
F10	Best	4.63	3.06	0.18	2.88	0.11	0.19
	Mean	9.58	15.83	3.44	14.54	2.72	2.26
	Std	6.45	9.36	6.24	5.30	5.92	4.10
F11	Best	0.19	0.11	0.00	0.06	0.00	0.00
	Mean	0.32	0.19	0.01	0.18	0.01	0.01
	Std	0.14	0.08	0.00	0.06	0.00	0.00
F12	Best	0.00	0.00	0.00	0.00	0.00	0.00
	Mean	0.00	0.00	0.00	0.00	0.00	0.00
	Std	0.00	0.00	0.00	0.00	0.00	0.00

Table 5. Comparing investigation between the recommended IWSO algorithm and the other algorithms.

solutions. These findings provide empirical evidence of the capabilities and advantages of the proposed IWSO algorithm over existing methods. The results demonstrate its potential as a powerful optimization algorithm for a wide range of optimization problems.

Sure, the Improved War Strategy Optimization (IWSO) algorithm is better than other methods as analyzed before, because it has special features that make it more suitable for the specific problems in this case.

Unique advantages of IWSO

Balanced exploration and exploitation The IWSO algorithm carefully balances the stages of exploration and exploitation. Unlike other metaheuristics which tends to rely on crossover and mutation of individuals to converge, or focuses on the external property of swarm for evolution, the strategy of dynamic adjustment in IWSO guarantees a comprehensive exploration of the solution space and a more effective exploitation of the Best solutions.

Adaptive Weighting In the IWSO context, each search agent (or "fighter") is given a special weight according to how well it is performing. Such an adaptive weighting mechanism enables dynamic adjustment of the influence of each agents, thus improving the convergence speed and accuracy of the algorithm. This strategy is more dynamic than the static parameters used with other metaheuristics.

Two-Step updating processing IWSO makes use of a two-phase position updating strategy, which greatly helps in jumping out of the local optimum as well as finding global solutions. It can also search for solutions more comprehensively than a single-step updating other metaheuristics, since this is a two-step updating.

Nonlinear weight variations While other metaheuristics normally change the weight linearly, IWSO presents nonlinear weight updates. Thus, the weights vary a lot in earlier iterations but get stabilized in later iterations which helps in faster convergence to global optimum.

Addressing specific challenges

The telecommunication towers are subjected to dynamic load variations due to variable traffic and environmental conditions. The IWSO algorithm adapts to the changing environment, which compensates for these variations and tightens power supply with real-time adjustments. It features a mechanism that adjusts dynamically to ensure efficient functioning.

Things like temperature and humidity can really affect how well the PEMFC works. IWSO tackles this issue by using a cool method that incorporates OBL with Sine Map Chaos Theory, which does a much better job of adapting to those changing conditions. This allows for a steady voltage when the environment changes.

In comparative studies, IWSO performed faster and yielded better results. Which means that it gets to the Best solution with the same or less number of evaluations but also more reliably than former methods.

Designing optimization strategy for supply of telecommunication

The suggested model utilizes an efficient boost converter, which a recently developed metaheuristic algorithm controls it. This algorithm effectively regulates the source and load voltages by incrementing the level of voltage. The use of the improved boost converter is implemented in response to the necessity for a regulated, dependable as well as an uninterrupted 48 V Direct Current power source for the Base Transceiver Station via the bus of distribution Direct Current. The used boost converter in this research utilizes MOSFET for its switching operation. Figure (3) illustrates the employed boost converter's universal scheme.

In Fig. (3), a method for controlling a PEMFC powered BTS system has been shown. This approach involves measuring the voltage (V_o) generated by the sensor and using it to generate an error signal via contrasting it with the desired value (V_d).

$$E = V_d - V_o \tag{31}$$

Subsequently, the error signal was directed towards the operational amplifier (op-amp) with the purpose of acquiring the optimal values for the proportional coefficients (K_P) and integral coefficients (K_I) of the PI controller. This process aimed to obtain the values, which are optimized for the proportionate (K_P) and integral (K_I) coefficients in the system.

$$u(t) = K_P + K_I \int e(t) \tag{32}$$

After that, the ideal signal that was obtained from the regulator has been conducted to the modulator in order to generate an optimum pulse width modulation (PWM) signal. The PWM signal is what activates the MOSFET (Metal Oxide Semiconductor Field Effect Transistor) within the boost converter, which is an essential part of the BTS distribution system. In the present inquiry, a comparison of the recommended optimization approach
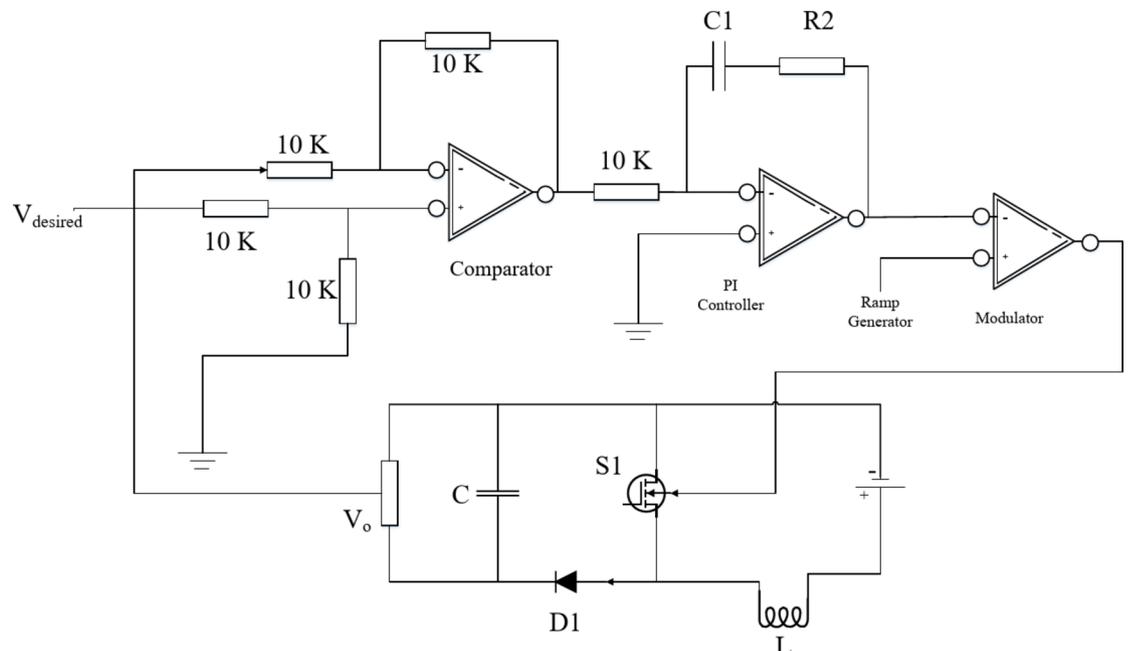

Fig. 3. General scheme of the employed boost converter.

to the Ziegler-Nichols (ZN) process is carried out in order to carry out an evaluation to assess the efficiency of the suggested optimal method. According to the Ziegler-Nichols method, the proportional coefficient should have a value of 0.48, and the integrator coefficient should have a value of 0.62. These are the ideal values for these coefficients. The recently developed method of Improved War Strategy Optimization (IWSO) has been used in order to make the system that has been proposed more effective. The following operation is what this method recommends for reducing the amount of the error signal, which is abbreviated as IWSO:

$$\min MSE = \min \frac{1}{t} \int_0^\infty t \times e^2(t)\, dt \tag{33}$$

where, MSE equals $f(K_P, K_I)$.

Results and discussions

During the simulation process, the system specifications include 16GB DDR4 RAM, an Intel Core i7-10700 K processor, a 1 TB SSD storage, and a NVIDIA GeForce RTX 3070 graphics card. The operating system used for the simulation is Windows 10. These hardware components provide a powerful computing setup for running simulations efficiently in MATLABR2019b.

In this part, we provide the simulation findings derived from the research that was done on an optimum new hybrid design built on a PEMFC for delivering power to BTS systems in distant rural regions of India. The study was conducted on an ideal new hybrid design based on a PEMFC. The purpose in the current research was to evaluate the effectiveness and functionality of several control methods, including the time-honored Ziegler-Nichols technique (ZN)[22], Particle Swarm Optimizer (PSO)[42], improved balanced owl search (IBOS) algorithm[43], War Strategy Optimization (WSO) algorithm, and our recently developed Improved War Strategy Optimization (IWSO) algorithm, among others.

In order to test the tracking skill of the regulators built on the various algorithms, it was expected that the distribution bus voltage would fluctuate within a range of 10% or less. In addition, the performance of the regulators was evaluated by taking into account a variety of changes in the voltage of input in the boost converter, which is in the range of 25 V and 40 V. In addition, the effectiveness of the regulators was investigated under a variety of loading circumstances, such as a state of 20% overloading that exemplified the peak flow of communication signals and a condition of 70% underloading that indicated the functioning of just one transceiver.

Based on the findings of the simulations, it was found that the IWSO algorithm provided was superior to other comparative methods in terms of its capability to track, voltage control, and overall efficiency.

Even in the face of unpredictability brought on by factors like as temperature and humidity, the IWSO boost converter, which was optimized, was able to keep the bus of Base Transceiver Station distribution at a constant voltage of 49.2 V.

The results of the comparative study of the various algorithms are shown in Table 6 as the values of variable in the proportional (K_p) and the integrator (K_I) gain for the boost converter.

These values were determined by the boost converter. These settings for the parameters were chosen so that the system would have the best possible performance and be as stable as possible.

The results of the simulation, taken as a whole, support the usefulness of the suggested IWSO approach in terms of managing the voltage of the BTS system, ensuring a dependable power supply, and decreasing the size of the battery bank. In India's most distant rural areas, the use of a system based on PEMFCs not only provides clean energy but also makes a contribution to the long-term viability and quality of the country's telecommunications infrastructure.

The voltage was incrementally increased from 0 to 30 V in order to conduct an analysis on the voltage tracking necessary (V_d is, assuming 49 V) for a 1.8 kW load utilizing the provided input signal. Figure (4) displays the results of the output voltage of the evaluation by different algorithms as the input voltage is stepped up from 0 to 30 V.

The findings indicate that the answer of the boost converter, when using the Ziegler-Nichols approach, exhibits an undershoot of 13% and decreases to around 33.44 V during this period. The converter returns to a stable state within a time frame of 100 milliseconds, indicating the least favorable performance compared to the other conditions. Furthermore, the suggested Integrated Weighted Scoring Optimization (IWSO) algorithm demonstrates superior performance compared to the other methods. The observation of A reveals that there is no presence of undershoot in the design, and it attains a steady state within a time period of 0.002 s. The analysis findings for the system based on the comparative methods are shown in Table 7.

Algorithm	K_p	K_I
ZN	0.0527	9.23
PSO	6.8	64.28
WSO	5.2	48.35
IBOS	4.5	53.8
IWSO	5.4	50.2

Table 6. The values of variable in the proportional (K_p) and the integrator (K_I) gain for the boost converter.
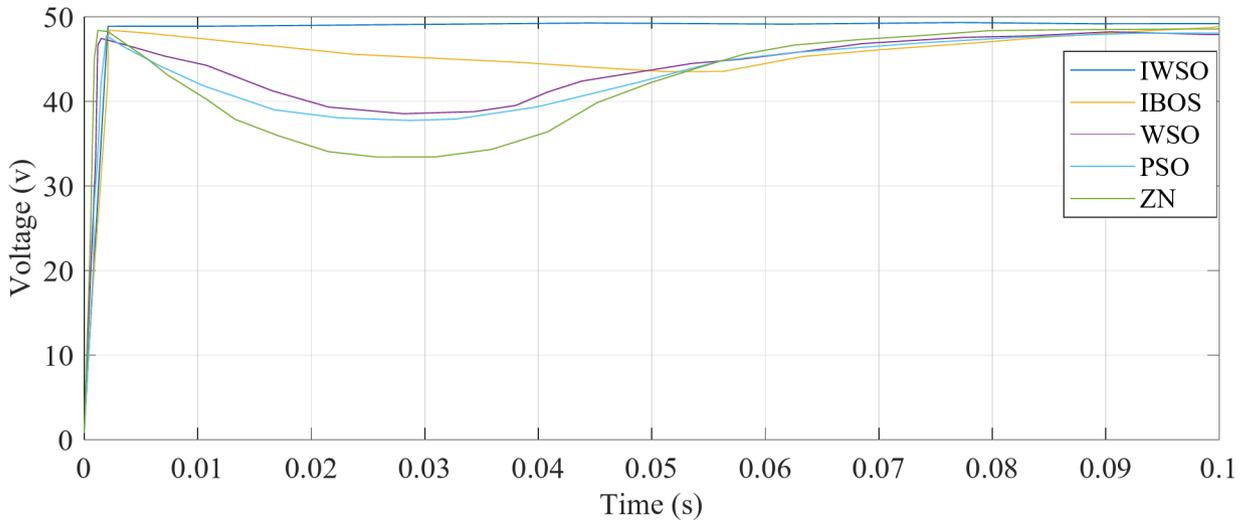
Fig. 4. Results of output voltage analyzed by comparative algorithms as the input voltage is stepped up from 0 to 30 V.

Dynamic response feature	Control Method				
	ZN	PSO	WSO	IBOS	IWSO
Settle time (ms)	120	15	36.83	40.33	43.26
Rise time (ms)	1.25	0.9	1.30	1.35	1.53
Overshooting (%)	-	-	-	-	-
Undershooting (%)	22	-	-	-	-
Peak time (ms)	24	1.4	17	26	29

Table 7. Analysis findings for the system based on the comparative methods.
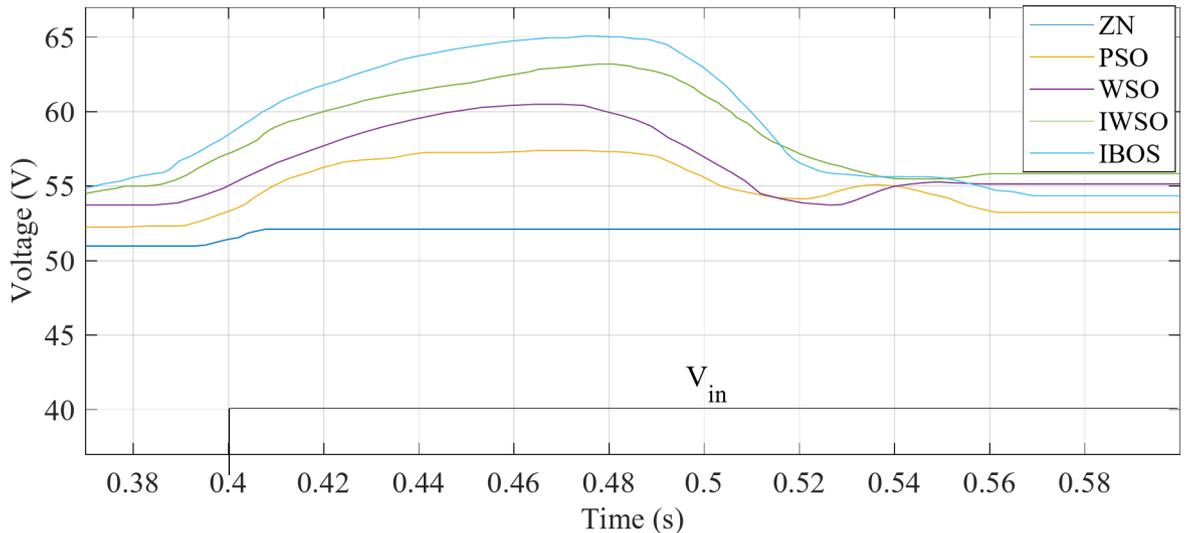
Fig. 5. Voltage outputs obtained from the study, which included the use of several techniques.

Figure (5) illustrates a contrasting scenario in which the input voltage undergoes an increment from 50.99 V to 52.11 V. In this case, the descending time for the Ziegler-Nichols-based controller has been determined to be around 0.41 s. It is evident that the suggested IWSO algorithms exhibit no undershoot and provide superior performance across several metrics when compared to other contemporary approaches. Figure (5) illustrates the voltage outputs obtained from the study, which included the use of several techniques. The input voltage was reduced from 63.20 V to 55.84 V.
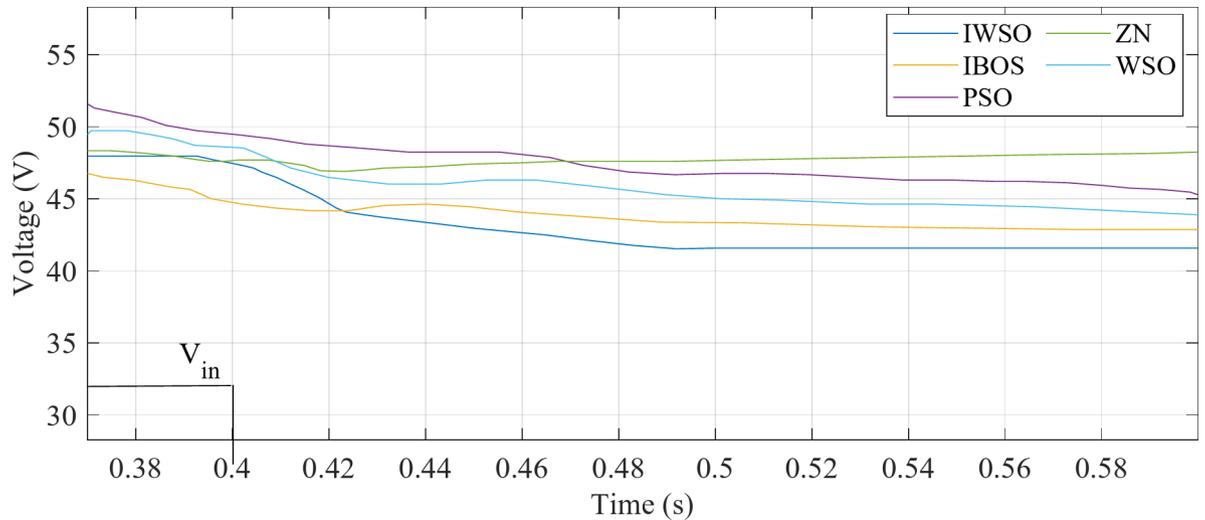
Fig. 6. Findings of the examination carried out by various algorithms on the voltage that was outputted by reducing the voltage that was inputted from 32 V to 0 V.
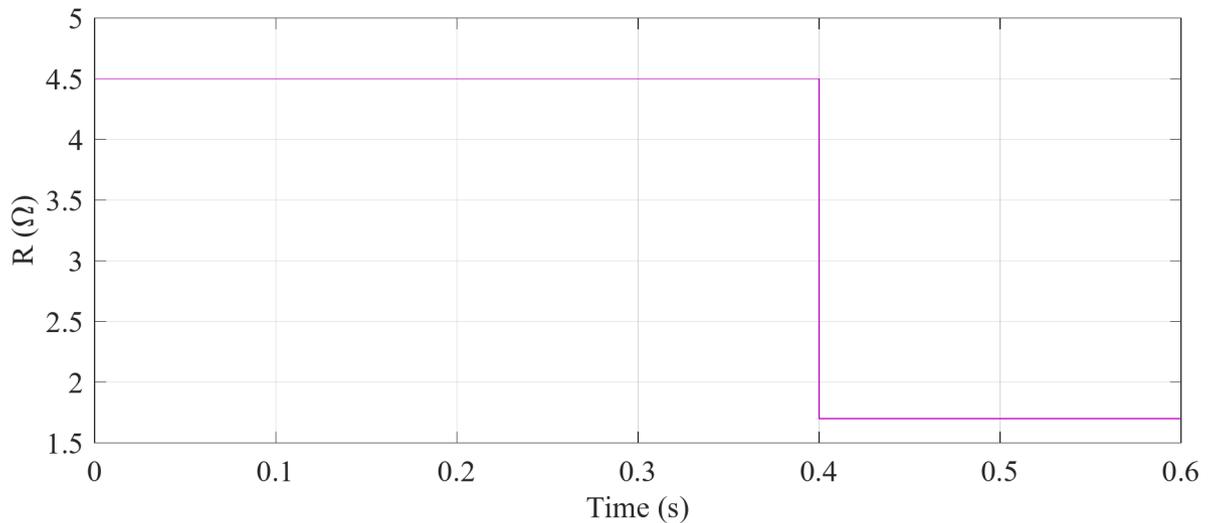
Fig. 7. Load Variation during a period of around 4.5Ω.

The findings of the examination carried out by different algorithms were displayed by Fig. (6) on the voltage that was outputted by reducing the voltage that was inputted from 32 V to 0 V.

The stability of the given IWSO while taking the load variations into consideration is investigated here. The variation in load that occurs during a period of around 4.5Ω is seen in Fig. (7).

Figure (8) depicts the system's dynamic answer built on the recommended IWSO-based controller compared to other controllers that have been stated when the load changes from the lowest to the associated load.

The analysis of Fig. (8) reveals the dynamic response of the ZN-based converter exhibits a significant undershoot of around 70.21%. This observation raises concerns about the possible negative effects this undershoot may have on the overall system performance. Furthermore, the methodology that is grounded on the proposed Improved War Strategy Optimization demonstrates superior outcomes, exhibiting less instances of undershooting. A further simulation is conducted by modifying the load in 1.2Ω for the system under evaluation, as observed in Fig. (9).

The system's dynamic response was represented based on the recommended IWSO-based regulator compared to other controllers in Fig. (10) that have been stated when the load changes from the lowest load to the associated one.

The suggested system offers various solutions tailored to particular scenarios, including direct technological interventions aimed at addressing fuel cell degradation and membrane aging, as well as systems necessitating regular maintenance. This approach ensures reliable operation with reduced downtime. Furthermore, the
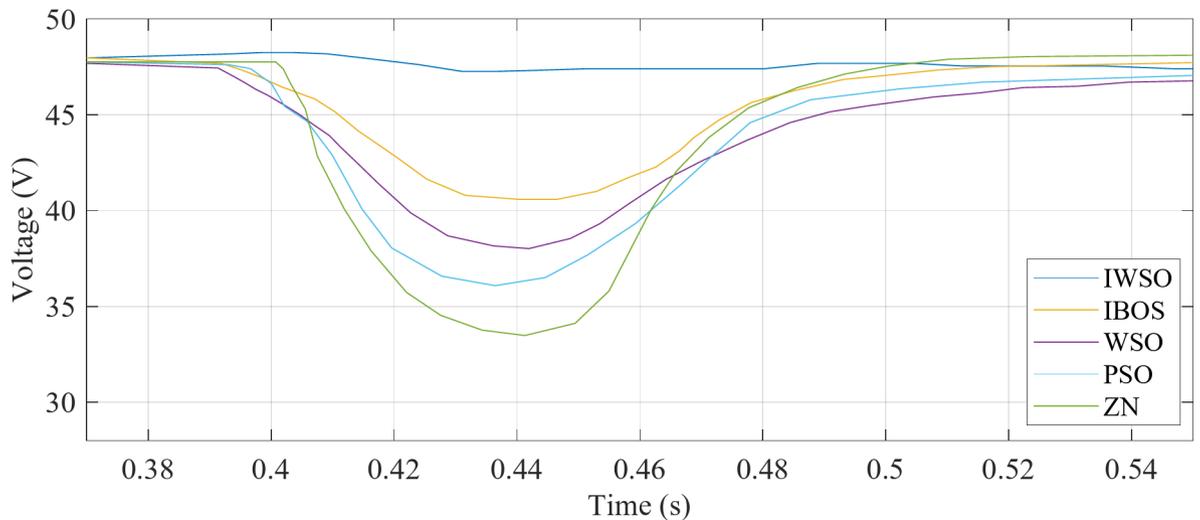
Fig. 8. The system's dynamic answer built on the recommended IWSO-based controller compared to the other controllers.
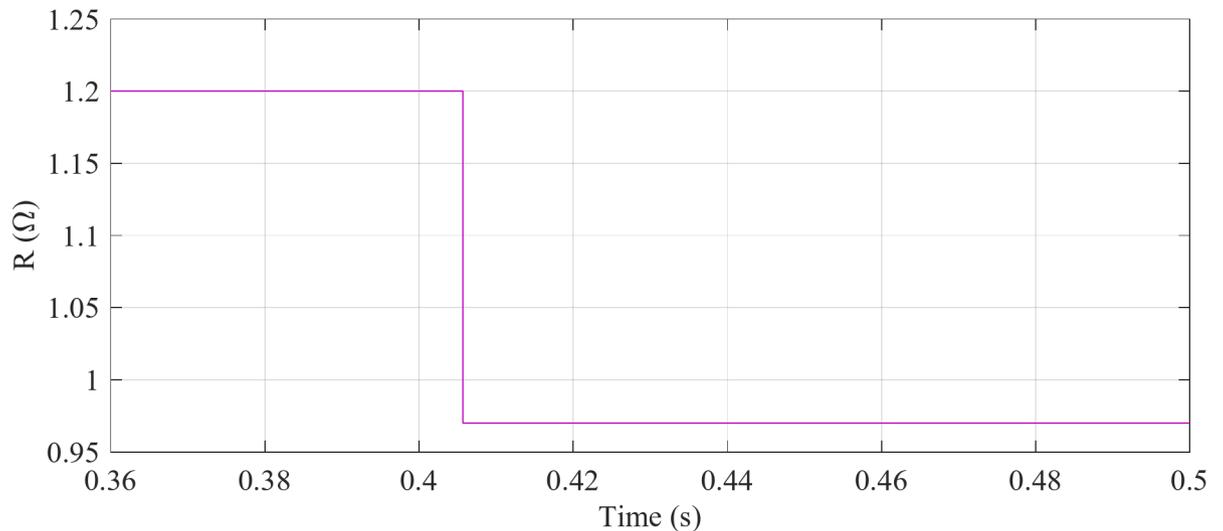

Fig. 9. Load Variation during a period of around 1.2 Ω.

monitoring capabilities are sophisticated, enabling the early detection of degradation and membrane aging, thereby facilitating proactive maintenance prior to the onset of significant deterioration.

The reliability of the system is also improved with automated maintenance alerts and a regular maintenance schedule for autonomous machines, which are both based on diagnostic data. The PEMFCs could have a longer lifetime and operating lifespan owing to the development of high-quality materials and design innovations in membrane materials and catalyst technology. Each of the 18 PEMFC unit converts 140 kW and provides redundancy, redundancy enables component replacement or upgrades without system interruption. Backup power failed to work during maintenance activities or other unexpected malfunctions and the optimized operation algorithms allow for the automatic adjustment of parameters to avoid unnecessary stress on the fuel cells and prolong their operational life. All of these approaches contribute to and guarantee the PEMFC-based energy supply system providing reliable, high-quality and continuous operation in extreme and remote environments.

The economic feasibility of the proposed power supply system utilizing PEMFCs must be established, particularly in light of the substantial initial expenses associated with PEMFCs and hydrogen fuel. When compared to diesel generators or grid-connected alternatives, PEMFCs may offer certain advantages in terms of total cost of ownership (TCO) over their operational lifespan. PEMFCs are characterized by elevated initial expenditures; however, they offer reduced operational and maintenance costs due to their efficiency, exceptional durability, and minimal maintenance needs. In contrast, diesel generators incur greater expenses related to fuel,
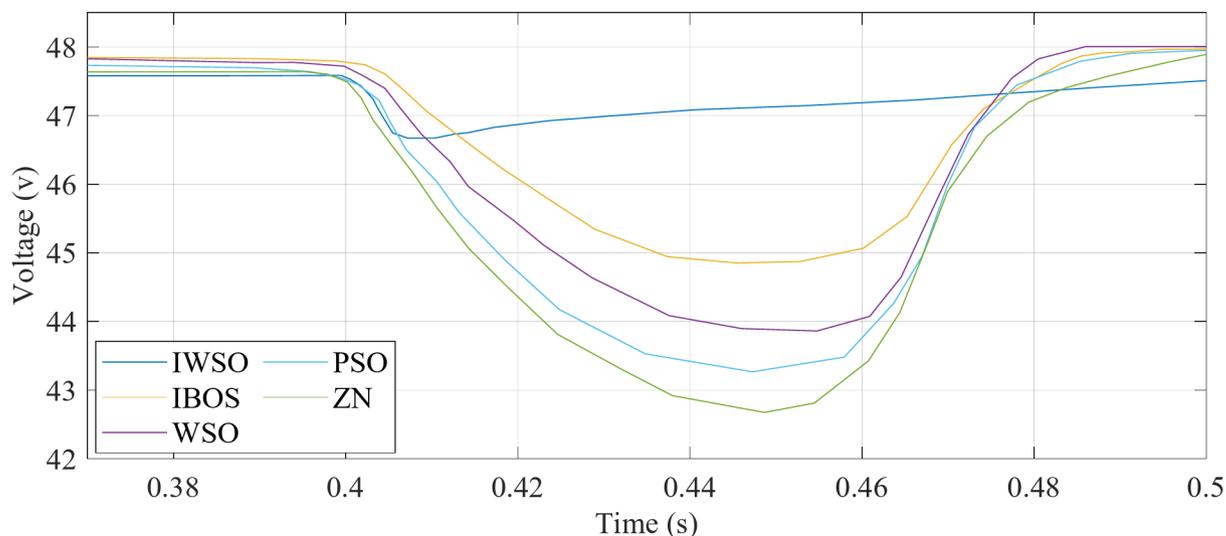
Fig. 10. The system's dynamic answer built on the recommended IWSO-based controller compared to the other controllers at almost 0.5 s.

maintenance, and adherence to environmental regulations. Additionally, in remote areas, the installation of grid-tied systems can be prohibitively expensive.

Moreover, cost-reduction efforts could enhance the profitability of PEMFCs. A great example is tax credits, grants, and subsidies for adoption of renewable energy. Decreasing hydrogen production prices, and improving PEMFC technology should reduce costs. Perhaps energy management systems that optimize the performance of the PEMFC or hybrid systems that leverage the availability of renewable energy sources can be cost effective as well.

Conclusion

This research work addressed a critical need in the telecommunication industry by presenting an optimized and robust power supply system for Base Transceiver Station (BTS) units. The reliable operation of telecommunication towers, especially in remote and challenging locations, heavily relied on a consistent and safe power source. PEMFCs arose as a promising solution due to their high efficiency and environmentally friendly nature. By implementing the improved war strategy optimization-based proportional-integral (PI) controller, this study ensured the seamless integration of PEMFCs into BTS power supply systems. This controller, based on advanced optimization techniques, effectively regulated the output voltage from the fuel cells, leading to stable and reliable power delivery. The comparative analysis between the proposed method and Ziegler-Nichols technique (ZN), Particle Swarm Optimizer (PSO), improved balanced owl search (IBOS) algorithm, and original War Strategy Optimization (WSO) algorithms conducted in this research clearly demonstrated the superiority of the proposed system over existing techniques. It showcased substantial benefits in terms of efficiency, reliability, and overall performance. Notably, the optimized power supply system offered significant cost savings by minimizing energy wastage and optimizing the utilization of PEMFCs. This cost-effectiveness was essential for the telecommunication industry as it reduced operational expenses and increased the profitability of telecommunication tower deployment. Furthermore, the environmental advantages of the proposed system could not be overlooked. By using clean and sustainable energy solutions like PEMFCs, this research contributed to reducing greenhouse gas emissions and promoting environmental sustainability in the telecommunication infrastructure sector. The adoption of such technologies aligned with global efforts to combat climate change and decrease dependence on fossil fuels. An environmental impact assessment could not be more thorough. Life cycle analysis (LCA) can be employed to determine the impact of hydrogen generation, PEMFC manufacture, and operation on the environment. Environmental risks of hydrogen storage and transportation. This study should include an LCA to examine the environmental impact of hydrogen generation, PEMFC manufacture, and operation. LCA captures energy and material inputs, emissions, and waste formation, from raw material extraction to end-of-life disposal or recycling. There are also environmental impacts associated with hydrogen storage and transportation. Hydrogen is extremely flammable and requires leak-proof storage devices, which renders both gaseous or liquid hydrogen storage difficult. If the infrastructure use fossil fuels, it would be energy-intensive and emit greenhouse gases to transport hydrogen over long distances. This could be resolved with renewable energy for hydrogen generation, advancements in storage technology, and improvements in transportation.

Data availability

All data generated or analysed during this study are included in this published article.

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Author contributions

Bo li, Sharina and Bahman Taheri wrote the main manuscript text and prepared figures. All authors reviewed the manuscript.

Declarations

Competing interests

The authors declare no competing interests.

Additional information