Communications on Applied Nonlinear Analysis
ISSN: 1074-133X
Vol 32 No. 2s (2025)

A Multi-Objective Energy Optimization Model for Renewable Energy Systems with Hybrid Energy Storage

Dr. Shailesh Madhavrao Deshmukh[1], Charpe Prasanjeet Prabhakar[2]

[1]Assistant Professor, Department of Electrical, Kalinga University, Raipur, India.
ku.shaileshmadhavraodeshmukh@kalingauniversity.ac.in

[2]Department Of Electrical And Electronics Engineering, Kalinga University, Raipur, India

Article History:

Received: *01-09-2024*

Revised: *11-10-2024*

Accepted: *28-10-2024*

Abstract:

Building a Renewable Energy System (RES) is a viable way to address resource depletion and accomplish decarbonization. This study presents a hybrid power system that combines wind, solar, battery, and thermal energy storage. It also examines the co-optimization of scheduling and operation for multiple objectives. The hybrid system combines the affordability of thermal energy storage (TES) with the adaptability of batteries to effectively address the issue of intermittent RES. A new approach for integrated operation is offered, which relies on the electrical block's operation limit. The planning-operation co-optimization system considers minimizing the Net Present Cost (NPC) and reducing power supply likelihood todetermine the best operation limit and sizing decision factors. The co-optimization issue is addressed using novel multi-objective decision-making (MO-DM). This approach incorporates the Decision-Maker (DM) preferences data to direct the evolutionary process toward the desired area. In addition, a data-driven prediction model captures the risks and losses associated with wind generation. The case study's findings indicate the following: (1) The data-driven system has a higher level of precision in wind power projection when compared with commonly used physical simulations. (2) The suggested MO-DM exhibits superior integration, variety, and robustness achievement in the DMchosen area compared to others. (3) The combined battery-thermal energy storing structure achieves improved economy and dependability through the optimum organized operation approach, in contrast to using a single energy storage system under various testing constraints..

Keywords: Multi-Objective Optimization, Renewable Energy Systems, Energy Storage, Decision-Making.

1. Overview of the Renewable Energy Systems and Hybrid Energy Storage

China announced in 2020 its commitment to limit carbon emissions and attain carbon neutrality by 2030 and 2060. These aggressive carbon emission objectives are anticipated to stimulate the growth of Renewable Energy Sources (RES) production in this rapidly advancing nation[1]. China has established a long-term objective in RES to surpass 1200 GW of overall installed capability via wind power and photovoltaics (PVs) by 2030. RES has the benefit of reducing CO_2 emissions but also presents power system operation and management issues due to generating instability. This leads to distribution congestion, increased strain on the grid, and a possible power decrease. Hence, thoroughly examining the design and functioning of energy systems, including wind and solar power, is essential.A robust simulation framework was developed to facilitate the transmission of backhaul energy from its source to its destination [2].

The escalated use of fossil fuels has led to environmental damage, prompting the development of eco-friendly RES alternatives. RES has issues with inconsistent power supply caused by weather conditions and seasonal fluctuations.To overcome this restriction, many sustainable energy sources are combined in a hybrid RES (HRES) architecture [22]. Considering its unique operational characteristics, the integration allows for greater efficiency than using a single RES. Because of this benefit, the HRES architecture is gaining popularity as a solution to satisfy future demand. HRES also provides a promising approach to achieving energy intensification by combining different processes and energy sources to ensure an ongoing energy supply. Designingan HRES encompasses many factors, including determining the appropriate size and rating of elements, establishing the mode of functioning, choosing materials that enhance system dependability, and reducing system cost and emissions. The abundance of space for operation often leads to a complex Decision-Making (DM) scenario where various goals must be carefully balanced [3]. Moreover, the issue formulation encompasses difficulties such as parameters with non-linear motion, necessitates the acquisition of optimum trajectories of control parameters in real-time amidst unpredictability, and entails additional complicating elements. Hence, achieving the multi-objective optimization of HRES is complex.

Multi-objective optimization yields a collection of equally optimal options that reflect a balance between many goals [4]. Evolutionary methods are frequently employed to solve multi-objective optimization problems. They are favored for simultaneously considering various goals and handling non-linearities. Traditional algorithms like weighted sum optimizing need several iterations to provide the whole trade-off.A methodology is presented in this article to find insecure code through the extraction of APIs utilizing a hybridization of machine learning techniques[21].Over the past few years, electric vehicles (EVs) have assumed a more prominent position within modern smart cities. Within the realm of electric vehicles (EVs), it is logical to include electric bicycles (e-bikes), which have experienced a rapid proliferation over the past decade [23].

The following sections are listed as follows. Section 2 illustrates the background and literature survey of the multi-objective optimization of RES. Section 3 proposes multi-objective decision-making for hybrid RES. The software analysis and outcomes are listed in section 4. Section 5 concludes the research and discusses the future scope.

2. Background and Literature Survey

An HRES comprises several additional RES and ESS systems. It is extensively studied in distant regions that lack connectivity to the primary power grid. HRES utilizes many ES methods, including Battery Energy Storage (BES), pumping hydro storage, TES, pressurized air energy storage, and hydrogen preservation. Mehmoodet al. thoroughly examined various ESS techno-economic and environmental evaluations to provide an up-to-date overview of their development condition [5]. In energy-constrained network, the reduction of energy usage associated with data acquisition is a critical concern [6].Data clustering is achieved through the utilization of four models in order to enhance energy-saving systems [25].

They also compiled a database including information on costs and pollutants. Cortés-Caicedoet al. examined the most effective approaches and methods for determining the appropriate ESS size to reduce carbon emissions in microgrid applications [24]. Hossainet al. thoroughly analyzed the advancements and potential of several ESS technologies [7]. They also examined the comparisons and constraints of multiple ESS techniques. Hosseinpouret al. provided a concise summary of the positive and negative aspects of several ESS methods and sets of measuring measures for making quantitative assessments [8]. El Hassaniet al. introduced a new molten salt TES design and confirmed its practicality in HRES via a techno-economic evaluation [9].Gaoet al. performed a quantitative techno-economic analysis comparing four shared ESS techniques [10]. The analysis focused on the optimum scaling of HRES. The study showed molten salt TES was the most economically efficient choice. Jafariet al. forecasted the average cost of storing energy in nine different technologies in other applications for power systems from 2015 to 2050 [11]. The Lithium-ion battery will likely be the most economically effective storage option after 2030.

Several research studies are now being conducted on the operation administration and scheduling optimization of HRES. Pattnaiket al. examined the synchronizedoperation method for battery Pumped Hydro Storage (PHS) in a freestanding wind-PV hybrid system [12]. They introduced a new rule-based operational approach that relies on the minimal part-load operating state of the bidirectional turbines. Atawiet al. developed an improved energy control method for a grid-connected battery-PHS system, considering the distribution factor throughout the charging process [13].Hu et al. examined the most efficient functioning of a grid-connected battery-TES system [14]. This system saved power from the electrical grid throughout off-peak hours and released it during peak periods to save costs. Moduet al. optimized a lifetime sizing of an HRES that used battery and hydrogen storage [15]. The issue of optimization was formulated as a mixed integer linear programming issue and addressed using the brand-and-cut approach. Liu et al. conducted a study to evaluate the technological and economic aspects of PV-concentrated solar power hybridization plants with molten salt TES and large-scale batteries [16]. They determined that a solar power scheme with battery-TES showed promise for generating electricity for continuous base load demand. Premadasaet al. introduced a multi-objective scaling optimizing approach for a PV-diesel hybrid engine [17]. This approach considers operating reserves to address the challenges posed by resource and load unpredictability. Sharmaet al. introduced a deterministic multi-objective optimization technique that utilizes scenario dominance to develop HRES [18]. Singhet al. introduced a multi-objective optimizing method considering socio-techno-economic factors [19]. Fenget al. suggested a multi-objective sizing technique incorporating technical, financial, ecological, and socio-political goals [20]. The existing literature primarily focuses on individual aspects of operations administration or size optimization, with little research.

3. ProposedMulti-Objective Optimisation for HRES

The system consists of wind and PV farms, conversions, batteries, an Electric Heater (EH) that uses resistive heating, a two-tank melting salt thermal energy storage system, and an electrical block that operates on a steam Rankine cycle. An AC/DC converter links the wind farm and energy block to the DC bus by an AC/DC converter. The battery pack is related to a bi-directional DC/DC conversion. All other elements are connected to a DC/AC converter. Wind and PV power are the primary forms of electricity production. To address the issue of intermittency and uncertainty in alternative energy sources, a Hybrid Energy Storage System (HESS) consisting of batteries and TES is used. The HESS operates under an integrated method that controls the imbalance between RES and power demand, enhancing the grid's dependability. The hybrid ESS system is shown in Fig. 1.

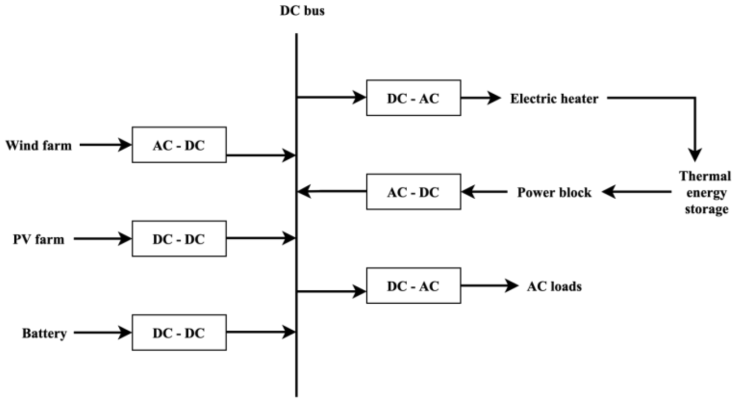

Fig. 1. Hybrid ESS system

3.1 Theory and Methodology

The technique considers the grid power balance and evaluates the techno-economic capabilities of HRES under multi-objective situations. The formulation of multi-objective optimizing situations is based on objectives that pertain to economics, dependability, and reliability of the grid. The initial scenario involves bi-objective works, namely the Cost Of Energy (COE) and the proportion of RES, without considering grid balancing concerns.

The second situation encompasses tri-objective operations, including COE, RES fractions, and the Energy Export Indicator (EEI), which considers the grid balancing. The HRES designs include solarPV panels and horizontal-axisWind Turbines (WT). The ESS consists of a battery and PHS, which serve as short-term and long-term energy storage systems. The expense of incorporating the grid is considered by using the net-metering pricing structure. A genetic algorithm is employed to address these multi-objective optimizing situations, and the resulting optimization outcomes are then evaluated to determine the compromiseamong techno-economic and grid balancing factors. The primary goal is to examine the function of short and long-term battery storage in enhancing the integration of HRES by reducing grid imbalances. This technique will deliver instructions for improving the incorporation of HRES with the current grid architecture as shown in Fig. 2.

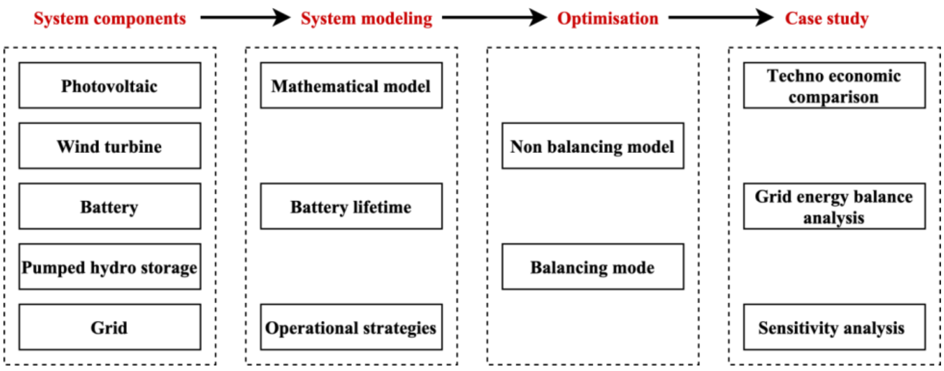

Fig. 2. Multi-objective model for HRES

3.2 System description and assumptions

The energy system comprises wind and solar materials and the potential for importation from the public grid. The energy inputs are transformed or controlled inside the system to meet the power demand. Any extra electricity is stored in the ESS to address the discrepancy between the amount of RES produced and the power needed. If there is still a surplus of RES in the electrical system, itis resold to the public network. The previous methods of WT, PV, lithium-ion batteries, and predicted technique of load needs were utilized. The energy system operated on the underlying assumptions:

(1) Wind and solar power production and load consumption relied on historical information instead of expected values.

(2) The output of RES and the need for load remained constant.

(3) Adequate land is available for constructing WT, PV systems, and ESS.

(4) The electricity network can consistently provide or use any excess or lack of power in the studied electricity system, and its ability to connect with the general grid is adequate.

3.3 Energy Management Strategy

The Energy Management Strategy (EMS) integratesenergy-producing and storage technologies with the electrical grid. Hence, it is an essential component in the planning, functioning, and enhancement of HRES since it aids in managing the sporadic nature of energy generation and ensuring a dependable supply of energy. This research applies a load-following technique using a simple rule-based EMS to optimize the meeting of demand by effectively controlling the energy flow within the integrated systems.

Case 1: Without an ESS, the energy produced is directly used to fulfill the energy requirements. During periods of surplus supply, the extra power is immediately supplied to the grid. Conversely, when there is a shortage in RES, energy comes in from the network.

Case 2: Single ESS: The EMS incorporates supplementary parameters that monitor the State of Charge (SoC) of the ESS. During periods of surplus supply, the ESS charges if the SoC is below the highest SoC.During periods of supply shortage, the ESS empties to satisfy customer demand if the SoC is above the lowest SoC. The grid is utilized when the ESS is wholly charged or released.

Case 3: The optimal energy distribution for a hybrid design is established depending on the ESS features. This research employs a battery as a short-term ESS and PHS as a long-term ESS. The battery is first charged or drained, then the PHS is used. It takes a significant amount of time for PHS to begin producing energy. The battery is designed to fulfill the energy requirements during the 4-minute delay period of PHS.

3.4 Optimization algorithm

This study presents a sophisticated Pareto-based multi-objective method incorporating a DM operation to steer the population into the desired regions. The suggested multi-objective system with DM is built using the (u+u) elitist approach.

3.4.1 General framework of multi-objective DM

The parent group is formed randomly. Second, the binary event approach chooses parent individuals for mating. A genetic operator is used to generate offspring people. Next, the combined population of parents and their offspring people is assessed based on the Pareto-based non-dominated rank, preferred DM level, and weighed length. Next, the ecological selection method is used to choose the new parent group for the next iteration, using the overall ranking as the basis for choice. The techniques above iterate until the permitted number of repetitions is reached and provide the Pareto front set afterward.

3.4.2 Decision-making criterion

The main innovation of MO-DM is the incorporation of DM criteria into the ecological selecting operator, which directs the development of the community into a desired location. The DM criteria are often used to choose the most favorable compromise option from the Pareto front based on the decider's preferences or acceptable minimum/maximum limits. The suggested MO-DM utilizes selection criteria to assess the desired level of every person and direct the population's development into the selected location. The preferred level of the xth person, PD(x), is defined as follows:

$$PD(x) = \sum_{i=0}^{N_O} (O(x,i) - O(i)) \quad (1)$$

The variable $N_O$represents the number of goals, whereas $O(i)$ is the acceptable limit of the ith goal.

3.4.3 Weighted distance

The weighted length and packed distance serve the same purpose of maintaining variety. The crowded distance measure has a possible weakness: it does not favorselecting individuals with a significantly closer crowded separation, which is not beneficial for maintaining population variety. A weighted length measure effectively overcomes the limitation above. This metric has been defined as follows:

$$WD(x) = \sum_{i=0}^{N-1} \frac{D_{ix}|D_{ix} - \widehat{D}_{ix}|}{\sum_{i=0}^{N-1}|D_{ix} - \widehat{D}_{ix}|} \quad (2)$$

The weighted separation of the xth individual, denoted as WD(x), is calculated using the Euclidean separation, D_{ix} , of the i-nearest neighbor from the xth single. N is the total length of the neighborhood, and $\widehat{D}_{ix}$ is the average of all D_{ix} values.

4. Simulation Analysis and Findings

The wind-PV-battery-TES hybrid energy system is planned for development in Karachi, Pakistan. Karachi has ample wind and solar resources, with a yearly average wind speed of 7.44 m/s and sun irradiation of 228.48 W/m2. The research addressed a multi-objective optimization issue, which included solving 21 scenarios with varying RES shares (ranging from 0% to 200% in increments of 10%). The optimization process considered two metrics: total cost and self-sufficiency. The optimization outcomes were shown and examined. The study investigated the influence of the proportion of RES on the storage capacity of the ESS in the final optimum solutions. An analysis was conducted to evaluate the effect of the suggested scheduling approach on the energy network's efficiency.

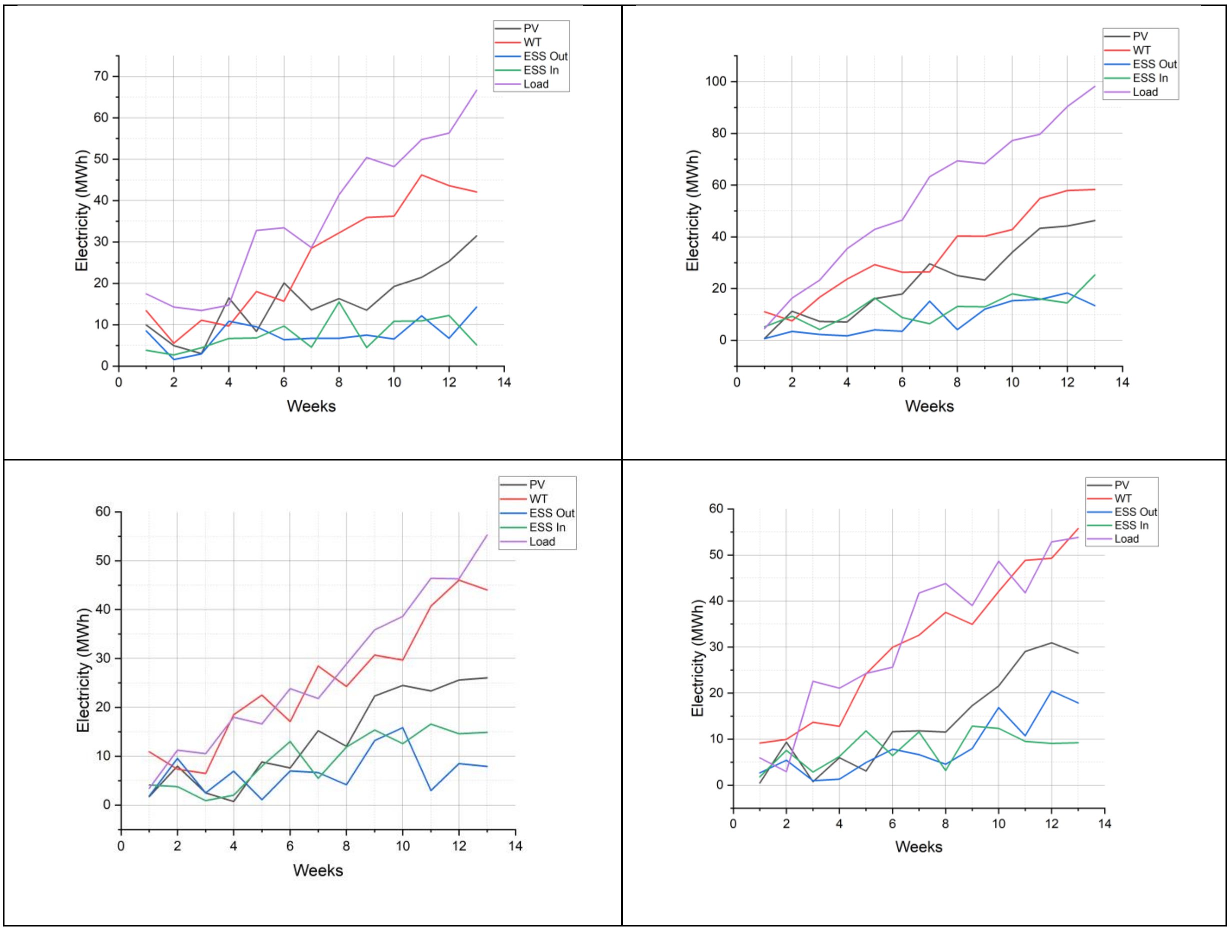

Fig. 3. Electricity (MWh) analysis (a). Spring, (b). Summer, (c). Autumn, and (d). Winter

Fig.3 illustrates how these common scenarios elucidate the underlying factors contributing to varying ESS capacities about varied proportions of RES. When the percentage of RES is below 40%, the weekly power output from RESneeds to be increased to meet the hourly demand. In this particular scenario, the construction of an ESS cannot offset the power supply deficit from the energy system, resulting in the decision not to build an ESS. The RES adoption rate must surpass 60% beforeinstalling an ESS. This study reveals a discrepancy in the findings since prior research only focused on off-grid energy systems and prioritized cost optimization exclusively. The generation of wind and solar energy is closely tied to the amount of capacity built. The output of ESS is determined by the difference between the energy generated by RES and the energy needed to meet demand.

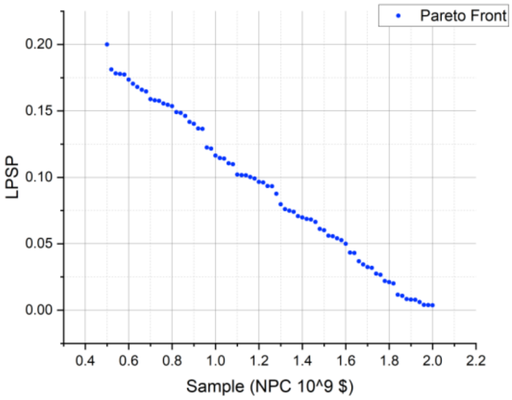

Fig. 4. Pareto front analysis of LPSP

The enumeration approach is highly computational for generating the global optimal solutions in an 8-dimensional decision area. Therefore, Monte Carlo simulation is used for sampling the decision space and verifying the concurrent state of the Pareto front achieved by the suggested MO-DM. Figure 4 displays the Pareto fronts with the highest hypervolume for Levelized Cost of Energy (LCOE) for Pumped Storage Power (LPSP). Red circles highlight the Pareto front completed by MO-DM. The Pareto front completed by MO-DMefficiently converges to the desired area based on the DM choice, confirming the efficiency and efficacy of the suggested MO-DM.

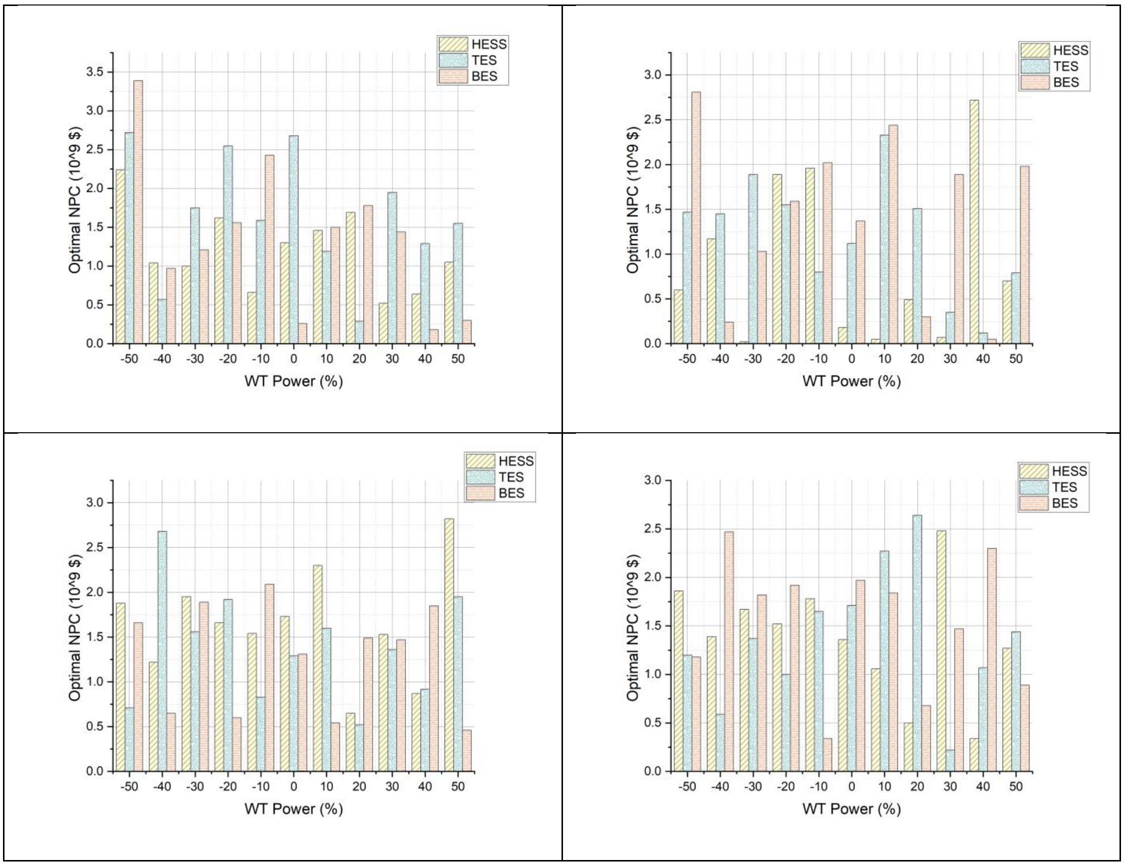

Fig. 5. Optimal Net Present Cost (NPC)analysis (a). Spring, (b). Summer, (c). Autumn, and (d). Winter

Fig. 5 shows the optimal NPC analysis of spring, summer, autumn, and winter. the ideal NPC drops rise as the WT and PV power levels grow. This suggests that more incredible RESresults in improved economic performance. When the amount of RESis reduced by 25%~50%, the ideal NPC of BES is lower than that of TES, suggesting that BES provides more cost-effectiveness in low-resource locations. The key finding is that the perfect NPC of HESS is consistently lower than that of TES and BES for any variation in RES, thereby verifying the correctness of the optimization findings mentioned above.

The ideal NPC of a HESS rises when the cost of ESS increases. The outstanding NPCs in TES and The BES are more responsive than those in HESS to changes in ESS costs. When the TES or BES costs increase, HESS offers more ES alternatives to manage overall costs. The maximum NPC value of HESS is consistently lower than that of both TES and BES. When the cost of BES lowers by 50%, the ideal NPC of both HESS and BES becomes almost identical since including TES in HESS is not economically advantageous. When BES costs grow by 50%, the NPC of HESS and TES become practically equal. This is because the inclusion of BES in HESS becomes prohibitively costly.

5. Conclusion and Discussion

The study examines the co-optimization of scheduling and operation for aRES that combines wind and PV sources with a hybrid battery-TES system. A data-driven model is used to predict wind power, considering the uncertainties in real-world operations. A strategy for coordinating operations, which relies on the power block's operation thresholds, is suggested. A techno-economic co-optimization model is then formulated, consideringminimizingthe net present price and the likelihood of power supply loss. This model is used to determine the best operation limit and sizing factors. The suggested MO-DM successfully solves the multi-objective co-optimization issue and then conducts sensitivity assessments under various test scenarios. Based on the findings, the following inferences were made.

(1) The Pareto front achieved by the proposed MO-DM can be efficiently converged to the desired region based on the DM choice. MO-DM demonstrates superior integration, variety, and robustness within the DM-chosen region, thereby confirming its efficacy and a sense of superior

(2) The analysis of HESS and unattached energy storage reveals that HESS decreases the NPC by 5.2% and 10.4% compared to TES and battery while adhering to the LPSP 6% constraint. This suggests that the suggested HESS can effectively utilize the economics of TES and the adaptability of the battery concurrently, resulting in improved economic effectiveness and dependability through optimally planned operation tactics.

(3) The sensitivity studies conducted on various technical variables, demand for load, RES stage, and energy storage cost factors demonstrate that HESS is more economically efficient than single energy storage systems under diverse test scenarios. This confirms the accuracy and reliability of the optimization findings.

The suggested hybrid energy storage system is viable and economical for many uses. The multi-objective co-optimization approach is used in various situations. Future research will be enhanced by including sophisticated load prediction techniques, long-term operating simulations that account for degradation rates, and addressing diverse load demand areas.

References

[1] Gajdzik, B., Wolniak, R., Nagaj, R., Grebski, W. W., & Romanyshyn, T. (2023). Barriers to Renewable Energy Source (RES) Installations as Determinants of Energy Consumption in EU Countries. Energies, 16(21), 7364.

[2] Zahra, M. M. A., & Abdul-Rahaim, L. A. Performance of RoF-MMW-WDM Backhaul System based on Hybrid Optical OFDM Transportation Enabling 128-QAM Format for B5G Communication Networks. J. Internet Serv. Inf. Secur., 12(4), 164-176.

[3] Ridha, H. M., Hizam, H., Mirjalili, S., Othman, M. L., Ya'acob, M. E., &Ahmadipour, M. (2023). Innovative hybridization of the two-archive and PROMETHEE-II triple-objective and multi-criterion decision making for optimum configuration of the hybrid renewable energy system. Applied Energy, 341, 121117.

[4] Sharma, R., Kodamana, H., & Ramteke, M. (2022). Multi-objective dynamic optimization of hybrid renewable energy systems. Chemical Engineering and Processing-Process Intensification, 170, 108663.

[5] Mehmood, A., Ren, J., & Zhang, L. (2023). Achieving energy sustainability by using solar PV: System modelling and comprehensive techno-economic-environmental analysis. Energy Strategy Reviews, 49, 101126.

[6] Khedr, A.M., Raj, P.P., & Al Ali, A. (2020). An Energy-Efficient Data Acquisition Technique for Hierarchical Cluster-Based Wireless Sensor Networks. Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications (JoWUA), 11(3), 70-86.

[7] Hossain, M. S., Kumar, L., El Haj Assad, M., &Alayi, R. (2022). Advancements and future prospects of electric vehicle technologies: a comprehensive review. Complexity, 2022, 1-21.

[8] Hosseinpour, M., Osanloo, M., & Azimi, Y. (2022). Evaluation of positive and negative impacts of mining on sustainable development by a semi-quantitative method. Journal of Cleaner Production, 366, 132955.

[9] El Hassani, S., Oueslati, F., Horma, O., Santana, D., Moussaoui, M. A., &Mezrhab, A. (2023). Techno-economic feasibility and performance analysis of an islanded hybrid renewable energy system with hydrogen storage in Morocco. Journal of Energy Storage, 68, 107853.

[10] Gao, Q., Bechlenberg, A., Jayawardhana, B., Ertugrul, N., Vakis, A. I., & Ding, B. (2024). Techno-economic assessment of offshore wind and hybrid wind–wave farms with energy storage systems. Renewable and Sustainable Energy Reviews, 192, 114263.

[11] Jafari, M., Botterud, A., & Sakti, A. (2022). Decarbonizing power systems: A critical review of the role of energy storage. Renewable and Sustainable Energy Reviews, 158, 112077.

[12] Jarad, Fahd. "A Special Issue in the Honor of the 55th Birthday of Dumitru Baleanu." Results in Nonlinear Analysis 2.4 (2019): 147-148.

[13] Pattnaik, A., Dauda, A. K., & Panda, A. (2023). Optimal utilization of clean energy and its impact on hybrid power systems incorporating STATCOM and pumped hydro storage. Renewable and Sustainable Energy Reviews, 187, 113713.

[14] Atawi, I. E., Abuelrub, A., Al-Shetwi, A. Q., &Albalawi, O. H. (2024). Design of a wind-PV system integrated with a hybrid energy storage system considering economic and reliability assessment. Journal of Energy Storage, 81, 110405.

[15] Hu, Y., Qiao, L., Gu, F., & Fathi, G. (2023). Comprehensive energy system optimization using developed coyote algorithm for effective management of battery, heat source, and thermal storage. Energy Reports, 10, 4218-4230.

[16] Modu, B., Abdullah, M. P., Bukar, A. L., & Hamza, M. F. (2023). A systematic review of hybrid renewable energy systems with hydrogen storage: Sizing, optimization, and energy management strategy. International Journal of Hydrogen Energy.

[17] Jajarmi, Amin, Samaneh Sadat Sajjadi, and Ahamad Hajipour. "Steam generator identification using piecewise affine model." Results in Nonlinear Analysis 2.4 (2019): 149-159.

[18] 0Sharma, R., Kodamana, H., & Ramteke, M. (2022). Multi-objective dynamic optimization of hybrid renewable energy systems. Chemical Engineering and Processing-Process Intensification, 170, 108663.

[19] Singh, P., Pandit, M., & Srivastava, L. (2023). Multi-objective optimal sizing of hybrid micro-grid system using an integrated intelligent technique. Energy, 269, 126756.

[20] Feng, Z., Huang, J., Jin, S., Wang, G., & Chen, Y. (2022). Artificial intelligence-based multi-objective optimization for proton exchange membrane fuel cell: A literature review. Journal of Power Sources, 520, 230808.
[21] Kim, K. C., Ko, E., Kim, J., & Yi, J. H. (2019). Intelligent Malware Detection Based on Hybrid Learning of API and ACG on Android. J. Internet Serv. Inf. Secur., 9(4), 39-48.
[22] Roy, P., He, J., Zhao, T., & Singh, Y. V. (2022). Recent advances of wind-solar hybrid renewable energy systems for power generation: A review. IEEE Open Journal of the Industrial Electronics Society, 3, 81-104.
[23] Giliberto, M., Arena, F., & Pau, G. (2019). A fuzzy-based Solution for Optimized Management of Energy Consumption in e-bikes. Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications (JoWUA), 10(3), 45-64.
[24] Cortés-Caicedo, B., Grisales-Noreña, L. F., Montoya, O. D., & Bolaños, R. I. (2023). Optimization of BESS placement, technology selection, and operation in microgrids for minimizing energy losses and CO2 emissions: A hybrid approach. Journal of Energy Storage, 73, 108975.
[25] Camgözlü, Y., & Kutlu, Y. (2023). Leaf Image Classification Based on Pre-trained Convolutional Neural Network Models. Natural and Engineering Sciences, 8(3), 214-232.