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Employing Crocodile Hunting Search Approaches to Manage Renewable Energy-Based Microgrid

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ABSTRACT

This study explores the benefits and achievements of Machine Learning models in guiding active optimization procedures for selecting the most appropriate hybrid renewable energy system. The system is known for its cost-effectiveness, reliability, and performance. The study focused on a specific example of a hybrid renewable energy system that combines solar photovoltaic and wind resources. The study also considered the use of a fuel cell to store any extra electricity generated. This work aimed to conduct a crocodile hunting search, which was achieved using optimization models. The MATLAB program and Simulink environment were utilized to implement and execute numerical simulation processes. Based on the numerical simulations, it was found that the hybrid renewable energy system consumed a total of 19.88 grams of hydrogen fuel. Meanwhile, the poorest performance was observed in CHS, which exhibited the highest hydrogen fuel usage, amounting to 25.73 g. The fuel cell voltage for CHS exhibited a range of 43 to 49.5 V. Furthermore, it is customary for the fuel cell current to fluctuate between around 20 and 160 A. However, the CHS model exhibited a wider range of fuel cell currents, ranging from 75 to 210 A. The average range for hydrogen fuel usage varied between approximately 10 and 75 L/m. In addition, it was discovered that all algorithms measured a hydrogen fuel consumption rate of 20 g, except for the CHS paradigm, which achieved a maximum hydrogen fuel consumption rate of 25 g. The whole duration of the simulation in this study was 350 seconds.

1. Introduction

Renewable energy has a lot of promise because it can supply more energy than the world needs. Biomass, wind, sun, hydropower, and geothermal can provide sustainable energy using locally available resources. Renewable energy systems are getting more popular as their costs fall and oil and gas prices vary. Costs for fossil fuels and renewable energy are moving in opposite directions, and the economic and political frameworks needed to sustain mass adoption and the long-term viability of renewable energy markets are changing rapidly. Hybrid renewable energy systems (HRES) emerged in response to the emergence of non-conventional energy sources (Alam & Mehar, 2021). HRES integrates two or more renewable energy sources. Different issues arise with managing renewable energy. These issues pertain to the distance between energy generation and use. Rising electricity demand affects users' source quality (Cabana-Jiménez et al., 2022). Microgrids (MGs) solved these challenges by dividing areas into small distribution areas. MGs connect energy resources. It manages energy resources. Therefore, it functions as a small-scale energy system that manages a variety of energy sources. MG systems reduce the dependence on consumption centers and power systems. These MGs may export and import renewable energy from electric power systems (Gaona et al., 2016; Komala, 2021). When employing MG, major concerns include concentrating on electricity quality and delivering local power during outages (Chen et al., 2022). The application of MG in bi-directional flows, electric power supply structures, configuration methods, grid locations, and generation unit characteristics presents obstacles (Martin-Martínez et al., 2016). However, fossil fuel use has led to climate change and global warming. Scientists have observed many harmful climate phenomena due to environmental concerns (Rashedi, 2020). Renewable energy sources like wind farms can reduce fossil fuels' environmental impact and attain sustainability (Sher et al., 2021). Wind energy provides clean, accessible electricity without GHG emissions (Nelson V. and Starcher K., 2018). Installation and use of wind systems have increased worldwide (Vairagi et al., 2017). Except for high-elevation areas, high wind speeds are not possible worldwide (Limpinsel et al., 2018). We can use multiple renewable energy sources such as wind, PVs, and FCs to generate more electricity to address this problem. Integrating multiple renewable energy sources can also help stabilize renewable power output by addressing wind speed changes (Talaat et al., 2019). This study will build a microgrid with PV, WT, battery, and FC. We will implement an energy management system between the distribution and generation phases to evaluate this architecture. We will use the optimization method to improve MG efficiency, reduce operation costs, and reduce GHG emissions. This study has great relevance. The study addresses issues such as elevated operating costs, greenhouse gas emissions, and losses in transmission. This study introduces the MG concept to increase power quality and reliability, cut transmission and distribution costs, and provide electricity to customers during main grid outages. This paper aims to manage energy between hybrids (PV/WT/ Battery/FC) in a microgrid to minimize operational costs and pollution. We are creating an optimization problem to reduce operating costs and emissions. We aim to improve the functionality of the constructed microgrid. Fuel cells store electricity for nighttime or cloudy use, while PV modules provide a second sustainable energy source. Follow and implement certain objectives to achieve the primary goal of the study. Examine the challenges and environmental issues associated with the use of fossil fuels in Iraq, particularly the pollution and electrical power issues caused by diesel generators. Iraq's fossil fuel resources are environmentally friendly and supply stable electrical power without variations. The alternative assumption is that using Iraqi fossil fuel resources is environmentally harmful and cannot deliver consistent electrical power without oscillations. A hybrid energy system cannot provide clean and accessible electrical power, nor can it replace fossil fuel dependence. A hybrid energy system can supply clean, accessible electricity and reduce fossil fuel dependence. A hybrid energy system cannot reduce annual carbon dioxide and GHG emissions. A hybrid energy system can reduce annual carbon dioxide and GHG emissions. Integrating PV modules and fuel cells into Iraqi wind farms is not going to improve reliability and power stability. According to an alternative assumption, adding PV modules and fuel cells to wind farms in Iraq can improve reliability and power stability. Renewable energy projects and hybrid energy systems that provide clean electricity are the focus of this endeavor. The research also seeks to identify important renewable energy issues, critical hurdles, and future opportunities for installation. The research also calculates the LCOE of a hybrid energy system suited for Iraqi solar irradiance and wind speeds. Experts in renewable energy and hybrid energy systems will refine, validate, and alter this research.

2. Literature Review

The MG system reduces the cost and improves energy efficiency and reliability of small-scale electricity production for grid-connected and standalone operations. An Energy Management System (EMS) is needed to minimize system costs at the best operating point and meet all technical and economic restrictions. Optimization methods that depend on dispatch strategy and system operation and maintenance can achieve this. The MG needs a good storage system to operate flexibly and maximize renewable energy generation to cut costs. Multiple studies have been done to optimize MG care. Using a cost-effectiveness model, researchers proposed many optimization methods for electric power transmission. and environmental impacts. The Kyoto Protocol's greenhouse gas (GHG) reduction targets may be the biggest environmental problem facing coal's future use. Unless dramatic carbon sequestration is done, an oil and coal-powered global economy cannot sustain atmospheric CO2 below 550 ppm. Renewable energy sources could supply many times the world's energy needs. Sustainable energy services can be provided via biomass, wind, solar, hydropower, and geothermal using readily available indigenous resources. As solar and wind power costs have declined significantly in the past 30 years and continue to fall while oil and gas prices vary, a transition to renewables is becoming more realistic. Indeed, fossil fuel and renewable energy prices, and social and environmental impacts are diverging. Additionally, the economic and policy structures needed to enable the adoption of renewable energy systems and sustainable markets have swiftly evolved. The US National Renewable Energy Laboratory (NREL) found that geothermal and wind energy may be cheaper than coal in 15 years. Shi et al. (2014) examined the optimal operation of a distributed EMS in standalone and on-grid power supply systems. Together, the MG central controller and local controllers estimated an appropriate timetable. An effective EMS and optimal configuration model for a standalone PV-FC MG was proposed by Mubaarak et al. (2020). TRANSYS was used. The total efficiency was 47.9%, better than previous research. Gavilema et al. (2021) reviewed the most recent MG management and operation optimization methods. When operating an MG, energy management is crucial. A good EMS may enhance MG efficiency, stability, and component life, regardless of the goal: increasing MG production, reducing CO2 emissions, etc. Murty et al. (2020) developed an optimal operation plan for on-grid and island-grid MG using PV, WT, FC, MT, DG, and BESS. Energy management at MG was meant to cut expenses and GHG emissions. MILP was used to create the EMS. Multi-objective issues and a Demand Response Program were proposed. The energy storage system was optimized using Fuzzy Decision-Making (FDM). The results showed that DG and MT fuel costs significantly affected energy costs. For an islanded system, carbon dioxide emissions decreased by 51.60 percent. Talaat et al. (2021) discussed the dynamic modelling and control of a new hybrid power system with a fuel cell (FC) that can be combined with solar and wave energy, with battery banks as backup energy sources. It also maximizes the three sources' potential by utilizing a novel, fast, and precise buck-boost controller that controls the power conversion systems' maximum power. The battery bank will fuel the system directly if a source fails. varied properties of these sources allow testing the controller under varied conditions and developing a reliable power system. It has recently improved efficiency by adding Savonius turbines, previously used to generate wind energy. This study used a two-stage Savonius rotor in the wave generator. The full hybrid power system simulation model was created using MATLAB/Simulink and experimentally validated in a distant place under diverse meteorological conditions. The controller maintained the hybrid system voltage at 11.8V, close to 12V, with 98% efficiency. Kumar (2022) examined networked HWSES modelling and control best practices. A grid-connected Dual-Feed Induction Generator (DFIG) integrated with a solar PV system is connected to a DC-coupled cascade inverter for a Hybrid-Wind Solar Energy System to maximize energy tracking efficiency. Stator flow-oriented control regulated the grid and rotary side transformers. This study applies Maximum Power Point Tracking (MPPT) to wind and solar energy systems to maximize energy extraction and improve hybrid system integration into electric grids. A solar PV system with varying sun saturation is used to assess the performance and efficiency of the Perturb and Observe (P&O) and Incremental Conductivity (IC) MPPT algorithms. Tip Speed Ratio (TSR) and Optimum Torque (OT) MPPT algorithms are used for fluctuating wind speeds and compared to the hybrid system with a solar PV system. MPPT for optimal torque offers better reactions than TSR. MATLAB/Simulink was used to assess a 2MW HWSES simulation model. The implemented algorithms track HWSES' optimal power output rapidly and precisely. The provided systems also manage HWSES and utility network power, improving transient response and stability. Elkadeem et al. (2021) created a systematic and conceptual framework for site-appropriateness and optimal human resource system design decision-making in Kenya, and Sub-Saharan Africa. The suggested framework contains three phases. First, GIS and Best-of-Worst-Method (BWM) decision-making are used to investigate and spatially analyze prospective solar, wind, and hybrid wind system locations. The spatial investigation included 9 climatology, ecology, location, and geography parameters. Second, an Energy Economy-Environment (3Es) design optimization is being done to consider grid expansion, autonomous HRES, and freestanding diesel generator electrification systems for a sample distant rural hamlet in Kenya. Third, a post-optimization MCDM study determines and evaluates the ideal energy access design against 12 sustainability indicators. BWM determines indicator weights in the third stage. Next, the DPTDSPS and VIKOR procedures are employed to narrow down the options. Kenya's site suitability maps show that 0.91% (5322 km) and 1.5% (8828.4 km) are highly suitable, 10.25% (59,687 km) and 33.04% (192360 km) are suitable, and 80.5 % (470313) km2 and 65% (378,407 km2) are not permanently suitable for solar and wind energy systems. The system has the lowest net current energy costs at \$2.6 million and \$0.28 per kWh, avoids 804 tons of CO2 compared to diesel, and operates reliably with an unfilled load of 552 kWh/year as shown in Figure 1 HRES use (Elkadeem et al., 2021).

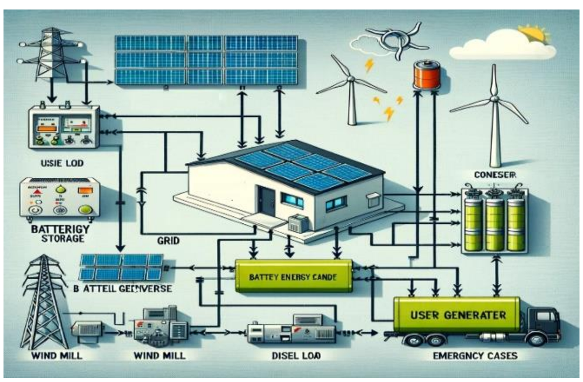

Figure 1: The use of a hybrid renewable energy system (HRES) (Elkadeem *et al.*, 2021)

Samy et al. (2020) evaluated the LCOE for a biomass-hydrogen fuel cell hybrid energy system to determine its crucial contributions and economic feasibility. LCOE was calculated using multi-objective particle swarm optimization. Installing two biomass generator sets, thirty-one fuel cells, sixty-five electrolyzers, and 186 hydrogen tanks cost 2,314,842 USD and had an LCOE of 0.335 USD/kWh.

Ammari et al. (2021) examined four key HRES categories: software and traditional sizing. Results showed that the software method was versatile and easy to use, however simplistic optimization equations limited it. Traditional methods solved multi-objective issues quickly but were difficult and inflexible optimisation with classical, artificial, and hybrid approaches. Classical approach findings indicated speed and efficiency but restricted optimization space. AI was efficient and accurate, but it required a complicated processing algorithm. Energy management goals (technical, economic, techno-economic). According to Mukhtar M. Salah et al. (2021), the Saudi government plans to generate 54 GW of renewable energy by 2032, investing \$108.9 billion. Due to Saudi Arabia's wide land area and wind speed fluctuation over regions and seasons, wind resource potential must be precisely assessed to maximize power output. Wind data from 12 meteorological stations in Saudi Arabia (KSA) was utilized to assess wind power generation potential. At heights of 10 m and 100 m, the mean wind speed of numerous sites in northern, central, and southern KSA was utilized to calculate Weibull parameters, depict wind frequency distribution, and calculate power density. The recorded 10 m wind speed is used to determine other height wind speeds numerically. Moment, least square, and maximum likelihood estimation methods estimate wind Weibull distribution parameters. The basic wind power equation calculates power density for all sites. As shown in Figure 2, the monthly and annual mean wind energy is estimated to determine each site's suitability for different wind turbines. Shayeghi et al. (2017) examined microgrid EMS DRP effects. A PV/WT/FC/MT/BESS model was examined. Cost and GHG emissions can be reduced using the Multi-Objective Group Search Optimization (MOGSO) algorithm. FDM was used to find the optimal compromise option after the Pareto fronts. Results showed that the suggested MOGSO is efficient and reduces costs more than GHG emissions. Wang et al. (2021) refined the grid-connected WT/PV/FC model. An enhanced GA was created to examine cost reduction. GA, PSO, and the non-dominated sorting genetic algorithm cost 18.7%, 17.1%, and 9.6% more than the upgraded GA. A heuristic-based programmable energy management controller (HPEMC) by Imran et al. (2020) could cut costs and GHG emissions. The ideal schedule was obtained using hybrid genetic particle swarm optimization (HGPO) using GA, ACO, BPSO, WDO, and BFA algorithms. HPEMC reduced PV/ESS costs by 25.55% and carbon emissions by 24.02%. Figure 2 Wind

Energy's Potential and Features Woldeyohannes et al. (2017) examined the benefits of wind turbines in Africa. They examined a case study of Africa to determine the benefits and sustainability of establishing wind energy plants there. Their analysis showed that installing wind energy farms in Africa helps maintain a green environment, reduce carbon emissions, increase clean and green electricity production, and make an effective economic investment with a lower payback period.

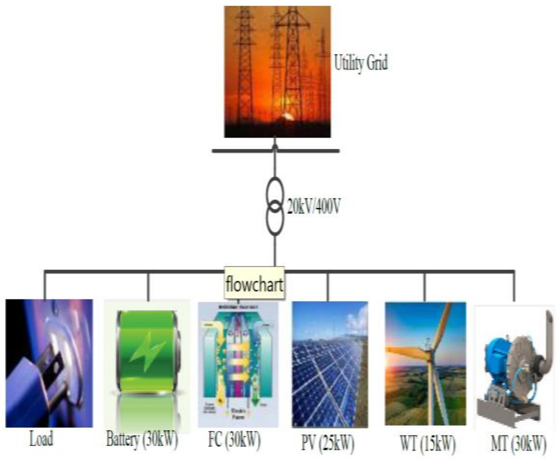

Figure 2: Understanding Migrogrid Shayeghi et al. (2017)

Kaldellis et al. (2011) reviewed wind energy systems' significance in sustainability and energy security. They analyzed many publications on wind energy systems' essential contributions and how they reduce fossil fuel use and pollution to achieve their study goal. The researchers identified California's wind energy system installation chances and challenges to reach 1,000 Gigawatts by 2030. Oliveira et al. (2012) examined wind energy economic, market, and industrial effects worldwide to identify notable developments and increases in wind farm installations and the wind energy market. They reviewed many research engines articles and publications to discuss the global effects of wind energy. Their investigation showed that wind energy has grown in importance over the last few decades, creating green jobs worldwide. Increased wind farm installation worldwide helped combat climate change, pollution, and other environmental challenges.

3. The Methodology

This paper proposes an approach to assess and develop renewable energy systems based on Machine Learning (ML) models and Artificial Intelligence (AI) paradigms. The main goal is to create hybrid renewable energy systems that are reliable as well as cost-effective, environmentally friendly, and economically viable. This paper evaluates the study of both dependent and independent variables to improve the feasibility, profitability, and economic benefits of these systems. The dependent variables in this study are added value and feasibility of the solutions based on renewable energy systems, while the independent variables are the robustness and performance of machine learning (ML) models and artificial intelligence (AI) algorithms. The Crocodile Hunting Search (CHS) algorithm, shown as a flowchart in Figure 3, begins with generating an initial population of random candidate solutions randomly distributed within the search space. Then the fitness of each candidate is calculated and evaluated about some objective function, and finally, we keep track of which is the best solution found so far.

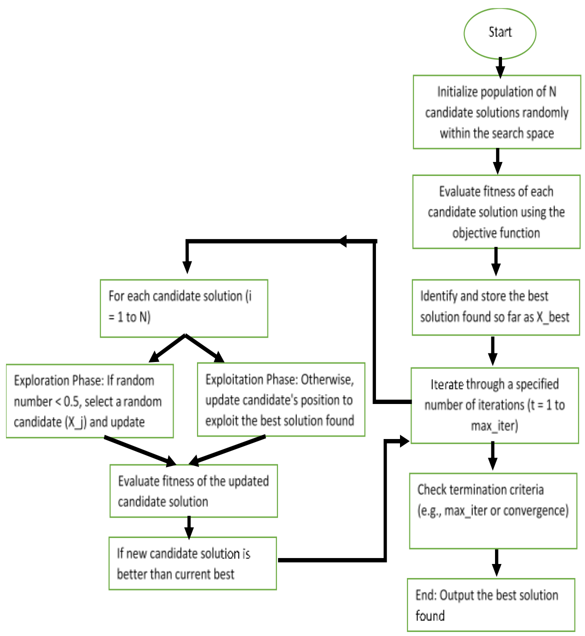

Figure 3: Crocodile hunting search algorithms (CHS)

The algorithm performs a fixed number of iterations. In the process of computing, each round divides candidate solutions into exploration or exploitation phases. During the exploration phase, candidates are always updated following the position of a randomly selected candidate, which ensures diversity in the search. Candidates reset their positions and refine the best-found solution so far to exploit the search domain; thus, convergence towards an optimal solution is promoted by a sequence of fine-tuning adjustments during this phase. The algorithm then evaluates the fitness of such an updated candidate solution. If a new candidate solution is better than the current best, then the best is set to be equivalent to the new one. This iterative process delivers a trade-off between an exploration and exploitation approach relying on adaptive techniques to tune the parameters according to search achievement. The algorithm terminates after maximum k iterations or achieves convergence criteria, returning the best solution we have obtained. This approach mimics the strategic hunting behaviour of crocodiles, effectively, navigating the search space to optimize complex problems. Researchers have assembled hybrid renewable energy technology by linking solar panels (PV), wind turbines (WT), batteries, and fuel cells (FC) into a MATLAB/Simulink framework. A standard PV power system delivers electrical energy from solar power with a standard size of 100 kW and produces a DC voltage output at 380 V under test condition standards. Wind turbines generate electric power automatically by capturing wind kinetics while delivering 120 kW at 12 m/s nominal wind speed but operation varies according to variable wind conditions. The storage battery setup provides 500 kWh power capacity along with 48 V DC output capability delivering 200 A peak current to support low renewable energy input conditions. As a backup power solution, the system runs at 60% efficiency producing 48 V DC with current levels between 20–160 A. All system components join together on a DC bus framework to establish integration possibilities between renewable power sources and storage units. The system implements bidirectional converters to regulate energy flow between storage devices and the DC bus network and distinct inverters transform DC voltage into AC power for grid consumption or load requirements. A detailed MATLAB/Simulink circuit diagram displays vital control mechanisms together with voltage regulation and system protection features. An appropriately designed control system functions as an essential instrument for managing the entire system. The crocodile hunting search (CHS) algorithm modifies power distribution arrangements in real-time to achieve optimal system performance. The control algorithm accepts information about solar irradiance and wind speed data, battery state of charge (SOC) and fuel cell operating conditions in real time. The system controls energy flow among PV, WT, batteries and FCs through command signals to achieve minimum system operations costs with reduced emissions and stable performance.

4. RESULT AND ANALYSIS

This paper compares the performance of different control strategies in optimizing fuel cell systems. The research analyzes the execution outcomes of four control tactics which include Equivalent Consumption Minimization Strategy (ECMS) and Classical State Machine Strategy (CSMS) as well as the Classical PI Control Strategy (CPICS) and Crocodile Hunting Search (CHS) algorithm under MATLAB/Simulink implementation. The ECMS achieves optimal fuel efficiency during immediate usage through precise component power distribution guided by established system dynamics and efficiency maps. Operational state transitions in the CSMS system follow predefined threshold criteria that include battery state of charge (SOC) and power demand specifications to determine the charging, discharging, or standby conditions. The CPICS implements proportional-integral (PI) controllers running system parameters such as voltage and current while achieving stability through predefined setpoints. The bio-inspired CHS optimization framework shapes power distribution through successive iterative processes which drive enhancement of performance criteria involving voltage stability and current stability combined with decreased fuel utilization. The MATLAB/Simulink program modelled a hybrid renewable energy system that joined PV panels with wind turbines along with batteries and a fuel cell through a DC bus to test control methodologies. Vehicle equipment specifications including PV capabilities battery State-of-Charge levels and fuel cell operational efficiency were implemented into testing with solar energy and wind power profiles and power requirements as system inputs. Program performance assessment utilized key metrics such as fuel usage and system current stability and voltage behavior stability as judgment criteria. The strategies' adaptation and enhancement processes utilized previous research findings to both maintain valid applicability and optimize effectiveness for fulfilling the study's goals.

ECMS (orange): Initially, the current rises rapidly, reaching around 200A at 50 seconds and maintaining this level until about 240 seconds before dropping as shown in figure 4.

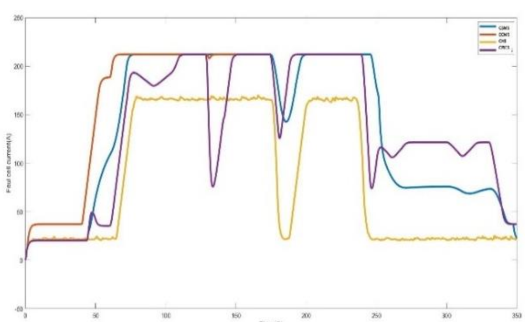

Figure 4: Fuel Cell Current Over Time

CSMS (blue): Shows a steady increase, peaking around 240A, but with fluctuations.

CPICS (purple): Exhibits significant fluctuations, indicating less stable control.

CHS (yellow): Maintains a steady current around 10A with minimal fluctuations, indicating stable performance. CHS shows the most stable current profile, suggesting efficient and consistent current management.

Figure 5 represents fuel consumption (lpm) over time. ECMS (orange): Shows an initial rise, reaching a peak of 90 lpm, maintaining this level before fluctuating significantly. CSMS (blue): Exhibits similar behaviour to ECMS but with higher peaks. CPICS (purple): Fluctuates widely, indicating inconsistent fuel consumption. CHS (yellow): Maintains stable fuel consumption around 10 lpm, highlighting efficient fuel use. Key Insight: CHS demonstrates the most efficient and stable fuel consumption, crucial for fuel cell longevity and performance.

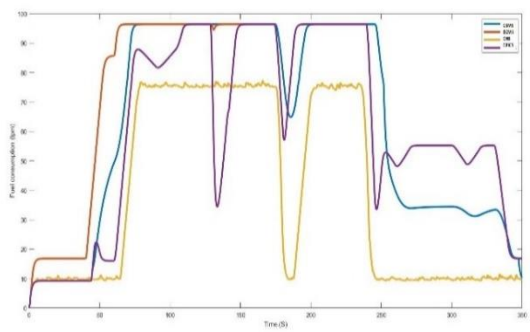

Figure 5: Fuel Consumption Over Time

Figure 6 shows the power split control (PSC) over time for the four strategies. ECMS (orange) and CSMS (blue): Show significant fluctuations, reflecting less stable power split control. CPICS (purple): Also exhibits considerable variability. CHS (yellow):

Maintains more consistent control, with fewer fluctuations. CHS offers a more stable PSC, crucial for effective power distribution and System efficiency.

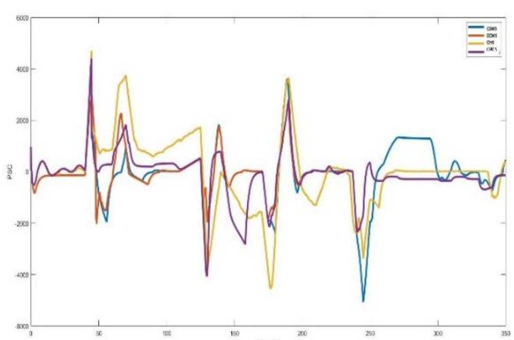

Figure 6: PSC Over Time

Figure 7 illustrates the battery power (Pbatt) over time. ECMS (orange): Displays significant peaks and troughs. CSMS (blue): Similar fluctuations, indicating unstable battery power management.

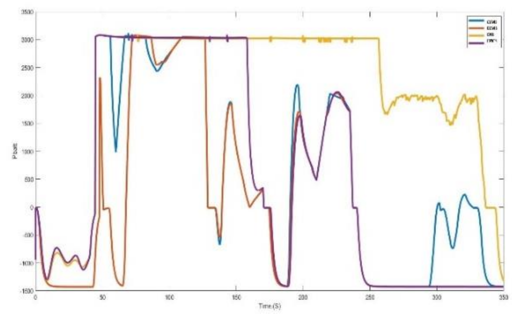

Figure 7: Battery Power Over Time

CPICS (purple): Shows erratic behaviour. CHS (yellow): Exhibits more consistent power management, with fewer fluctuations. Key Insight: CHS provides the most stable battery power management, essential for overall system reliability.

Figure 8 shows the fuel cell voltage (V) over time. ECMS (orange): Voltage drops initially and fluctuates significantly.

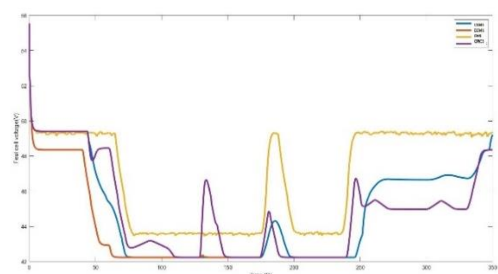

Figure 8: Fuel Cell Voltage Over Time

CSMS (blue): Similar fluctuations. CPICS (purple): Shows significant variability. CHS (yellow): Maintains a relatively stable voltage of around 48-49V.

CHS shows better voltage stability and; hence, better power output. ECMS and CSMS: Both show good initial performance but suffer from large fluctuations in current, fuel consumption, PSC, and battery power. This, hence, indicates less stability and effectiveness. CPICS: Erratic behaviour is seen for all parameters, which also indicates its inconsistent performance and lack of control. CHS: Those hybrid controllers show good, stable performance for all parameters—current, fuel consumption, PSC, battery power, and voltage. This shows the salient effectiveness of giving reliable and effective control in hybrid renewable energy systems.

5. Conclusions

The performance of the CHS-based microgrid optimization was analyzed in renewable energy-driven microgrids during continuous operation and was compared with the ECMS (Equivalent Fuel Consumption Minimization Strategy), CSMS (State Machine Control Strategy), and CPICS (Classical PI Control Strategy). For the study, a configuration of the hybrid renewable energy system coupled with a fuel cell to store excess electricity from the wind and solar photovoltaic resources was considered.
The simulation in MATLAB and Simulink was performed for the analysis of the numerical simulations of the fuel cell voltage, fuel current, and PSC, and also the battery power and fuel cell consumption. Fuel Cell Current: The CHS algorithm demonstrated good and stable management by holding the fuel cell current nearly constant with minimal noise. The other strategies were characterized by much less systematic (often negative) change, which was usually unstable.

Fuel Consumption: CHS had the most consistent and efficient fuel consumption profile, which is crucial for the durability and performance of the fuel cell. Variability was common in the fuel consumption trends, with significant oscillations observed by ECMS, CSMS, and CPICS.

Power Split Control (PSC): The improved design provides steadier Power Split Control (PSC) with reduced oscillations, helping to keep the gas engine in its peak efficiency band more of the time. The power-management side of things fluctuated even more on the other strategies.

Battery Power Stability: CHS gave the smoothest battery power management with minimal spikes and dips that disrupted system availability. The other techniques were more inconsistent in terms of battery management.

Cell Voltage: CHS achieved robust cell voltage while ECMS, CSMS, and CPICS had severe fluctuations.
The results indicate that the proposed CHS algorithm can maintain above-average default values when compared with other control strategies, making it an effective and robust solution for controlling the hybrid renewable energy system. The CHS is thereby illustrated as a strong candidate to be used for efficient solutions in the setup of renewable-based microgrids, such that good power supply assurance, resource effectiveness, and enhanced system stability could be guaranteed. Additional research would be necessary to fine-tune and validate the CHS approach concerning various renewable energy system layouts, under different real-world conditions.

References

[1]. Imran, A., Hafeez, G., Khan, I., Usman, M., Shafiq, Z., Qazi, A. B., & Thoben, K. D., “Heuristic-based programable controller for efficient energy management under renewable energy sources and energy storage system in smart grid,” IEEE Access, vol.8, pp.139587-139608,2020.
[2]. Alam, A., & Mehar, M. V., “Hybrid Renewable Energy System Integration with,”, vol., pp.-,2021.
[3]. Amine, K., “Multiobjective simulated annealing: Principles and algorithm variants,” Advances in Operations Research, Article ID 8134674, pp.1-13,2019.
[4]. Cabana-Jiménez, K., Candelo-Becerra, J. E., & Santos, V. S., “Comprehensive Analysis of Microgrids Configurations and Topologies. Sustainability (Switzerland),” https://doi.org/10.3390/su14031056, vol.14(3), pp.1-25,2022.
[5]. Chang, T.-P., Liu, F.-J., Ko, H.-H., Cheng, S.-P., Sun, L.-C., & Kuo, S.-C., “Comparative analysis on power curve models of wind turbine generator in estimating capacity factor. Energy,” doi:10.1016/j.energy, vol.73, pp.88-95,2014.
[6]. Chen, X., Ju, Y., & Zhang, R., “Land-sea relay fishery networked microgrids under the background of cyber-physical fusion: Characteristics and key issues prospect. Information Processing in Agriculture,” https://doi.org/10.1016/j.inpa.2021.02.002, 9(1), pp.159-169,2022.
[7]. Elkadeem, M. R., Younes, A., Sharshir, S. W., Campana, P. E., & Wang, S. (2021). Sustainable siting and design optimization of hybrid renewable energy system: A geospatial multi-criteria analysis. Applied Energy, 295, 117071. doi: 10.1016/j.apenergy.2021.11707’
[8]. Gaona, E. E., Mancera, P. A., & Trujillo, C. L. (2016). sensores inalámbricos aplicada a una Microrred en modo “ Isla ” Routing Algorithm with topology reconfiguration for Wireless Sensor Network applied to microgrid in Island mode. Revista UIS Ingenierías, 15(2), 93–104.
[9]. Komala, K., Kumar, K. P., & Cherukuri, S. H. C. (2021). Storage and non-storage methods of power balancing to counter Uncertainty in Hybrid Microgrids - A review. Journal of Energy Storage, 36. https://doi.org/10.1016/j.est.2021.102348
[10]. Kareem, Shahab Wahhab. "A nature-inspired metaheuristic optimization algorithm based on crocodiles hunting search (CHS)." International

Journal of Swarm Intelligence Research (IJSIR) 13.1 (2022): 1-23.

[11]. Kareem, S. W., Ali, K. W. H., Askar, S., Xoshaba, F. S., & Hawezi, R. (2022). Metaheuristic algorithms in optimization and its application: A review. JAREE (Journal on Advanced Research in Electrical Engineering), 6(1).

[12]. Kareem, S. W., Mohammed, A. S., & Khoshabaa, F. S. (2023). Novel nature-inspired meta-heuristic optimization algorithm based on hybrid dolphin and sparrow optimization. International Journal of Nonlinear Analysis and Applications, 14(1), 355-373.

[13]. Limpinsel, M., Kuo, D., & Vijh, A. (2018, June). SMARTS Modeling of Solar Spectra at Stratospheric Altitude and Influence on Performance of Selected III-V Solar Cells. IEEE 7th World Conference on Photovoltaic Energy Conversion (WCPEC) (A Joint Conference of 45th IEEE PVSC, 28th PVSEC & 34th EU PVSEC) (pp. 3367-3373). IEEE.

[14]. Martin-Martínez, F., Sánchez-Miralles, A., & Rivier, M. (2016). A literature review of Microgrids: A functional layer based classification. Renewable and Sustainable Energy Reviews, 62, 1133–1153. https://doi.org/10.1016/j.rser.2016.05.025

[15]. Ma, R., Kareem, S. W., Kalra, A., Doewes, R. I., Kumar, P., & Miah, S. (2022). Optimization of electric automation control model based on artificial intelligence algorithm. Wireless Communications and Mobile Computing, 2022.

[16]. Murty, V. V. S. N., & Kumar, A. (2020). Multi-objective energy management in microgrids with hybrid energy sources and battery energy storage systems.

[17]. Nelson V., Starcher K. (2018). Wind Energy: Renewable Energy and the Environment. Reading: Textbook. Third edition. Publisher: CRC Press.

[18]. Sher, F., Curnick, O., & Azizan, M. T. (2021). Sustainable Conversion of Renewable Energy Sources. Sustainability, 13(5), 2940. doi:10.3390/su13052940

[19].Sayegh E. Shahryar (2017). Optimal Operation Management of Grid-connected Microgrid Using Multi-Objective Search Optimization Algorithm, Journal of Operation and Automation in Power Engineering.

[20]. Talaat, M., Elgarhy, A., Elkholy, M. H., & Farahat, M. A. (2021). Integration of fuel cells into an off-grid hybrid system using wave and solar energy. International Journal of Electrical Power & Energy Systems, 130, 106939. doi: 10.1016/j.ijepes.2021.106939

[21]. Talaat, M., Farahat, M. A., & Elkholy, M. H. (2019). Renewable power integration: experimental and simulation study to investigate the ability to integrate wave, solar and wind energies. Energy, 170, 668-682.

[22]. Vairagi, B. D., Tandon, A., & Dewra, R. S. (2017). Performance Analysis of DFIG Based Standalone 2.2 kW Laboratory Prototype Wind Turbine Emulator. Journal of Scientific Approach, 1, 16-21.