This article has been accepted for publication in IEEE Access. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2025.3535520

IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Date of publication xxxx 00, 0000, date of current version xxxx 00, 0000.

Digital Object Identifier 10.1109/ACCESS.2017.Doi Number

Optimal Sizing, Techno-Economic Feasibility and Reliability Analysis of Hybrid Renewable Energy System: A Systematic Review of Energy Storage Systems' Integration

Akhlaque Ahmad Khan[1], Ahmad Faiz Minai[2,5], Rakesh Kumar Godi[3], Vijay Shankar Sharma[4], Hasmat Malik[5] and Asyraf Afthanorhan[6]

[1]Department of Electrical Engineering, Integral University, Lucknow 226026, India; (e-mail: akhlaque@iul.ac.in)
[2]Department of Electrical Engineering, Integral University, Lucknow 226026, India; (e-mail: fzminai@gmail.com)
[3]Department of Computer Science, Manipal Institute of Technology Bengaluru, Manipal Academy of Higher Education, Manipal, India; (e-mail: rakesh.godi@gmail.com)
[4]Department of Computer and Communication, Manipal University Jaipur, India; (e-mail: vijayshankar.sharma@jaipur.manipal.edu)
[5]Department of Electrical Power Engineering, Faculty of Electrical Engineering, University Technology Malaysia, Johor Bahru 81310, Malaysia; (e-mail: hasmat.malik@gmail.com; fzminai@gmail.com)
[6]Universiti Sultan Zainal Abidin (UniSZA), Terengganu 21300, Terengganu, Malaysia; (e-mail: asyrafafthanorhan@unisza.edu.my)
Corresponding Author: rakesh.godi@manipal.edu (R.K.G) and vijayshankar.sharma@jaipur.manipal.edu (V.S.S)

ABSTRACT

One of the most significant ways to improve energy reliability and lessen reliance on fossil fuels is to combine renewable energy sources with energy storage systems. Using wind, solar, and battery storage as case studies, the article examines hybrid renewable energy system (HRES) size, optimization, techno-economic potential, and reliability in extensive detail. In order to minimize expenses and emissions while satisfying energy demands, the sizing process consists of evaluating the appropriate capacity of each component. In order to tackle the growing demand with a low carbon footprint, this study investigates the prospect of leveraging hybrid renewable energy (HRE) storage. System demands, budget, and performance indicators are some of the most critical considerations when selecting an energy storage system (ESS) for a renewable energy system. Whether or not the storage option is appropriate for HRE systems depends on the setup requirements. The selection of an ESS technology necessitates taking into account aspects like energy and power requirements, efficiency, cost-effectiveness, versatility, and reliability. The investigation also considers factors such as electricity long-term viability, dependability, technical and financial feasibility, and ecological sustainability when evaluating hybrid renewable energy power-producing technologies. Improving dependability and smoothing down power output are two major benefits of ESS integration. The findings show that integrating HRES with ESS can lead to more sustainable energy systems, providing a long-term, reliable, and cost-effective solution. Findings emphasize the need for further study of optimization methods, meta-heuristic algorithm strategies, system components, design constraints, and desired techniques.

INDEX TERMS Energy storage system; Solar PV; techno-economic assessment; reliability assessment; optimization methodologies; EMS; sizing softwares; emission assessment

Nomenclature/ Abbreviation:

ABSO	Artificial bee swarm optimization
AC	Alternating current
BESS	Battery Energy storage system
BG	Biogas
BM	Biomass

BW	Bio waste
CAES	Compressed air energy storage
COE	Cost of energy
CRF	Capital recovery factor
CSA	Crow search algorithm
DC	Direct current
DG	Diesel generator
DoE	Department of Energy
EENS	Expected energy not supplied
EIR	Energy index of reliability
ELF	Equivalent loss factor
E-PSO	Evolutionary particle swarm optimization
ESS	Energy storage system
FA	Four algorithm
FC	Fuel cell
FFIA	Firefly-inspired algorithm
GA	Genetic algorithm
GPAP	Grid power absorption probability
GW	Giga-Watt
GWh	Giga-Watt-hour
HRE	Hybrid renewable energy
HRES	Hybrid renewable energy system
HSO	harmony search optimization
IRR	Internal rate of return
LA	Level of autonomy
LCOE	Levelized cost of energy
LOLE	Loss of energy expectation
LPSP	Loss of power supply probability
MADEA	Mutation adaptive differential evolution algorithm
MBA	Modified bee algorithm
MES	Mechanical energy storage
MHT	Micro hydro turbine
MOGWA	Multi-objective grey wolf algorithm
MOMVO	Multi-objective multi-verse optimization
NGB	Natural gas boiler
NPV	Net present value
NS	Not Specified
PEI	Power electronic interface
PHES	Pumped hydro energy storage
PMC	Power management control
PoU	Period of Use
PPO	Proximal policy optimization
PV	Photovoltaic
RE	Renewable energy
RF	Renewable Fraction
RT-SWP	Real-time stepwise pricing
SAIDI	System average interruption duration index
SAIFI	System average interruption frequency index
SC	Super capacitor
SCA	Sine cosine algorithm
SES	Supercapacitor energy storage
SMES	Superconducting magnetic energy system
SPP	Simple payback period
TAC	Total annual cost
TES	Thermal energy system
WCA	Water cycle algorithm
WOA	Whale optimization algorithm
WT	Wind turbine

I. Introduction

The use of energy storage systems on public power networks is expanding rapidly. Increased reliance on fossil fuels has led to a substantial rise in the electrical loads of homes, businesses, municipalities, and industries. To lessen reliance on fossil fuels, it is of the utmost importance to promote the consumption of RES as an alternative form of electric power generation. According to the US Department of Energy (DOE), pumped hydro energy storage (PHES) plants had stored over 95% of all ESSs deployed by mid-2018. This equates to about 177 GW of ESSs deployed at the grid service level. In 2018, reports of novel pumped storage projects increased worldwide by more than 14 GW [1]. The majority of these initiatives have a lengthy gestation period and are unlikely to yield fruit until beyond the year 2030. There are an additional 4 GWh of BESS that are either in operation, under agreement, or have been announced for 2018. As a result, yearly BESS receives more installations and contracts than comparable storage technology. Furthermore, more than 80% of the over 4 GWh of BESS projects in the pipeline are LiB-based. The vast majority of these LiB projects are grid-tied, while the remainder are isolated. Less than 10% of the forthcoming LiB-powered BESS will have a battery backup for behind-the-meter applications like bill monitoring and demand response [2].

One strategy for mitigating climate change is to encourage energy-efficient appliances and boost education about the value of cutting down on electricity use at home and within industry [3]. Scholars are working on a variety of solutions to these problems. Alternative strategies that promote RESs and associated technology are the most reliable, cost-effective, ecologically sound, and widely adopted solutions. Much focus has been given to strengthening long-term energy supply infrastructures by developing distinct HRESs. HRESs are dependable, CO_2-free, and an efficient option for lowering reliance on a single renewable resource, which is essential in spots where natural resources are scarce [4]. Implementing RES offers an emissions-free selection for energy generation, allows delivery of energy in a district's topography, and serves as a trustworthy future power source for solo generating programs, as demonstrated in [5, 6].

RES is evocative of the sporadic nature of the environment, as it derives most of its power from it. The reliance of wind and solar power on weather patterns is a major drawback. An HRES, which integrates several energy sources and a backup power source, could potentially address this problem [7]. HRES can be combined with resources that function together, such as wind and natural light. Additionally, ESS can work together with traditional power sources like diesel generators (DGs). When used with the right application, HRES can provide a more reliable and cost-effective power source [8, 9]. Hybrid electrical systems have an assortment of challenges, including high upfront costs, increased maintenance costs, rate fluctuations, and depreciation [10, 11]. Additionally, site factors, technical and social limitations, and the accessibility of energy sources all have an impact on an HRES's power generating configurations and overall electricity generation cost [12, 13].

Improved consistency at the lowest possible cost relies significantly on finding the optimum size arrangement here. Because it depends on data pertaining to power sources, specifications for technology, environmental factors, and consumption patterns [14], identifying the most effective design of HRES is a challenging task [15]. Numerous locations and restrictions have been studied in order to identify the best HRES model [16], design [17], size, and optimization approaches [18]. Most of these investigations employed solar-wind hybrid structures [19], due to the fact that these two technologies complement each other so effectively [20].

Improvements in optimization and monitoring of grid-tied [21] and independent HRES [22] have arisen from the integration of technology for sizing solar and wind combined systems [23, 24]. These approaches include essential performance evaluations for scalability of all kinds of wind and solar hybrid systems, innovative single-algorithm and hybrid algorithms, and software tools tailored for grid-tied or isolated regions and islands [25]. Too far, there have only been a few specific artificial algorithms designed for isolated and grid-tied applications [26] that have been extensively studied in relation to the use of AI approaches in sizing HRES. Emphasis revolved around HRES self-reliance in terms of integrating settings, storage system choices, approaching sizes, and control and monitoring [27].

A real-life instance of RE production from solid waste collected by municipalities in Oman is presented in [28]. Researchers in the Arabian Gulf area discussed their research findings on the hurdles they've experienced on their way to renewable energy generation in [29]. In [30], the author discusses the most effective approach to creating numerous artificial single-algorithm and software-driven tool arrangements, along with some hybrids. In [31], the author examined the size of numerous hybrid system arrangements for both standalone and grid-tied applications, utilizing both artificial and traditional sizing approaches. In [32], the author primarily focused on multi-objective optimization strategies for hybrid power systems that make use of fuel cells (FCs), solar, and wind. The author of [33] dealt with using AI optimization techniques to investigate, regulate, and simulate HREs. Solar-biomass hybridization is known and widely accepted among different types of HRES [34] because it could be easy to get to, cheap, and free of pollution, according to ecological evaluation results [35]. Hybrid designs make the best possible use of solar and indigenous biomass resources. Such technologies for sustainable energy can contribute to a better regional power structure if they're fully adopted. Numerous biomass subsystems in hybrid solar-biomass energy systems consume biomass directly from forests or waste from agriculture [36].

Whenever electricity demand exceeds supply, an ESS will accumulate the difference and then release it later. Energy storage has also gained popularity [37] as a result of the quest for methods of transportation that produce fewer greenhouse gas emissions [38]. Storage systems for RE are widely utilized [39], and these systems can be electrochemical, mechanical, electrical, or mixed. An in-depth review of ESS technologies and their applicability to solar PV power plants is presented in [38]. From 1850 through 2022, contributors to [38] examine and contrast trends in ESSs, including their history, categorization, working concepts, and correlations. The ESS perspective presented in reference [40] is very comprehensive. Storage in PV systems is the primary subject of references.

Batteries, hydrogen-storing fuel cells, and flow battery packs are all examples of electro-chemical ESSs. Flywheels, compressed air energy storage (CAES), and pumped hydroelectric storage are all mechanical techniques that can be employed for storing energy. In situations with high demand, CAES pumps compressed air from subterranean caverns to power generators. As its acronym implies, the flywheel is used to store kinetic energy that comes in the form of rotational motion. Considerations including cost, effectiveness, and ecological impact will influence the decision of which mechanical energy storage system (MESS) to select [41].

Electrical energy may be stored in three different ways: in a supercapacitor energy storage (SES) system, a superconducting magnetic energy system (SMES), or a thermal energy system (TES). Electrostatic fields in SES are a means of storing energy. The use of regenerative braking in electric automobiles and grid stabilization are two areas where its high-power delivery and quick response time come in handy. Many different types of storage materials are used by TES. It has a lower power output than most other technologies, but it is capable of storing energy for a long time [42].

A hybrid or multi-ESS system combines numerous ESS technologies into one system in order to boost the overall system's performance [43]. The use of several storage technologies in a hybrid ESS allows for the best features of each to be used while the downsides of individual storage methods are mitigated. The requirements, cost, and operational features of a HRE system all play a role in determining which ESS technology will be selected. It's also worth remembering that a hybrid approach, including features derived from several ESS technologies to take advantage of each one's capabilities and mitigate its weaknesses, can be the most effective choice in certain cases [44]. Power management controls (PMCs) have been utilized to effectively control various ESS technologies in a HRE system [45]. PMCs provide smooth operations and maximum utilization of RE sources. In most cases, algorithms and software are used to implement PMCs, with constant monitoring of the system's energy generation. It was used for HRE systems that also have storage [41]. Hybrid systems, such as PV/batteries for electrical power and PMCs for water pumps, were utilized in [42]. The authors [44] demonstrate how a similar PMC system can be utilized to track and manage solar PV, fuel cells (FCs), and batteries (BS). It is crucial to the design of effective RESs to model and size batteries in solar power systems and PMCs in ESS technologies. Their specificity aids our capacity to comprehend the actions of such systems. HRE systems can benefit from ESS because of the variety of functions it can execute, such as balancing load, back-up power, time utilization maximization, and grid stabilization. This study compares and contrasts many ESSs, outlining their respective benefits and drawbacks, so that readers may choose the most appropriate ESS technology for their individual hybrid system applications. The primary goal of this study is to help scholars in the areas of RE and cutting-edge power systems gain an instantaneous understanding of the various storage technologies utilized in HRE plants. It also makes it feasible to demonstrate how an ESS contributes to the value of RESs in the overall energy mix worldwide [43].

Even though optimal sizing has been studied in depth and the latest solo and hybrid optimization techniques and sizing software tools have been used, the available literature does not objectively compare the performance of the many sizing optimization solutions [46]. There is currently no published analysis of how different types of standalone hybrid solar and wind systems perform in far-flung areas and islands. Possible uses for HRES include grid-tied systems for periods where the national grid is problematic and independent systems for more distant or island locations [47]. This paper aims to give an in-depth review of the latest developments in stand-alone algorithms, hybrid algorithms, and programs (software tools) to perform such tasks. This will help figure out the best size for HRES and look at things like price, reliability, environmental impact, and social acceptance. In addition, this study evaluates the size optimization strategies used by different scholars and provides an extensive assessment of the literature for both off-grid and on-grid HRES using a wide range of energy generation and storage options.

Das and Zaman [48] investigated various storage modules and dispatch mechanisms as they constructed a HRES for a separated group in Bangladesh. The study looked at lithium-ion (Li-ion) and lead-acid (LA) batteries and found that their COE is the same. However, Li-ion batteries work better than LA batteries, and the load that followed the dispatch method had the highest renewable proportion (77–80%).

Using the Homer program, Shezan et al. [49] assessed the efficiency of a Klia Sepang Depot off-grid hybrid power system that included wind, diesel, batteries, and PV. The enhanced system managed to reduce net NPC emissions by about 29.65% and CO_2 emissions by around 16 tons

This article has been accepted for publication in IEEE Access. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2025.3535520

compared to traditional power configurations, according to the results.

Mahbub et al. developed a hybrid power system for McCullum in Newfoundland and Labrador, Canada, using Homer Pro software [50]. They addressed issues such as inappropriateness for a hydropower facility and lack of flat surfaces by incorporating floating solar photovoltaic modules (FSPV) into their design. Using FSPV reduced the number of generators needed from three to one, saving 150 kW. By comparison to a diesel generator, the new FSPV power plant can decrease fuel usage by around 70%. Findings also indicate that renewable energy sources significantly cut down on emissions of greenhouse gases when used in place of diesel generators.

Erasmus et al. [51] did a study in Cameroon, Africa, and used Homer software to look at how well different hybrid systems worked. These systems had SPV, WT, small hydro, BES, DG, and inverter parts. The most cost-effective solution that met both the load needs and the design constraints was the PV/DG/small hydro/BS arrangement. Communities may find these renewable-energy-only constructions costly and unreliable, despite the fact that they produce no emissions.

With the help of Homer, Baig et al. [52] examined the merging of WT, BS, and PV resources at a distant site in Pakistan. They concluded that, economically speaking, micro-grid systems that rely mostly on solar panels would be better off than those that use wind power. Including wind turbines in the model is inefficient due to the low wind speeds and plentiful solar radiation in the area.

Farivar et al. [53] evaluated the Iranian island of Kish using a mix of PV, WT, DG, and BS. They found that the DG-BS system is the most economical, but it does have certain negative effects on the environment. They came to the conclusion that the WT-DG-BS hybrid system is an attractive option since it offers competitive economic indicators and a significant decrease in carbon dioxide emissions.

The objective of this article centered on HRESs in conjunction with ESS and to identify the optimal size in order to be utilized as either grid-tied or isolated power sources for the entire nation and globe. The contribution is rendered with regard to the mentioned analysis's obstacles and limitations via the following implication:

- Elaborating hurdles in identifying optimal size for HRESs.
- Examining optimal size (considering cost) and advancements in HRESs.
- Finding that ESSs should be the correct size for optimal performance, and reliability.
- Recognizing current technological difficulties in identifying optimal HRES-ESS size.
- Evaluating possible optimal sizing techniques and approaches.
- Anticipating future trends in optimum sizing of HRESs with ESSs.

Apart from the introduction, the following is the framework for this article: In Section 2, the review process and the paper's contribution are briefly explained. In Section 3, the appropriate design parameters, indicators, and objective functions for an HRES are explained. In Section 4, meta-heuristic techniques and software tools are used to optimize the size of energy production units. Section 5 contains demonstrations and evaluations of the most prevalent and cutting-edge ESS used in HRE systems. Integration of ESSs in HRESs is addressed in Section 6; the discussion, suggestions, and conclusion are found in Sections 7 and 8.

II. Description of the Review Process

Figure 1 shows the process that was used to evaluate this study. There were four main procedures involved in accomplishing this study's objectives. The initial step in identifying the problems was an evaluation of the pertinent feasibility restrictions, components, objective functions, and methodologies. The second phase was an examination and categorization of the literature on the issue according to key factors such as component, target function, and method. The study's problems were highlighted and addressed in depth. The third stage also accounted for and addressed novel data. In the procedure's last stage, emerging patterns in optimum component planning for off-grid power supplies were discussed.

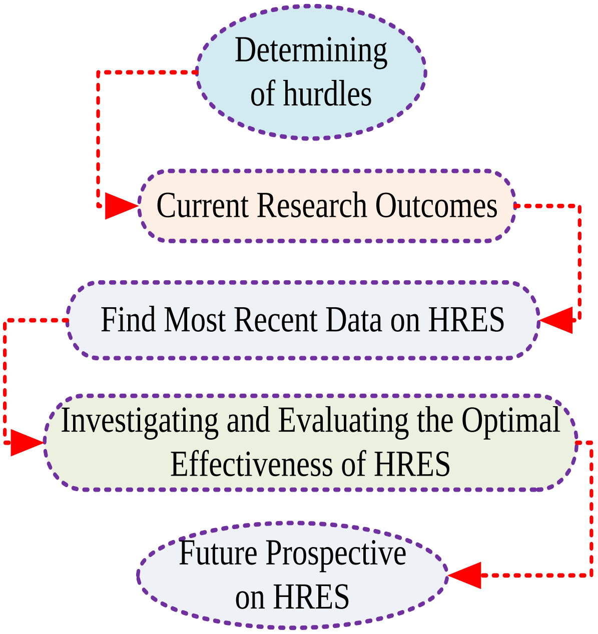


FIGURE 1. Methodology for evaluating the overall evaluation pertaining to HRES system sizing

This article has been accepted for publication in IEEE Access. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2025.3535520

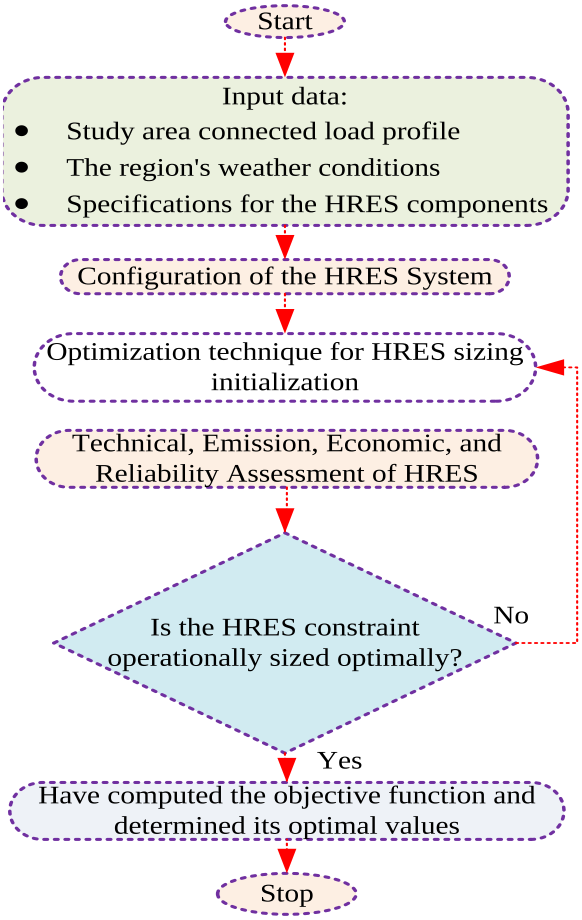


FIGURE 2. Method to figure out an appropriate size HRES system

III. An Overview of the HRES System Size Optimization

Evaluating the system components with the maximum capacity while taking feasibility and reliability restrictions into account is a challenge when sizing HRES systems to their full potential [54]. Remember that during the present investigation, HRES grids are assumed to be placed in location, while only strategies for optimization to figure out the appropriate size of generating and storing units are examined [55]. As a result, governments tend to be accountable for constructing and expanding HRES networks [56, 57]. This means there isn't sufficient data to accurately assess the expense of grid setup for HRES systems [58, 59]. Furthermore, generating and storage plants are frequently located in relatively close proximity to rural areas [60], and the HRES grid than is much cheaper typical power networks [61, 62].

A typical method for optimizing HRES system size is presented in Figure 2. The input data has been used to initiate HRES system layout using optimum sizing methods. Following that, researchers established the structure of the HRES system. It formulated the size issue as an optimization problem. After that, the efficiency of the HRES system was evaluated. Once the HRES system was functioning properly, the constraints on its viability were examined. The issue of optimization was dealt with by evaluating the objective function, given that all constraints were satisfied.

A. HRES Components

Higher initial costs, geographical constraints, and intermittent production are also issues with HRES [63]. Despite the declining expense of HRES, ESS remains necessary to address the intermittent problem [64]. However, the expense of ESS is substantial, especially considering that huge-scale green power plants require an enormous amount of electricity. It is suggested to utilize a hybrid RES with DG/ESS systems since it is both affordable and environmentally beneficial. Contrarily, a multi-component hybrid isolated region electrification system is a challenging system that demands meticulous design. The idea of optimum planning is important for making a trustworthy and affordable system. The cheapest approach to storing and utilizing natural electricity without interruption is to implement a HRE system [65]. Researchers have been concentrating more and more on HRES in conjunction with ESS because of its reliability and affordability in providing electricity to isolated and distant places [66, 67]. Utilization of resources and technological and economic performance have been the subject of

This article has been accepted for publication in IEEE Access. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2025.3535520

numerous studies [68, 69]. An HRES generation arrangement system usually consists of more than one RE generating unit [70], a possible standby FC power producing unit [71], conditioning units [72], and a storage facility [73, 74]. As can be observed in Figure 3, the PV and WTs are the major load service providers, with the biogas (BG) generator serving as an additional back-up. The battery is responsible for optimizing the entire system and maintaining a stable power flow.

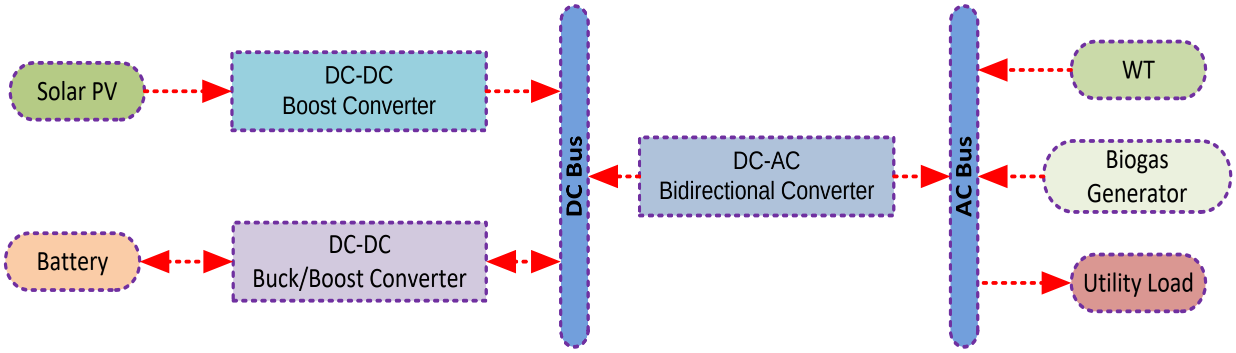


FIGURE 3. An HRES system's schematic diagram.

Equipment like DG or gas generators that use fossil fuels to generate electricity significantly increases the amount of greenhouse gas emissions [75]. In recent years, an extensive range of renewable energy (RE) components that can be included with systems for electrifying remote regions and interacting with national networks has become accessible. Isolated utility and national grid-associated networks frequently employ and are associated with SPVs, WTs, hydropower, and BG generators. Although the way they are used is significantly affected by where the study's site is located [76]. Biogas generators will get greater consideration in the coming years due to the substantial amount of biomass in rural areas [77]. The system components of HRES systems are depicted in Figure 4.

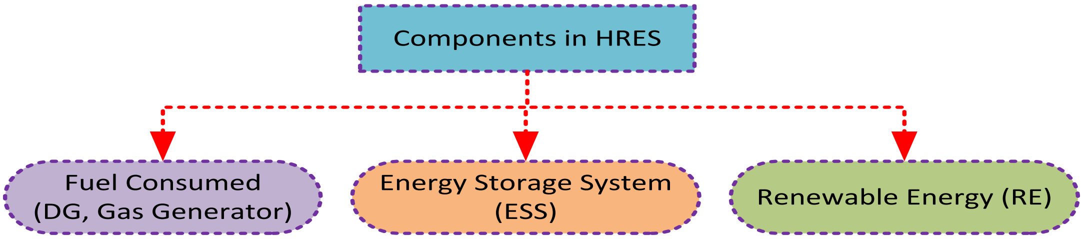


FIGURE 4. Components of a typical HRES system

B. HRES System Design Parameters

Economics and reliability are both significant variables to take into account while designing an HRE system. Emissions and technical difficulties have links to these factors. The nature of the study defined the objective function that had been adopted. In numerous instances, financial considerations will take priority. If funds are restricted, reliability takes priority over other concerns. In various circumstances, the public's focus has been directed at emissions. Due to the variety of objectives that are involved, the optimum size of HRE systems may be attained via the use of either solitary or multi-objective optimization strategies. Pareto fronts are a way to solve problems with numerous goals by finding a balance between them [78]. Figure 5 depicts the numerous types of objective functions that can be laid out. Several modern studies focus first on costs, then on reliability, and lastly on technical and emission aspects. Subsections 3.2.1, 3.2.2, and 3.2.3 provide elaborate descriptions of the various types of objective functions.

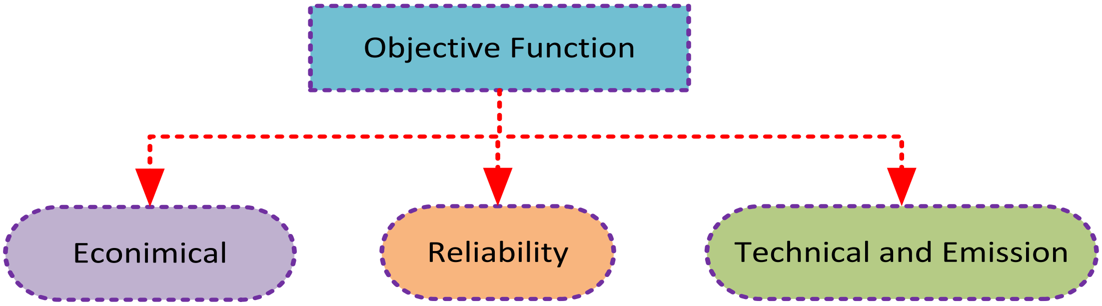


FIGURE 5. Objective function-based sizing of HRES systems

This article has been accepted for publication in IEEE Access. This is the author's version which has not been fully edited and
content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2025.3535520

a. Objective Functions Of Economic Assessment

Among the economic targets are the simple payback period (SPP), internal rate of return (IRR), levelized cost of energy (LCOE), and total annual cost (TAC). The NPC of a DG is estimated through combining the amount of its initial purchase cost, annual maintenance and repair costs, salvage value, and fuel costs [79]. The capital recovery factor (CRF) multiplies the NPC and then adds the result to the system's annual energy consumption when calculating the LCOE [80]. To estimate the TAC, add the cost of fuel to the aggregate of the annual expenditures for constructing and maintaining [81]. The SPP estimates the number of years required for annual earnings to satisfy the capital costs of the system's individual components [82]. When the NPV of all cash flows into the foreseeable future is zero, the IRR corresponds to a discount rate [83]. Every economic goal function for the HRES size is presented mathematically in Table I.

TABLE I: Every economic objective function for the HRES size and its mathematical formulation

Parameter	Description	Objective Function	Ref.
NPC	The aggregate of all future gains and losses from carrying out the project.	$NPC_{min} = NPC_{GI} + NPC_{FU}$ --------------------------(1) $NPC_{GI} = PV_{CC} + PV_{MC} + PV_{RC} - PV_{SC}$ --------(2) $NPC_{FU} = \left(\frac{\{1+D_R\}^n - 1}{D_R\{1+D_R\}^n}\right) . \left(\sum_{t=1}^{T}\{f(t) . P_F\}\right)$ -(3)	[84]
LCOE	Calculated on a per-kilowatt-hour basis, it represents the annually cost of generating power from the system as a whole.	$LCOE_{min} = \left(\frac{NPC_{GI} + NPC_{FU}}{OAE_D}\right) . \left(\frac{D_R\{1+D_R\}^n}{\{1+D_R\}^n - 1}\right)$ --------(4)	[85]
TAC	It includes all from initial investment to running expenses to the price of fuel and components for the electrical system over the span of a year.	$TAC_{min} = \left(\sum_{t=1}^{T}\{f(t) . P_F\}\right) + C_{AC}$ -----------------(5)	[86]
SPP	This is the time frame in which an investment will yield a profit.	$SPP_{min} = \frac{PV_{CC}}{AP_{HRES}}$ ----------------------------(6)	[84]
IRR	A discount rate is employed in a discounted cash flow evaluation in order to ensure that the NPV of all cash flows is equal to zero.	$IRR_{max} = -PV_{CC} + \sum_{y=1}^{Y} NCF_Y . (IIR)^y$ --------(7)	[87]

b. Reliability's Objective Functions Assessment

The most typical metrics and objective functions for the reliability of HRES optimum sizing are loss of load expectation (LOLE), expected energy not supplied (EENS), loss of power supply probability (LPSP), and loss of energy expectation (LOLE). Additionally, two more reliability indices that garnered lesser consideration for the most effective HRES sizing are the system average interruption frequency index (SAIFI) and the system average interruption duration index (SAIDI). The LPSP, which may apply to grid-tied or isolated HRE systems, assesses the probability of an unmet load over the entire system's energy demands [88]. The EENS is the energy that a HRE system could be generating but doesn't seem to be [89]. The LOLP, additionally referred to by the acronym LOLE, is the total amount of hours per year when the energy is more than what the HRE production system is capable of supplying [90]. The total amount of energy that a grid-tied or isolated HRE system fails to generate is known as the LOEE [91]. In the HRES endeavor, SAIFI is the typical number of times a customer experiences power outages over the duration of a year. The SAIDI index calculates the average number of interruptions experienced by customers throughout the duration of a project. The energy index of reliability (EIR) refers to evaluating the reliability of every possible hybrid system configuration [92]. The percentage of required power that was not delivered due to load reduction is called the equivalent loss factor (ELF) [93]. Level of autonomy (LA) refers to the percentage of load indicated by the overall demand on the system when it was accessible [94], and the potential of the system having to procure power from the utility grid because RESs are insufficient to satisfy the demand is known as novel grid power absorption probability (GPAP) [95]. The mathematically calculated expression of every reliability objective function for HRES size is outlined in Table II.

TABLE II: Every reliability objective function for the HRES size and its mathematical formulation

Parameter	Description	Objective Function	Ref.
LPSP	Unmet load over the total energy requires of a grid-tied or isolated HRE system.	$LPSP_{min} = \frac{OAE_D + TE_D + TEO_{CB} - TO_{RES} - EO_{DG} - TEO_{DB}}{OAE_D}$ --(8)	[88]
EENS	As a portion of energy needs that are not being satisfied by an HRE system.	$EENS_{min} = \sum_{t=1}^{T}(AL_Y . UL_D)$ --(9)	[89]

This article has been accepted for publication in IEEE Access. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2025.3535520

LOLE / LOLP	The annual average of demand for electricity that cannot be satisfied by the HRE generating system.	$LOLE_{min}/LOLP_{min} = \sum_{t=1Sec}^{T} \sum P_{MS} . L_{LD}$ ----------(10)	[90]
LOEE	Total amount of power that is not provided by the HRES, whether it is linked to the grid or not.	$LOEE_{min} = OAE_D + TE_D + TEO_{CB} - TO_{RES} - EO_{DG} - TEO_{DB}$ -(11)	[91]
EIR	Evaluate the reliability of every possible hybrid system configuration.	$EIR_{max} = 1 - \frac{EENS}{OAE_D}$ ----------(12)	[92]
ELF	The percentage of required power that was not delivered due to load reduction.	$ELF_{min} = \frac{1}{T} \sum_{t=1}^{T} \frac{Q(t)}{P(t)}$ ----------(13)	[93]
LA	The percentage of load indicated the overall demand on the system when it was accessible.	$LA_{min} = 1 - \frac{TNH_{LF}}{TNH_{LO}}$ ----------(14)	[94]
GPAP	The potential of the system having to procure power from the utility grid because RESs are insufficient to satisfy the demand.	$GPAP_{max} = \frac{\sum_{t=1}^{T} PP_G}{\sum_{t=1}^{T} L_D}$ ----------(15)	[95]
SAIFI	The average number of sustained interruptions per consumer during the year.	$SAIFI_{min} = \frac{\sum PI_R . NOC_s}{\sum NOC_s}$ ----------(16)	[96]
SAIDI	The average total duration of outages (in hours) experienced by a customer in a year.	$SAIDI_{min} = \frac{\sum PO_D . NOC_s}{\sum NOC_s}$ ----------(17)	[96]

c. *Emission & Technical's Objective Functions Assessment*

The most typical metrics and objective functions for emission and technical aspects of HRES optimum size are battery lifespan (BL), renewable factor (RF), customer comfort level (CCL), carbon emission (CE), and discharged energy (DE). The RF displays the percentage of the energy demand that HRES is able to meet [97]. The CE indicates the total amount of CO_2 that the suggested HRES system is expected to produce during the course of the project [98]. The BL expresses how degradation has reduced the battery's lifetime in HRES. To avoid damaging batteries and extending their lifetime, an appropriate implementation plan has to be developed. HRES optimal sizing challenge Table III consists of the emission and technical objective functions with expressions based on mathematics. However, the demand response mechanism used in this study has an effect on the formation of CCL. As an illustration, changing the load can decrease the amount of time needed to reach the highest CCL. The inverter control system, which limits power fluctuations and provides a steady supply of energy, is taken as a factor in the EFR computation. The emission and technical goal functions are mathematically pointed out for the optimal size of a HRE system in Table III.

TABLE III: Every emission &technical objective function for the HRES size and its mathematical formulation

Parameter	Description	Objective Function	Ref.
RF	It reveals what percentage of energy demands are met by HRES.	$RF_{min} = \left(\frac{1 - EO_{DG}}{OAE_D}\right) X\ 100$ ----------(18)	[97]
CE	It is a measure of how much CO_2 the planned HRES system will release during the execution of the project.	$CE_{min} = \alpha + \beta \sum_{t=1}^{T} PG_{DG}(t) + \gamma \left(\sum_{t=1}^{T} PG_{DG}(t)\right)^2$ ---------(19)	[98]
BL	In HRES terms, this indicates the diminished useful life of the battery.	$BL_{max} = 1 - BCD_{Charging/discharging\ cycles}$ -----------(20)	[7]
CCL	The time commitment demanded to maximize CCL	CCL_{max} ----------(21)	[9]
DE	All energy delivered to the delivery point from the storage facility.	$DE_{min} = TO_{RES} + EO_{DG} + TEO_{DB} - OAE_D - TEO_{CB}$ -(22)	[11]

C. *Constraints of Feasibility Assessment*

The size of an HRE system must take into consideration two distinct types of feasibility constraints. Limitations on individual parts and technical limitations on the whole system are examples [3]. Figure 6 depicts the challenges associated with the proper size of the national grid linking system and its constraints on electrifying rural areas.

This article has been accepted for publication in IEEE Access. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2025.3535520

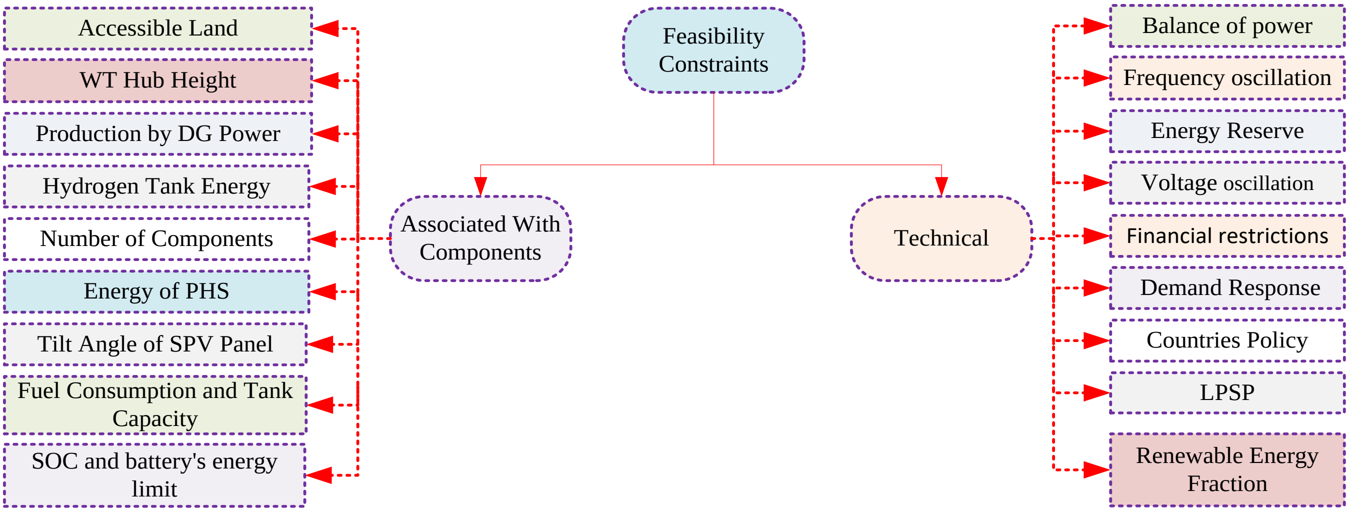


FIGURE 6. Constraints on HRES size optimality

IV. Power Generation Unit Sizing Optimization

The contributor presents a thorough analysis of the problem of sizing the crucial units for HRE systems in [99]. It is a strategy for calculating the sizes of components in hybrid systems, and it assists in reducing costs along with enhancing reliability [100]. Under-sizing can result in an energy supply failure or insufficient energy to satisfy the load, while oversizing can increase the system's overall cost [101]. There are numerous techniques available to figure out what size HRE system is desired [102]. Multiple strategies to strengthen the footprint of power-producing units have been demonstrated in Figure 7, with the two most prevalent strategies highlighted for reference.

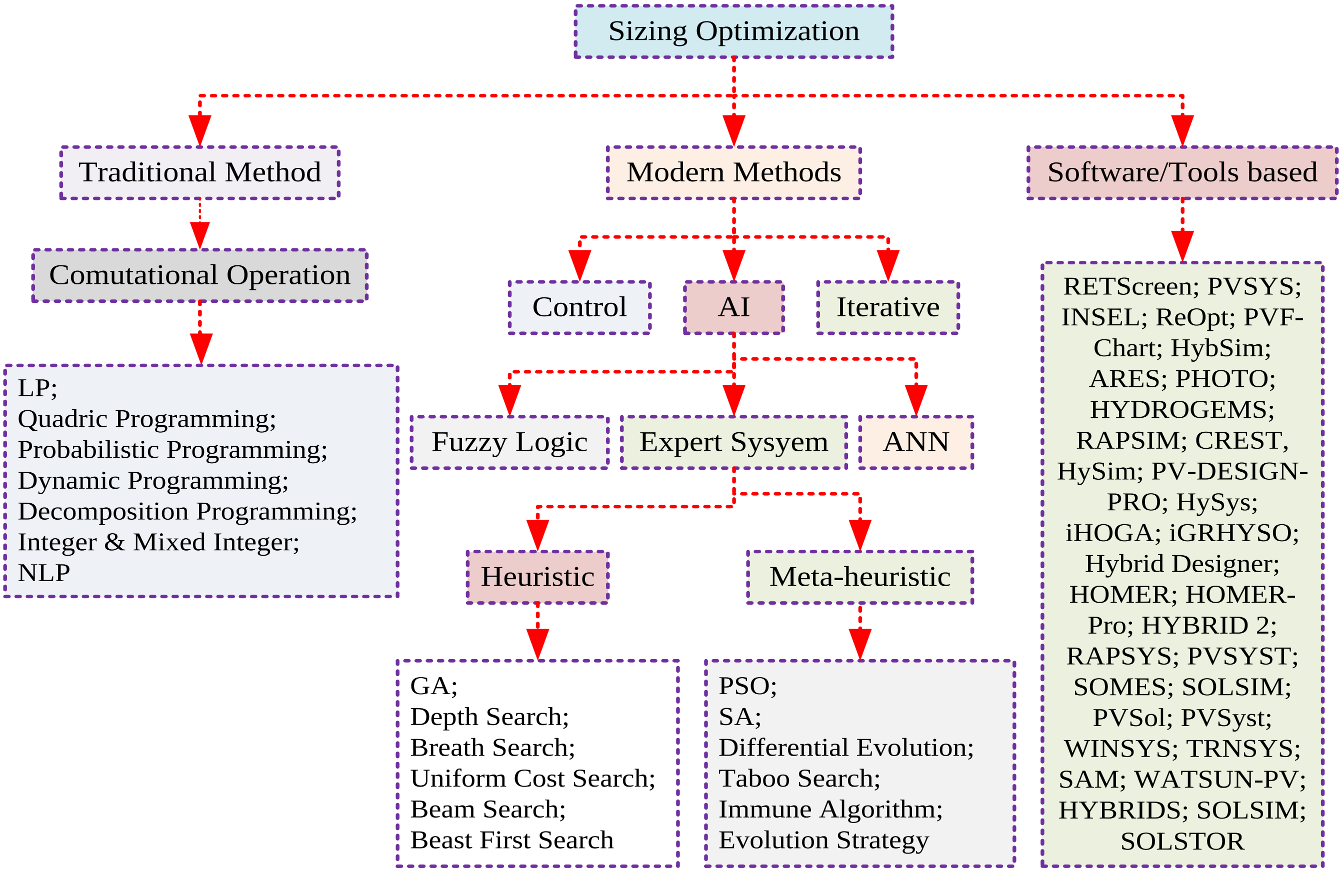


FIGURE 7: The most popular strategy of sizing optimization

A. Software-Based Modeling and Optimization

The most prevalent techniques to determine a hybrid system's functionality are simulation tools. It is possible to find the best architecture by utilizing software simulations to compare the cost and effectiveness of energy production among different system designs [45]. In order to evaluate the implementation of renewable structures, there are a number of paid and free software tools freely available [47]. These include RETScreen, PVSYS, INSEL, REopt, PVF-Chart, HybSim, ARES, PHOTO, HYDROGEMS, RAPSIM, CREST, HySim, PV-DESIGN-PRO, HySys, iHOGA, iGRHYSO, Hybrid Designer, HOMER, HOMER-Pro, HYBRID 2, RAPSYS, PVSYST, SOMES, SOLSIM, PVSol, PVSyst, WINSYS, TRNSYS, SAM, WATSUN-PV, HYBRIDS, SOLSIM, SOLSTOR, etc [103].

Over 200,000 installations of the RETScreen and 28,000 installations of HOMER are the two most prevalent applications in academia [103]. The tools required to evaluate the effectiveness, unit dimension, supply losses, and price of generated electricity for different hybrid system designs are easily accessible. The majority of modeling tools are able to simulate EES in the form of battery banks; only iHOGA and HOMER are capable of modeling hydrogen energy storage. With a unique combination of technology and economics, HOMER is the most effective tool for optimizing a hybrid system's layout. The program offers users a broad spectrum of optimized design possibilities based on the least NPC, all of which are presented in a simple and palatable efficiency graph. Inadequacies of this tool include its inability to deal with time series of metrological and load data and a limitation on tackling first-degree linear equations [104]. Second, only HOMER [105] is capable of modeling the incorporation of compressed air energy storage (CAES). HOMER, on the other hand, leverages a single objective function while discarding intra-hour variations. The high cost of electricity is another factor that isn't taken into consideration by HOMER when evaluating the system's overall ranking. It's also noteworthy that HOMER doesn't take into account the implications of an upcoming rise in load or the degree of drain on batteries. Discharge depth plays an important role in HRES optimization since it has an adverse correlation between the capacity of batteries and their lifespan. Superior performance in this area of the HOMER program is necessary to get optimal results [106].

iHOGA is a software tool that was created at the University of Zaragoza for modeling and optimizing the performance of renewable-powered microgrids. That's multi-objective, so it can find the best answer with minimal interruption to the simulations. Their biggest weakness is a daily load restriction of 10 kW. At the University of Wisconsin, researchers designed a program for modeling called TRNSYS. SolarDesign, particularly passive and active, has become prevalent in RE technology and architectural modeling. It's possible to utilize models from their library, which is readily accessible, as are computational simulations and precise unit sizing. One of its greatest assets is that it can replicate the behavior of integrated structures when they experience temporary conditions [107]. In another study, HOMER and RETScreen were identified as the two most prevalently utilized programs for evaluating the capacity of RE systems. To make future research and hybrid-powered programs easier, more software tools need to be made. For example, RESs and EVs need to work together, operations need to be controlled, and different ecological and social metrics and the costs of emissions need to be taken into account [47].

Numerous HOMER-based research projects have been performed in order to identify the optimal design for HRE systems devoid of ESS [108]. HRE systems that include PV/WT/DG/BES [109], PV/WT [110], WT/mini-hydro [111], PV/biomass [112], and PV/WT/hydro [113] were all optimized through HOMER. With its user-friendly interface, HOMER was able to determine the optimum size of a PV/WT/BG/DG structure to be used in a decentralized energy project [114]. In [115], the author evaluates the configuration of a biogas generator to be deployed in a hybrid WT/PV/DG remote power system in an isolated town. Because solar irradiance and wind speed varied during the day, this combined system failed to provide a reliable delivery for the associated loads. Hybrid power plants that utilize numerous types of RE ought to utilize energy storage methods to solve the reliability problem. A lot of universities are looking into how the HOMER platform can be used to design and build infrastructure for RE-based energy production, how ESSs can be used to bring electricity to rural areas, and how local and national grids can be connected [116]. Table IV summarizes the optimal HRES system size as estimated by the HOMER software program/tools.

For islands, isolated rural areas, and off-grid community centers, the ideal WT/BES/DG size was designed [117], taking into consideration the optimum levied cost of energy [118, 119]. For the grid connections and electric power of rural areas, the PV/WT/BES arrangement is one of the most prevalent solutions [120]. Furthermore, PVs and WT, FCs, super-and ultra-capacitors, and PHS are also employed to provide power and connect remote areas to the national grid. Ideally, it can categorize ESSs as either short- or long-term in nature. Batteries and super-and ultra-capacitors are utilized for short-term storage, while PHS and FC systems are utilized for long-term storage. The overwhelming majority of studies suggest that large-scale solar installations should also include long-term energy storage technologies [121]. The use of HESS for off-grid power generation and distribution has been the subject of substantial investigation. A FC/SC HESS hybridized with a solar PV system was deployed into operation to perform commercial remotely loaded operations on the African continent [122]. It was concluded that a BES and FC combination was the optimum size for a PV/WT hybrid structure [123]. By integrating a biogas-producing unit with a PV/WT/BES structure, researchers can develop an environmentally friendly hybrid system featuring greater

This article has been accepted for publication in IEEE Access. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2025.3535520

power production versatility [124]. The optimal size for a biogas and biomass system on farms was identified in [125]. Using HOMER [126], researchers explored how BG production units can be utilized in conjunction with hydropower in ecological rural area energy networks and national grid link networks.

TABLE IV. HRES system size optimization by deploying the HOMER software

Hybrid System	Optimization Strategy	Objective Function	Design Constraints	Cost of Electricity	Ref.
WT/PV/BES/DG	HOMER	COE; NPC	Balance of power; Economic Plan	PoU	[127]
PV/WT/ BES	HOMER	TNPC	Balance of power; Economic Plan	PoU	[128]
PV/DG/BES	HOMER	LCOE; CO_2 emission	Balance of power; Economic Plan; Initial investment cost	PoU	[129]
PV/HT/FC/BES	HOMER	COE; NPC	Capital costs; Energy production; Overwhelming energy; Renewable penetration	PoU	[130]
PV/WT/BG/PHS	HOMER -Pro	COE; NPC	Balance of power; Economic Plan; Fuel consumption	PoU	[131]
PV/WT/BES/FC	HOMER -Pro	COE; NPC	Balance of power; Economic Plan; Initial Capital Expenditure; Running expense	PoU	[132]
PV/VT/BG/FC	HOMER-Pro	COE; NPC	Balance of power; Economic Plan	PoU	[133]
PV/WT/DG/BES	HOMER	COE; NPC; RF	Load requirement; Cost of diesel fuel; Project Duration; Rate of Interest	PoU	[134]
PV/WT/DG/BES	HOMER	LCOE; NPC	Energy generation; The Running Expense Emission; Fuel consumption	PoU	[135]
PV//MH/DG	HOMER	Cost of operations; Investment Profitability	Balance of power; Economic Plan	RT- SWP	[136]
PV/DG/BES/BM	HOMER	LCOE	Power consumption specifications; Potential Energy Sources	PoU	[137]
PV/WT/BES/DG	HOMER	NPC	A Single criterion-total NPC	NS	[138]
PV/WT/BES/DG	HOMER-Pro	COE; NPC	Capital Expenditures; Unmet load; Energy production; Overwhelming energy; Emissions throughout the life cycle; Penetration of RE	PoU	[139]
PV/WT/BES	QRod, PROSPER, and HOMER	LCOE; NPC	Load requirement; Capital Expenditure; Potential Energy Supply; Energy production	NS	[140]
PV/DG/BES	HOMER Pro	COE; NPC	Load requirement; Capital Expenditure; Potential Energy Supply; RES Configuration	PoU	[141]

The primary focus of every analysis, as shown in the scholarly articles in Table IV, is the authors' strategy for resolving the community's energy shortage. Each hybrid system has a DG, except when problems with power shortages in the whole community are emphasized in the evaluations shown in Table IV due to different factors. DGs are not merely unsustainable commercially; additionally, they are also hazardous ecologically. Additionally, BES is not fully financially feasible. For assurance that the wholly innovative, completely sustainable hybrid structure design utilized on the plant reflects all of the aforementioned advantages and downsides, further study is required. Furthermore, the future investigator should solve the problems by integrating meta-heuristic optimization strategies to cope with both the desired function and the constraints.

B. Meta-Heuristic Optimization Strategies

To choose the ideal system size and layout for HRES, researchers must provide a realistic optimization strategy [142]. There are several optimization strategies for designing a HRE system; however, meta-heuristic optimization is an extremely appreciated and efficient strategy [143]. In order to determine an adequate HRES size, meta-heuristic strategies are often utilized. There are a variety of objective optimization research studies that fit into the framework of current meta-heuristic strategy examinations [144]. Table V lists the referencing number, hybrid system, optimization strategies, objective function, design constraints, and consumption rate for all documented meta-heuristic studies pertaining to single-and multi-objective ideal designs for HRES. The PV/WT/BES/DG hybrid system was sized employing meta-heuristic strategies to minimize the cost of electricity production [145]. A restriction termed the LPSP was utilized to enhance reliability [146]. Likewise, the total quantity of components and the power surplus or shortfall within generation and utilization were mentioned most commonly as feasibility constraints [147]. Nevertheless, the authors recommended a system that was simultaneously economical and size-optimized and had a PV/WT/BES/DG [148]. The RF, unit devotion, and fraction of RE were all enhanced through an assortment of strategies [149]. The studies described above each had a single objective and were peer-reviewed [150].

Additionally, Table V reveals that the referencing numbers correlate to the HRES's single-objective best possible layout, while the remaining references correlate to the system's multi-objective ideally suited layout. The financial benefits are a top concern for numerous researchers [151]. In addition, reliability and pollution-related objective functions became the most frequently utilized [152]. Additionally, the researcher suggested that in order to develop optimal HRE plants, three objective functions, which include RF, CE, and LCC, be collaboratively assessed [153]. Since CE and RF are both considered to mitigate emissions target functions, their inclusion to create a proper size is voluntary. In [154], the author considered not just traditional constraints such as WT hub height and PV inclination angle but also three objective functions.

As was discussed in the previous two segments, a solo or multifaceted meta-heuristic strategy is necessary for the best possible layout of an HRE plant in an electricity-generating network that is gentler on the natural environment. The most desirable HRE plant designs, however, fail to incorporate emission target functions due to the restricted number of DGs that can be used in green power generation plans. [155] describes the manner in which the author developed a PV/WT/BES hybrid system that was optimized for an assortment of 20 families, leading to affordable and emissions-free energy production with cheaper energy costs. The reliability of the meta-heuristic strategy for the best size of HRE plants has been evaluated in multiple studies, like [156], using four different strategies.

The author of [101] explored the support of both thermal and electrical loads utilizing a PV/thermal hybrid system. Furthermore, NGB/RES was designed to optimize [157]. The optimal HRES size was established utilizing an MBA in addition to the GWO-SCA [158, 159]. The WT/PV/BES and PV/WT/BG hybrid systems have been enhanced with the incorporation of PSO [160, 161]. For supplying loads in a beach community, a PV/WT/PHS hybrid system was developed [162]. Such a strategy performs very effectively in coastal areas because there's plenty of seawater readily accessible to PHS. The PSO strategy, which has numerous objectives, became the strategy with the most widespread adoption and broadest applicability. The current investigation takes into account objective functions including unpredictability [163], the reduction of overall energy costs, and the possibility of power supply failure [164]. PV/WT/FC [165], PV/WT/PHS [166], PV/WT/BES [167], PV/WT/FC [168], and PV/BES/FC [169] comprised the HRES designs that were most often explored. However, the author [170] suggested a two-component PV/BES system that was enhanced.

TABLE V. Meta-heuristic optimization methods for HRES with single- and multi-objective capability optimization.

Hybrid System	Optimization Strategy	Objective Function	Design Constraints	Cost of Electricity	Ref.
WT/PV/FC	FFIA-HSO	NPC	Balance of power; Techno-economics	PoU	[171]
PV/WT/FC	GWO-SCA	LCC	NS	PoU	[172]
PV/WT/PHS/BES	FA	NPC	Components count; SOC; battery power	PoU	[173]
PV/WT/MT/TES/NGB/EES	E-PSO	TAC	Investment cost; O&M cost; Fuel cost; Replacement cost; Energy management system prioritizes the application	PoU	[174]
PV//WT/PHS	GA	LPSP	Balance of power; Techno-economic viability	PoU	[175]
PV/WT/PHSS	WOA	COE	Balance of power; Economic Plan	PoU	[176]
PV/WT /BES	CSA-PSO	Reduction of energy production cost	Distribution of energy supply-demand planning	PoU	[177]
PV/WT/BES/BG/DG	GWO-PSO	LPSP; COE	The most affordable configuration	PoU	[178]
PV/WT/BES	GA-III (NSGA-III)	Total cost; End-user satisfaction loss; Tie-line power fluctuation	Balance of power; Economic Plan	PoU	[179]
PV/WT/FC/BES	PPO	Overall economic cost saving; Carbon emission reduction	Balance of power; Techno-economic viability	PoU	[180]
PV/WT/DG/BES	MOMVO	LPSP; COE; RF	Appropriate electrical load; Techno-economic viability	PoU	[181]
PV/WT/BES/FC	WOA	LPSP; NPC; COE	Generate enough power to meet the required load; Minimal cost	ToU	[182]
PV/FC/BW	WOA	LPSP; NPC	Appropriate electrical load; The best possible configuration; Techno-economic viability	NS	[183]
PV/WT/BM/PHS	WOA	COE; LPSP	Reliability limitations Operational limitations	PoU	[184]
PV/WT/DG/BES	GA-II (NSGA-II)	CO_2 emissions; COE; NPC	Balance of power; Techno-economic viability	PoU	[185]

This article has been accepted for publication in IEEE Access. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2025.3535520

According to the summary of papers in Table V, the most significant strength of every investigation program is the authors' strategy for solving the community's electrical problems. The references provided in [173, 175, 176, 178, and 185] well outperform the rest of the research papers presented in terms of their financial and ecological ramifications.

Summary: Each hybrid system has a DG, except when problems with power shortages in the whole community are emphasized in the evaluations shown in Table IV due to different factors. DGs are not merely unsustainable commercially; additionally, they are also hazardous ecologically. Additionally, BES is not fully financially feasible. For assurance that the wholly innovative, completely sustainable hybrid structure design utilized on the plant reflects all of the aforementioned advantages and downsides, further study is required. DGs cannot meet the financial and ecological demands of a hybrid system. Consequently, BES is also not a practical alternative financially. Future research needs to take into consideration the benefits and drawbacks, and the ecologically sound hybridization system's layout should be developed with these in perspective.

Furthermore, the future investigator should solve the problems by integrating meta-heuristic optimization strategies to cope with both the desired function and the constraints.

V. Most Common and Cutting-Edge Renewable Energy Storage Systems

Electrical [185], Electro-chemical [186], thermal [187] mechanical, and hybrid or multi-storage systems are the most prevalent and cutting-edge sorts of ESS [188]. Fig. 8 outlines the most common and cutting-edge types of ESS technologies.

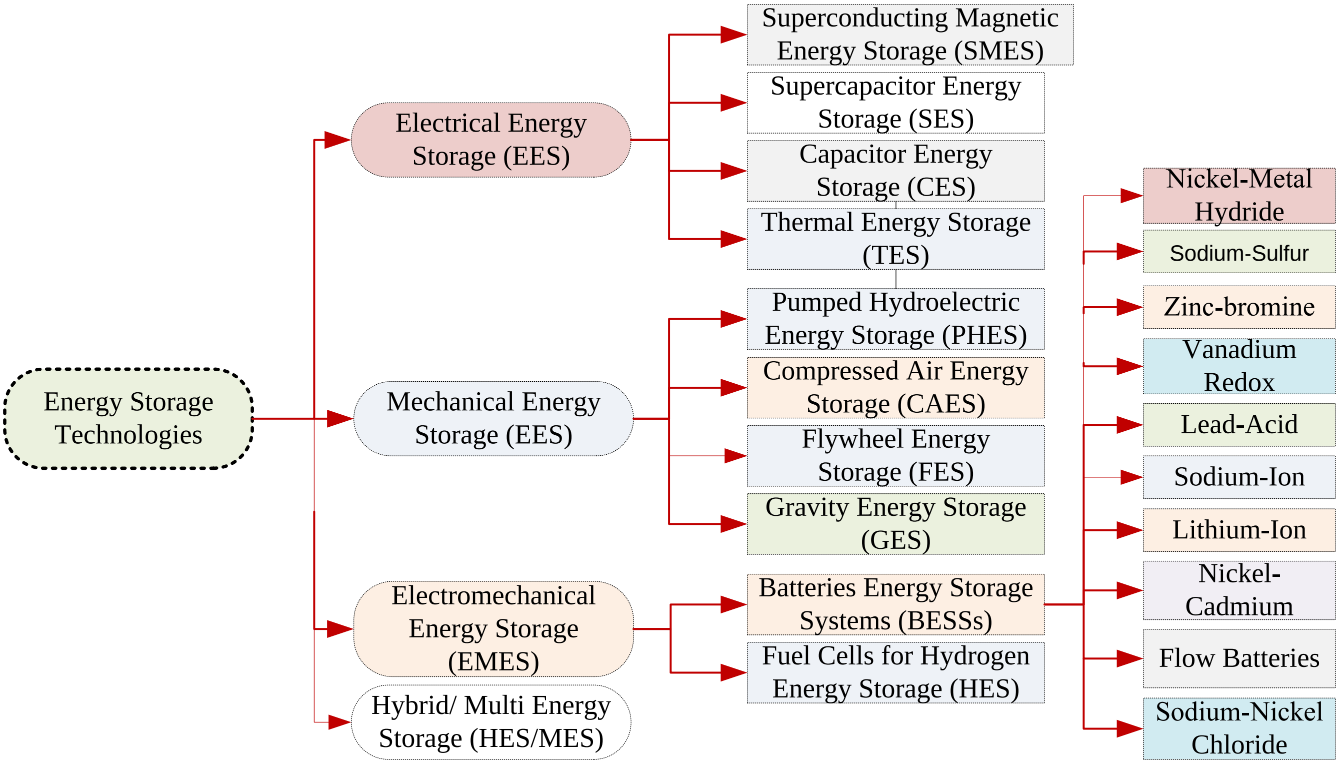


FIGURE 8. Technologies for energy storage systems

Battery and fuel cell technology are only two kinds of electrochemical storage (ES) systems that find broad usage [189]. The benefits of ES are numerous [190]. It's adaptable to different power and energy storage needs, and it's modular and expandable [191]. As an additional benefit, several forms of electrochemical storage technology exhibit very high degrees of round-trip efficiency. However, there are downsides to ES as well, such as the fact that it demands specialized structures, has a short lifespan, and is expensive to implement [192].

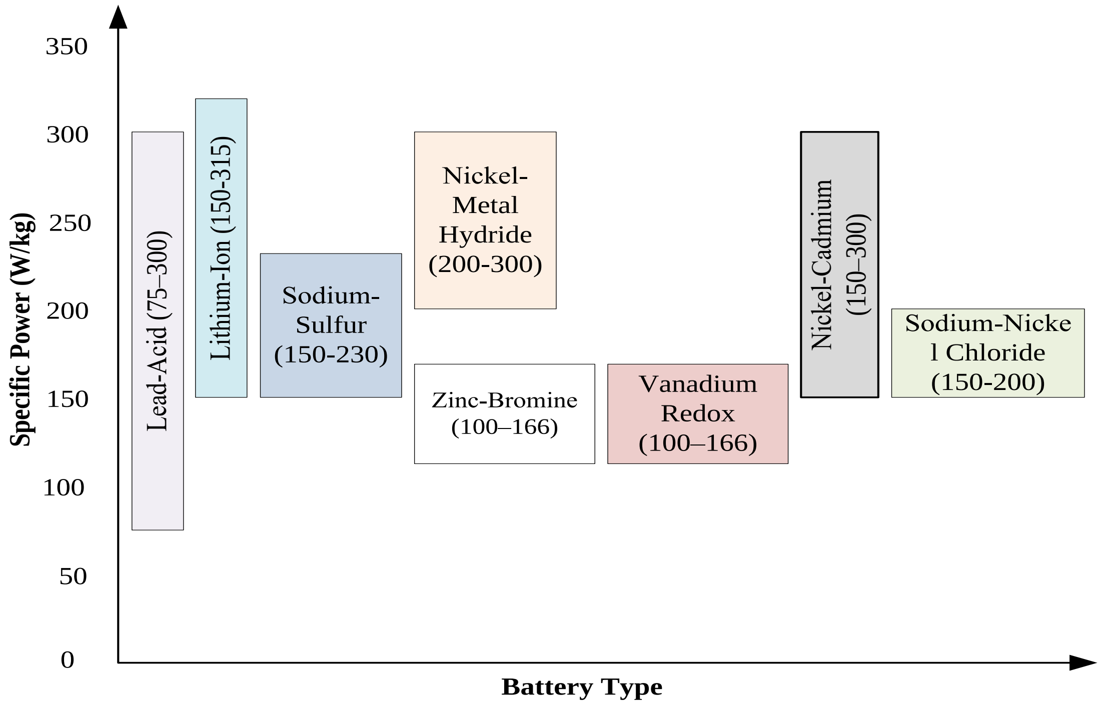
Table VI and Fig. 9 summarize some of the most important aspects of these BS, comprising their price [193], technology [194], durability [195], cycle [46], power density, and performance [196]. These numbers change based on the battery type, manufacturer, and intended use.

TABLE VI: Features of the most popular batteries.

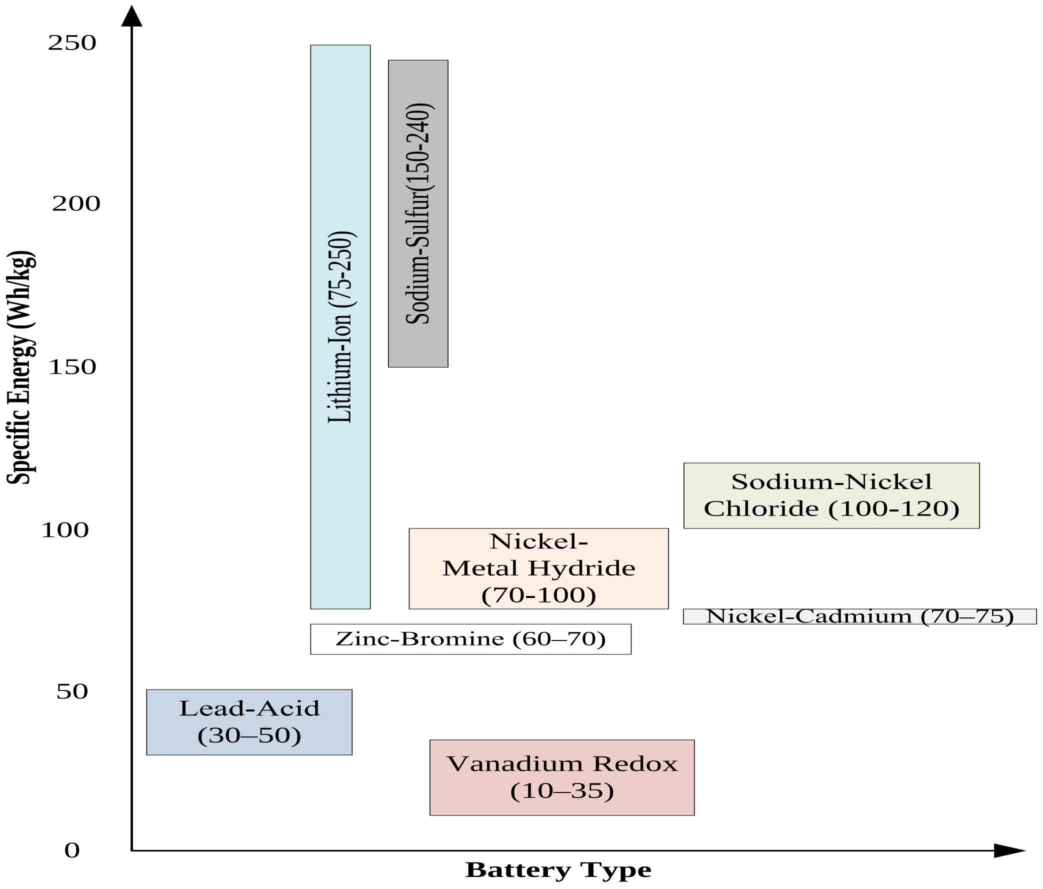
Battery Type	Technology	Cost	Ref.
Lead-Acid	O	L	[46, 180, 181]
Lithium-Ion	A	H	[182,183]
Sodium-Sulfur	A	H	[183, 185]
Zinc-Bromine	A	H	[186]
Vanadium Redox	A	H	[187]
Nickel-Cadmium	O	M	[188,189]
Nickel-Metal Hydride	O	M	[184]
Sodium-Nickel Chloride	A	H	[186]

> L=Low, M=Moderate, H=High, O=Old, A=Advanced

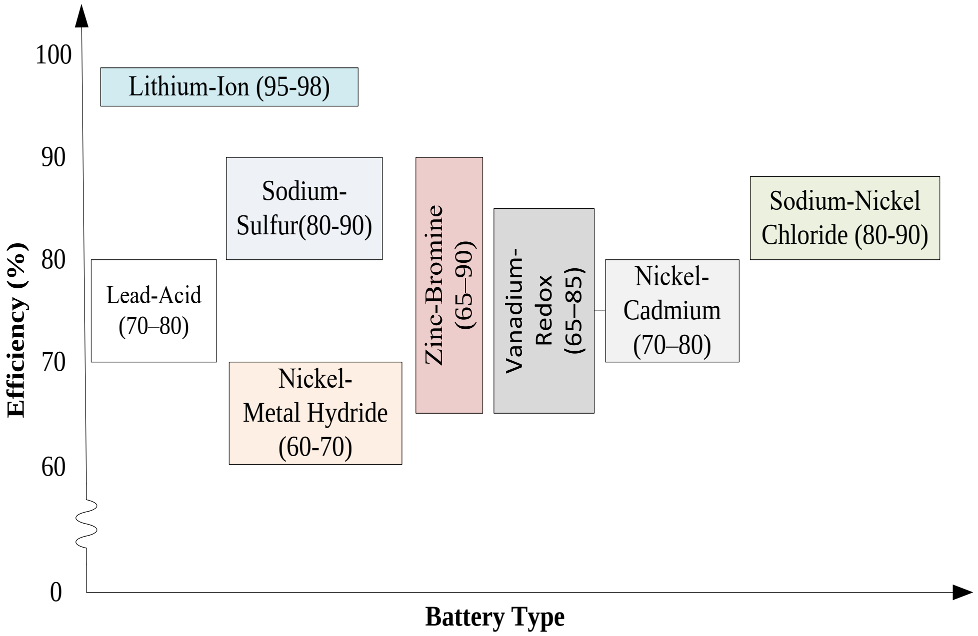
This article has been accepted for publication in IEEE Access. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2025.3535520



(a) Correlation between the most popular batteries and specific power



(b) Correlation between the most popular batteries and specific energy



(c) Correlation between the most popular batteries and efficiency

FIGURE 9: Correlation of the most popular batteries

The continually declining capital costs ($/kWh-cycle) of certain storage systems are depicted in Figure 10. The levelized cost outlined in the diagram normalizes the capital cost throughout the course of the project by taking into account the total expected cycle life, or the operational lifespan, of the technology [1].

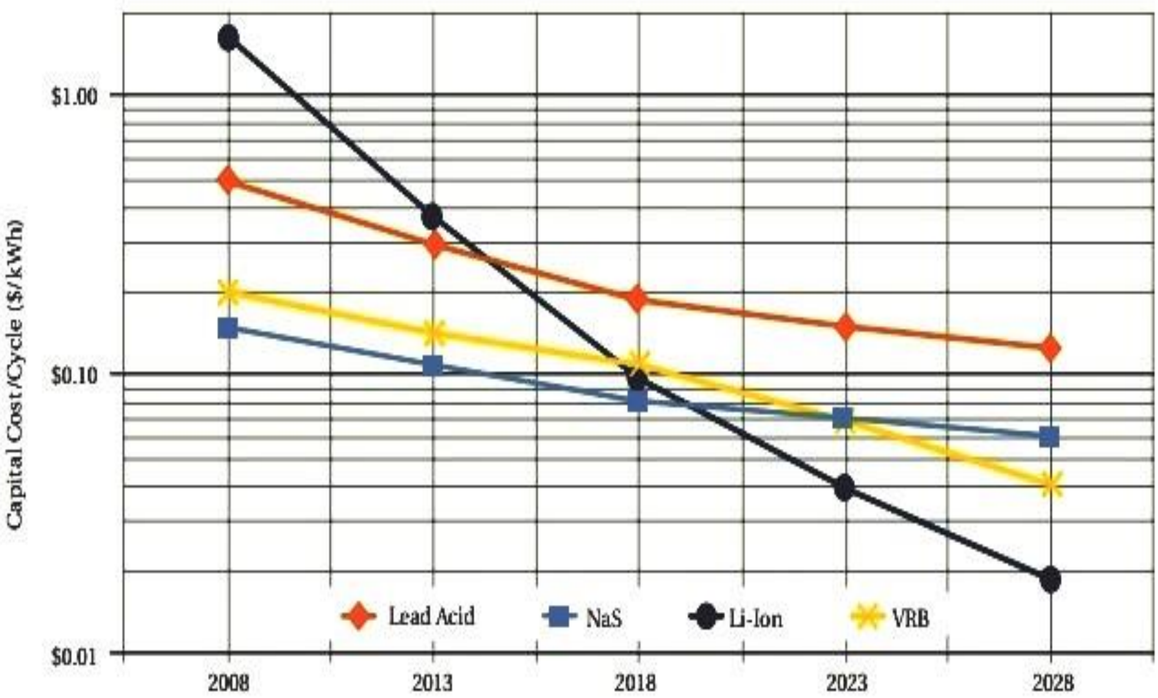


FIGURE 10: Predicted levelized capital costs, sorted by the most prevalent and widely used forms of storage

For storing the hydrogen (H_2) that an electrolyzer produces, a container is necessary. The H_2 is stored and then injected into a FC as necessary, where it reacts with O_2 to produce water and useful energy. Energy storage by HES has numerous benefits over other methods. Independent or remote areas can significantly benefit from this RES-

This article has been accepted for publication in IEEE Access. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2025.3535520

generated, long-term-storable energy source as a substitute for grid-supplied ESS. Furthermore, it is a reliable and flexible source of energy. Nonetheless, HES does have a few shortcomings. The manufacturing and storage costs of hydrogen may be greater than those of certain competing energy storage methods. It may be costly to establish and maintain the specialized infrastructure needed for HES, which includes components like pipes and fuel cells. The benefits and drawbacks of the distinct hydrogen storage methodologies employed by HES are outlined in Table VII [2].

TABLE VII: The benefits and drawbacks of the distinct hydrogen storage methodologies employed by HES

Storage Type	Benefits	Drawbacks
CHS	Very little maintenance needed No chemical processes involved Prolonged durability in storage	Preferably at high pressures There must be large tanks for storage Energy is needed for compression Compressing gases produces heat If tanks are cracked, there is a risk of leakage
LHS	Low maintenance No chemical processes involved Prolonged durability in storage	Cryogenic temperatures are needed There must be large tanks for storage It's possible for boil-off losses to be rather high Cryogenic temperature maintenance is notoriously difficult and costly If tanks are cracked, there is a risk of leakage
MHS	Very little maintenance needed No risk of injury, and simple to use Prolonged durability in storage	Restricted by the metal hydride's carrying capacity High temperatures and/or pressures may be necessary It may take time to charge or discharge Comparatively lower energy density compared to compressed or liquid hydrogen storage One possible obstacle is the high price and limited supply of metal hydride materials

> CHS= Compressed Hydrogen Storage, LHS= Liquefied Hydrogen Storage, MHS= Metal-Hydride Storage

The design of efficient and dependable RESs depends greatly on the modelling and size of batteries in photovoltaic (PV) systems and also on EMS of ESS technologies. The benefits and downsides of RESs, which collect energy from naturally replenishing sources, varied based on the technology used, the region, and the deployment scenario (Table VIII) [2].

TABLE VIII: The benefits and downsides of RESs.

Benefits	Drawbacks
Green: safe for the environment	The intermittent and variable nature
Long-lasting and aplenty	Highly expensive to begin with
Diversifying one's energy source	Necessary Acreage and Materials
Prosperous monetary outcomes	Challenges with transmission and infrastructure
Betterment of community health	Limits on the ability to store energy

The expenses and savings realized by adopting a BESS may vary greatly depending on the laws and regulations and market situations in a specific location. When weighing the benefits and drawbacks of BESSs (Table IX), it's crucial to take into account the consumer's specific scenario and demands.

Table IX: The benefits and drawbacks of BESSs.

Benefits	Drawbacks
▪ Adaptability in energy storage	▪ High initial expenses
▪ Integrating renewable energy sources more effectively	▪ Restricted capacity to store energy
▪ Peak shaving and grid stabilisation	▪ Concerns for the Environment
▪ During blackouts, backup power	▪ The longevity and battery deterioration
▪ Demand control and load balancing	▪ Regulatory and safety-related difficulties

Table X: Prominent features of ESSs used in PV power systems.

ESS	Major Features	Benefits	Drawbacks	Ref.
Lead-acid Batteries	Cheaper Easily accessible	Design Simplicity straightforward in terms of maintain Tested and tried techniques	Reduced longevity Reduced energy density A restricted number of charge/discharge cycles	[196]

This article has been accepted for publication in IEEE Access. This is the author's version which has not been fully edited and
content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2025.3535520

Lithium-ion Batteries	Greater Power Density Increased longevity	Charging and discharging quickly and effectively Reduced rate of self-discharge	Expensive Possible Risks to Safety BMS is required	[197]
Flow Batteries	Scalable Increased longevity	May be completely discharge without crack or damage	Very sophisticated design Reduced energy density	[198]
Redox Flow Batteries	High capacity for expansion Greater longevity in comparison to numerous battery sorts	Well suited for uses that call for a slow, steady discharge	Periodical maintenance is required Expensive in comparison to lead-acid and certain types of lithium-ion batteries Poor energy density compared to other battery types	[199,200]
Sodium-Sulfur Batteries	Intense energy density	Superior durability compared to other common battery options	Expensive compared to lead-acid batteries Current manufacturing constraints cause very limited numbers available	[201]
Supercapacitors	Quick charging Intense power density	Extremely durable Minimal maintenance	Capacity constraints for energy storage Expensive Overcharging and discharging must be controlled by a separate circuit	[202]
Flywheel Systems	Quick reaction Increased longevity	Extremely productive Non-hazardous materials only	Expensive Technical precision is required	[203]
Hydrogen Fuel Cells	Intense energy density Increased longevity	Capable of continuous operation Zero emissions	Expensive Hydrogen fueling infrastructure is required	[204]
Compressed Air Energy Storage (CAES)	Lower cost than certain other technologies	Intense energy capacity	Needs caves or subterranean tanks for storage Small-scale use not recommended	[205]
Pumped Hydro Energy Storage (PHES)	Intense energy capacity Fully developed technology	Extremely durable	Only for use in very large installations Expensive to construct	[200,206]
Thermal Energy Storage (TES)	Fully developed technology Intense energy density	Easily adaptable to preexisting heating and cooling infrastructures	Expensive to construct Small-scale use not recommended	[207]
Capacitor Banks	Quick reaction High capacity to cycle	Minimal maintenance	Inadequate for storing energy in the long-term	[208]
Gravity Storage	Less expensive than competing technologies Superb effectiveness	The absence of potentially harmful substances	Comparatively low energy storage capacity when compared to other technologies	[209]

Summary: Considerations like charging and discharging cycles, available storage space, and the potential for expansion should be made. The storage price and the expected lifetime (in terms of cycle frequency before degradation sets in) should both be included in any cost-benefit assessments. Cost, reliability, and environmental impact will each play a role in determining whether or not a certain energy storage system is a good fit for a given photovoltaic system (Table X).

VI. Role of ESS in HRE Power Plants

One of the most significant disadvantages of utilizing it is that it's incapable of providing reliable electrical power because of its unpredictable nature [210]. The utilization of ESSs is beneficial for conserving energy during instances of minimal demand while supplying it during instances of substantial demand [211]. Uninterrupted electric power on demand cannot be achieved without storage technology [212]. The possibilities for storage of HRES include PHS, CAES, SC, FWES, BES, SMES, etc [213]. These tools are frequently utilized in extremely expensive systems. On the other hand, they can be utilized to maintain an uninterrupted power supply regardless of deteriorating HRES situations [214]. The BESS serves as one of the most prevalent ESSs presently in operation [215]. As a result, coupling HRES with BESS is not just an appealing possibility in India but also internationally as a feasible isolated solution [216]. During the past few years, MGs' prominence has risen as their implementation in electrical distribution systems via small-scale HRES has become more prevalent. Furthermore, numerous hybrid MG models for the HRES system have been presented in studies [217], and the MG paradigm has been believed to be the better choice for rural electrification.

MGs have been viewed as the cleanest, cheapest, most consistent, and most reliable energy source today. An MG is an independent power plant that can generate sufficient power for families or communities. Due to their prevalence, HRES provide a promising potential for electrifying far-flung regions [218]. SPVs and WTs are only two examples of energy-conversion technologies that can be combined in hybrid designs, namely the MGs or the HRES. Additionally, there will be fewer variations in generation, investment, and storage space system size with these hybrid configurations, and the system's resiliency and performance will get better as an outcome [219]. Therefore, the ESSs serve as a backup source for electricity whenever the HRES's electrical output is inconsistent. When combined with the HRES, the ESS enhances the reliability of the system while decreasing overall costs [220].

Utilizing meta-heuristic optimization approaches, the optimum size of HRES with ESS setups is projected in Table XI. In addition, the HRES's steady power supply to meet demand ensures the system's reliability [217]. DGs are employed to maintain power and everything functioning throughout HRES. MGs driven by RESs have the potential to operate in island configuration, greatly minimizing the requirement for fossil fuels. There are substantial financial and ecological benefits as an outcome [220]. To reliably fulfill the energy requirements of load centers, therefore, regional HRES combined with ESS is recommended.

The collection of studies in Table XI highlights the researchers' utilization of unpredictable forms of energy generation like solar and wind as an answer to society's energy problems. As far as the bottom line is concerned, BES is far superior to the other ESS. Moreover, PHS, FC, and BES are unable to capitalize quickly when a peak demand arises suddenly; so, researchers should add quick-responding ESSs like SMES and FWES on the sporadic HRES. All of these pros and cons ought to be considered seriously when designing the eventual HRES system that will ultimately be used on the system; subsequently, more research must be conducted.

TABLE XI: Size optimisation of HRES with ESS utilizing meta-heuristic strategies

Hybrid System	Optimization Strategy	Objective Function	Design Constraints	Cost of Electricity	Ref.
WT/PV/BES	FFIA	COE	Battery energy; Components Count; Load disappointment index	PoU	[221]
PV/BES/BG/PHES	WCA	LPSP; NPC	Components Count; SOC; Top Reservoir Capacity;	PoU	[222]
PV/WT/FC	ABSO	LCC; LPSP	Probability of Load Interruptions; Components Count; Tank energy	PoU	[223]
PV/BES	MADEA	LCC; LOLP; LCOE	SoC	PoU and RT-SWP	[224]
PV/WT/BES	MOGWA	COE; LPSP; DE	SoC	PoU	[225]
PV/WT/PHS/BES	MOGWA	COE; LPSP	Battery energy; PHS	PoU	[226]

Table XII summarizes technical and economic information pertaining to a selection of ESSs presently in operation for green and hybrid power options. Dispatching, effectiveness, longevity, accessibility, rapid reaction, energy investment cost, etc. are frequently mentioned as the most essential characteristics of storage systems. The PHES may render 100 to 5000 MW of power accessible, but BESSs can only render 0 to 40 MW of power accessible. It's a better solution than thermal and CESTs. The PHES's superior durability compared to other storage techniques is a major promotional feature. PHES offers a minimal initial investment for energy storage when compared to other systems. The author [227] stated that PHES plants are capable of rapidly starting up and shutting down, shifting loads, coping with fluctuations in frequency, and maintaining a steady voltage.

The article [228] highlights PHES technology as an invaluable tool for ensuring a steady flow of electricity to individuals and companies. When compared to other methods of energy storage, PHES typically has a much lower LCOE. Considering these benefits, the PHES system is undoubtedly superior to any other option. The Mo6+-P5+co-doped Li2ZnTi3O8 anode was suggested by the author in [229] for Li-storage in a wide spectrum of temperatures and for deployment in LiNi0.5Mn1.5O4/Li2ZnTi3O8 FCs. The author published his research findings in [230] regarding how digital twin technology can be used to promote the cooperative creation of significant technological innovations in the emerging field of energy-efficient automobiles. In [231], researchers explored the thermal performance of future possibilities for environmentally friendly and completely carbon-free fuels for nautical engines.

Author [232] provided a computational analysis of the ignition of ammonia and emissions characteristics in a sluggish 2-stroke nautical engine. The author of [233] offered an extensive research report on the topic of intelligent distribution networks that provide awareness of circumstances for exceptional O&M. In [234], the author suggested a regulatory algorithm for expanding the number of environmentally friendly businesses as the mechanism that drives the technological economy. In [235], the author states a refined technique for drift modification in olfactory detectors. The author of [236] suggested a novel weighted kernel for processing fragrance, which forms the basis of a semi-supervised machine learning technique. In [237], the author proposed the asymmetrical encoder-decoder framework for estimating the lifespan of Zn-ion batteries.

This article has been accepted for publication in IEEE Access. This is the author's version which has not been fully edited and
content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2025.3535520

Table XII. Technical and financial considerations for different energy storage (ES) strategies

ES Strategy	Investment Cost ($/kW)	Power Rating (MW)	Energy Density (Wh/kg)	Power Density (W/kg)	Life Cycle	Response Time	Life Expectancy	Efficiency (%)	Ref.
Lead Acid	300–600	0–40	24–45	180	1.5k–2k	5–10 ms	3–12	70–90	[238, 239]
SC	100–300	0.01–1	0.1–5	800–2000	100k+	<5 ms	10–20	85–95	[240, 241]
WES	110–330	0.01–10	10–30	400–1500	10k–100k	sec	15–20	70–95	[242, 243]
FC	500–10k	0.001–50	300–1.2k	500+	20k+	min	5–20	20–50	[244-246]
CAES	400–800	5–300	30–60	-	8k–12k	min	20–40	70	[247, 248]
SMES	200–300	0.1–10	0.5–5	500–2000	100k+	<5 ms	20–30	90–98	[249, 250]
PHS	600–4.3k	100–5k	0.5–1.	-	10k–30k	min	30–60	65–85	[251-252]

VII. Perspectives and Future Direction

In light of arising current capacity and peak demand for and supply, the PV/WT/PHS combination is viewed as an illustration of massive renewable energy promise. Incorporating the whole system can reduce return on investment time, COE, LPSP, and adverse environmental effects. A PHS system combined with a PV/BG system has been shown to enhance energy production reliability while minimizing expenditures on investments and operational expenses. As a side benefit, hybrid systems with grid connections often have a significant COE. The initial costs for getting power from RESs are substantially greater than the cost per kilowatt-hour (kWh) taken from the grid. Despite this, in recent years, it has been observed that RE's initial costs have decreased to a tolerable level.

For a reliable and consistent power supply, PHS continues to be linked to HRES, which relies on PV, WT, and BG, with a fossil fuel-powered plant serving as a backup. A number of scholars have investigated hybrid PHS designs as well. When contrasted with batteries and other storage solutions, the combined structure offers more effective round-trip efficacy, strengthened power supply reliability, lower revenue losses, lower expenses, an affordable capital cost, optimum accessible power, an extended lifespan, and a lower release of greenhouse gases. Based on previous studies, PHS and freshwater resources are two of the most feasible possibilities for HRES storage. For the HRES optimal size with ESS integration to overcome the aforementioned issues, a number of suggestions have been made:

- When integrated with ESS, the current state of HRES technologies can address the capacity, effectiveness, and reliability issues related to earlier technologies. Prospective applications of this technique in MG are being stated, as is the area of focus of its current advancement. Size, affordability, security, and effective utilization of energy are becoming more explored concerns.
- To identify the appropriate sizes for HRES and ESS system parts, it is necessary to combine smart strategies (meta-heuristic strategies) with the right ways to control them.
- Based on the framework's several objective functions, the simultaneous incorporation of RESs and the control of constraints can significantly raise its degree of complexity. Therefore, in order to successfully manage this level of complexity, a practical optimization strategy that has enhanced convergence, an optimal solution, a high degree of precision, and minimal control variables must be implemented.
- RES and storage device lifespan are both affected by the substances utilized to create them. The substances utilized can have a major impact on the requirements, such as capability, energy and power density, longevity, resistance to corrosion, and charging as well as discharging characteristics. Due to accessible, long-lasting, cutting-edge technology, MG programs can benefit from increased energy efficiency, credibility, and consistency in the substrate selection of HRES and ESS.
- When combined, the HRES and ESS designs offer a desirable distribution of energy. In addition to FC, PHS, CAES, and Li-ion batteries, there are several additional ESS that can be designed for broad implementation. In terms of medium-scale power control, TES devices, small and medium-sized power systems, flywheels, and flow batteries work admirably. Existing ESS management could benefit from an effective management system, particularly for HRES operations that need uninterrupted and reliable performance.
- For short-term requirements, lithium-ion is used, while pumped hydro and hydrogen are reserved for longer durations. Based on their projections, the Energy Commission contends that by the year 2040, lithium-ion batteries may play an essential role in a broad spectrum, flywheels may perform a minor role for restricted periods with elevated discharge frequency ranges, pumped hydro may play an essential role for the 16 to 60-hour

assortment, compressed air may play an important role for long periods, and H2 in FCs may serve the key role for the longest periods.

- Various ESS technologies are both space- and money-intensive because of their considerable size and complexity. An excessively sized ESS is inappropriate. The pricing is all-inclusive, including arrangements and maintenance. It also helps ensure the longevity of the data being stored. When combined, they can improve the overall storage capacity of the system. It would be difficult for traditional and RESs to implement an all-encompassing energy storage strategy.
- An ESS integrating the characteristics of both a high-power and a high-ESS is required for HRES in order to improve system reliability and consistency while reducing energy-related problems. High-power ESS systems obtain fast responses at elevated rates over a shorter duration of time, while high-energy systems respond slower over a longer duration of time. Integrating these two types of ESSs presents the benefits of superior power quality with associated loads.
- Software tools generally provide the most cost-effective strategy and do not steer consumers toward certain kinds of solutions based on performance metrics. The basic optimization strategy used in software tools is a "black box" that is hidden from the consumer and doesn't reveal if or how the results are obtained.
- The proper size of RE components is essential to attaining the appropriate technical effectiveness and dynamic responsiveness of the energy system. Tools for planning and improving energy systems in various consumer industries are few. As a result, a comprehensive tool that can examine the impact of components and resource uncertainties across an assortment of energy resources, demand sectors, and features must be constructed.
- Climate change has a significant impact on the resilience of HRE systems. Prospective research should look at the effects of changing weather patterns to see if hybrid electric power systems are more resistant to the effects of climate change. This is important because the local climate has a big impact on how much power is needed and what resources are available.
- To establish the site's long-term existence, a predefined operational policy can be put into practice. Considering the development of technology, numerous constraints can be eliminated. By selecting the most suitable PHS setting, transmission losses can be mitigated. PHS's integration with solar farms, which can operate independently of a power source, will minimize transmission expenses for both corporations. Raising public interest in the newest PHS requires disseminating awareness regarding how effective and practical the scheme is as an alternative to fossil fuels. Additionally, community involvement and dialogue can promote a rise in the public's interest. To increase visibility and acknowledgement, successful instances of initiatives that have been executed effectively must be made accessible to the general public.
- The production of harmful pollutants and atmospheric greenhouse gases will decrease as RESs produce more energy. By integrating intermittent HRES with ESS, energy costs can be reduced, along with fossil fuel and gas emissions. Researchers are working to minimize installation and maintenance expenses despite the fact that generating entirely renewable power is exorbitant.
- Very few studies have delved into HRES-appropriate designs from a technological, social, economic, ecological, and legislative perspective. HRESs have been optimized by taking account of the carbon footprint of RE elements, land requirements, and expenses associated with them, as well as social implications such as the eradication of power impoverishment, health effects, job prospects, etc.

Due to rising electrical requirements and the unpredictable nature of RESs, it has become more challenging to supply reliable energy to connected loads. An affordable and durable ESS can solve the issues of HRES's sporadic nature by lowering operational costs and reducing maintenance costs. Meanwhile, the sporadic characteristic of the HRES can be dealt with via integration in cooperation with technologies that store energy.

All existing forms of data storage are currently going through development aimed at making them more efficient and affordable for consumers to use. Graphene and other nanoscale concept-based materials have possibilities for increased efficiency in a number of EESs, including supercapacitors and thermal storage. It is anticipated that the value and economics of pumped hydro will increase with the addition of renewables like floating solar PV and digitalization. An additional factor pushing down prices needs to include competition and economies of scale.

There are a number of additional methods for storing mediums, but PHS is probably the most effective. The system improves upon its forerunners in a number of respects, including response time, start-up and shut-down times, load change management ease, base-load plant effectiveness, and discharge losses. Several researchers utilized PHS as a large-scale energy medium for HRES in their experiments and computations. The beneficial effect of PHS in a wide range of scenarios has been regularly shown by a number of studies. It represents one of the most trustworthy and technically feasible HRES supplies for utilization in any electrical demand field, whether off-grid or associated with the grid.

Three energy storage technologies may eventually stand out as the most prominent pioneers in their pursuit toward the Energy Transitions Commission's objective of achieving a carbon-free energy generation system by 2050. That's not to imply that other possibilities won't play a role; the most effective arrangement will depend on factors like specific use cases, market conditions, and many more. For short-term requirements, lithium-ion is used, while pumped hydro and hydrogen are reserved for longer durations. Based on their projections, the Energy Commission contends that by the year 2040, lithium-ion batteries may play an essential role in a broad spectrum, flywheels may perform a minor role for restricted periods with elevated discharge frequency ranges, pumped hydro may play an essential role for the 16 to 60-hour assortment, compressed air may play an important role for long periods, and H_2 in FCs may serve the key role for the longest periods.

VIII. Conclusion

This article's research focused on determining the optimal size of HRES systems, when combined with ESS, for any given system or building. Authors have classified the issues in the current investigations into subcategories based on whether they involve solo- or multi-objective solutions, and whether they utilize HRES (i.e., optimization methodologies or software tools). Researchers have investigated recent developments and ongoing challenges in determining the appropriate size of HRES and ESS systems for a building-based system. We have presented futuristic viewpoints to scholars to stimulate new areas of study. To help readers better understand how to tackle the optimization difficulty, this article delves into the optimization methodologies employed, combining objective functions and other evaluation criteria. The most popular program is HOMER, which facilitates optimization and sensitivity analyses, allows for a wide variety of possible RE combinations, and speeds up the process of comparing different system configurations. But using only one objective function limits HOMER's capabilities. Meta-heuristic optimization procedures are the focus of the current wave of studies. These are believed to outperform more conventional approaches due to their ability to seek global optimality, superior computing accuracy, and rapid convergence rates. Nevertheless, artificial strategies continue to face challenges because of their increased input requirements. This means that optimization tactics need to be far more sophisticated and precise. There is evidence that hybrid algorithms, which can solve multi-objective optimization problems and provide better results than solo algorithms, have attracted a lot more interest. Based on various research findings, the summary of the key contributions and innovation of this study as follows:

An in-depth review of design factors for the most commonly utilised storage. For the ESS to function in harmony with PV systems and operate at its best in terms of performance, dependability, and lifespan, the ESSs must be of an appropriate size.

BESS is now the most popular option for needs up to a few hours in size, for small-scale residential uses, and for electric-powered automobiles because of the remarkable cost drops that lithium-ion has experienced and will probably keep having in the future. However, when the necessary quantity of storage time expands, the possibilities change to include thermal, mechanical, pumped hydro, and eventually hydrogen.

To size HRES effectively, meta-heuristic optimization strategies are recommended. Although contemporary software tools exist, like the HOMER tool, they're incapable of tackling multi-objective problems. An additional drawback of the tool is that it makes it challenging to set response mechanisms for demand-side management. Thus, software can be implemented, allowing designers greater leeway to identify the optimal size for HRES systems.

Evaluation into appropriate meta-heuristic optimization strategies, hybridizing them, and accurately dealing with various objectives ought to be the main concern for the future of scientific study.

Acknowledgements

The MCN "IU/R&D/2023-MCN0002118" was provided by Integral University, Lucknow, and is gratefully acknowledged by the authors. The authors alone are accountable for the claims stated in this article.

References

[1] ISGF report on Energy Storage System Roadmap for India: 2019-2032. Available online: https://www.niti.gov.in/sites/default/files/2019-10/ISGF-Report-on-Energy-Storage-System-%28ESS%29-Roadmap-for-India-2019-2032.pdf (accessed on 01 May 2023).

[2] Amrouche, S.O.; Rekioua, D.; Rekioua, T.; Bacha, S. Overview of energy storage in renewable energy systems. Int. J. Hydrogen Energy 2016, 41, 20914–20927. https://doi.org/10.1016/j.ijhydene.2016.06.243

[3] Agajie, T.F.; Ali, A.; Fopah-Lele, A.; Amoussou, I.; Khan, B.; Velasco, C.L.R.; Tanyi, E. A Comprehensive Review on Techno-Economic Analysis and Optimal Sizing of Hybrid Renewable Energy Sources with Energy Storage Systems. Energies 2023, 16, 642. https://doi.org/10.3390/en16020642

[4] Zebra, E.I.C.; van derWindt, H.J.; Nhumaio, G.; Faaij, A.P. A review of hybrid renewable energy systems in mini-grids for off-grid electrification in developing countries. Renew. Sustain. Energy Rev. 2021, 144, 111036. https://doi.org/10.1016/j.rser.2021.111036

[5] Semaoui, S.; Arab, A.H.; Bacha, S.; Azoui, B. The new strategy of energy management for a photovoltaic system without extra intended for remote-housing. Sol. Energy 2013, 94, 71–85. https://doi.org/10.1016/j.solener.2013.04.029

[6] Robitaille, M.; Agbossou, K.; Doumbia, M.L. Modeling of an islanding protection method for a hybrid renewable distributed generator. In Proceedings of the Canadian Conference on Electrical and Computer Engineering, Saskatoon, SK, Canada, 1–4 May 2005; pp. 1477–1481. https://doi.org/10.1109/CCECE.2005.1557259

[7] Jha, S.K.; Bilalovic, J.; Jha, A.; Patel, N.; Zhang, H. Renewable energy: Present research and future scope of Artificial Intelligence. Renew. Sustain. Energy Rev. 2017, 77, 297–317. https://doi.org/10.1016/j.rser.2017.04.018

[8] Moria, H. Techno-Economic Optimization of Solar/Wind Turbine System for Remote Mosque in Saudi Arabia Highway: Case Study. Int. J. Eng. Res. 2019, V8, 090037. http://dx.doi.org/10.17577/IJERTV8IS090037

[9] Mamaghani, A.H.; Escandon, S.A.A.; Najafi, B.; Shirazi, A.; Rinaldi, F. Techno-economic feasibility of photovoltaic, wind, diesel and hybrid electrification systems for off-grid rural electrification in Colombia. Renew. Energy 2016, 97, 293–305. https://doi.org/10.1016/j.renene.2016.05.086

[10] Siddaiah, R.; Saini, R.P. A review on planning, configurations, modeling and optimization techniques of hybrid renewable energy systems for off grid applications. Renew. Sustain. Energy Rev. 2016, 58, 376–396. https://doi.org/10.1016/j.rser.2015.12.281

[11] Kazem, H.A.; Chaichan, M.T. Evaluation of grid-connected photovoltaic system in Omani harsh weathers CO2. AIP Conf. Proc. 2022, 2415, 030006. https://doi.org/10.1063/5.0092304

[12] Kazem, H.A.; Chaichan, M.T.; Al-Waeli, A.H.; Sopian, K. Evaluation of aging and performance of grid-connected photovoltaic system northern Oman: Seven years' experimental study. Sol. Energy 2020, 207, 1247–1258. https://doi.org/10.1016/j.solener.2020.07.061

[13] Wang, G.; Xin, H.; Wu, D.; Ju, P. Data-driven probabilistic small signal stability analysis for grid-connected PV systems. Int. J. Electr. Power Energy Syst. 2019, 113, 824–831. https://doi.org/10.1016/j.ijepes.2019.06.004

[14] Su, S.; Yan, X.; Agbossou, K.; Chahine, R.; Zong, Y. Artificial intelligence for hydrogen-based hybrid renewable energy systems: A review with case study. J. Physics Conf. Ser. 2022, 2208, 012013. https://doi.org/10.1088/1742-6596/2208/1/012013

[15] Sinha, S.; Chandel, S. Review of recent trends in optimization techniques for solar photovoltaic–wind based hybrid energy systems. Renew. Sustain. Energy Rev. 2015, 50, 755–769. https://doi.org/10.1016/j.rser.2015.05.040

[16] Bashar, A.; Smys, S. Integrated renewable energy system for stand-alone operations with optimal load dispatch strategy. J.Electron. Inform. 2021, 3, 89–98. https://doi.org/10.36548/jei.2021.2.002

[17] Ullah, Z.; Elkadeem, M.R.; Kotb, K.M.; Taha, I.B.; Wang, S. Multi-criteria decision-making model for optimal planning of on/off grid hybrid solar, wind, hydro, biomass clean electricity supply. Renew. Energy 2021, 179, 885–910.Al-Quraan, A.; Al-Qaisi, M. Modelling, Design and Control of a Standalone Hybrid PV-Wind Micro-Grid System. Energies 2021, 14, 4849. https://doi.org//10.1016/j.renene.2021.07.063

[18] Yan, B.; Luh, P.B.; Warner, G.; Zhang, P. Operation and Design Optimization of Microgrids with Renewables. IEEE Trans. Autom. Sci. Eng. 2017, 14, 573–585. https://doi.org/10.1109/TASE.2016.2645761

[19] Pascasio, J.D.A.; Esparcia, E.A.; Castro, M.T.; Ocon, J.D. Comparative assessment of solar photovoltaic-wind hybrid energy systems: A case for Philippine off-grid islands. Renew. Energy 2021, 179, 1589–1607. https://doi.org/10.1016/j.renene.2021.07.093

[20] Amer, M.; Namaane, A.; M'Sirdi, N. Optimization of Hybrid Renewable Energy Systems (HRES) Using PSO for Cost Reduction. Energy Procedia 2013, 42, 318–327. https://doi.org/10.1016/j.egypro.2013.11.032

[21] Marocco, P.; Ferrero, D.; Lanzini, A.; Santarelli, M. Optimal design of stand-alone solutions based on RES + hydrogen storage feeding off-grid communities. Energy Convers. Manag. 2021, 238, 114147. https://doi.org/10.1016/j.enconman.2021.114147

[22] Bohre, A.K.; Sawle, Y.; Acharjee, P. Optimal design and techno-socio-economic analysis of hybrid renewable system for gird connected system. Renew. Energy Syst. 2021, 653–686. https://doi.org/10.1016/B978-0-12-820004-9.00024-3

[23] Fares, D.; Fathi, M.; Mekhilef, S. Performance evaluation of metaheuristic techniques for optimal sizing of a stand-alone hybrid PV/wind/battery system. Appl. Energy 2021, 305, 117823. https://doi.org/10.1016/j.apenergy.2021.117823

[24] Riaz, M.; Hanif, A.; Hussain, S.J.; Memon, M.I.; Ali, M.U.; Zafar, A. An Optimization-Based Strategy for Solving Optimal Power Flow Problems in a Power System Integrated with Stochastic Solar and Wind Power Energy. Appl. Sci. 2021, 11, 6883. https://doi.org/10.3390/app11156883

[25] Cai, W.; Li, C.; Agbossou, K.; Bénard, P.; Xiao, J. A review of hydrogen-based hybrid renewable energy systems: Simulation and optimization with artificial intelligence. J. Physics Conf. Ser. 2022, 2208, 012012. https://doi.org/10.1088/1742-6596/2208/1/012012

[26] Frimpong, S.O.; Millham, R.C.; Agbehadji, I.E. A Comprehensive Review of Nature-Inspired Search Techniques Used in Estimating Optimal Configuration Size, Cost, and Reliability of a Mini-grid HRES: A Systemic Review. In Computational Science and Its Applications—ICCSA 2021; Springer: Cham, Switzerland, 2021; pp. 492–507. https://doi.org/10.1007/978-3-030-87013-3_37

[27] Umar, T. Sustainable energy production from municipal solid waste in Oman. Proc. Inst. Civ. Eng. Eng. Sustain. 2022, 175, 3–11. https://doi.org/10.1680/jensu.21.00040

[28] Umar, T.; Egbu, C.; Ofori, G.; Honnurvali, M.S.; Saidani, M.; Opoku, A. Challenges towards renewable energy: An exploratory study from the Arabian Gulf region. Proc. Inst. Civ. Eng. Energy 2020, 173, 68–80. https://doi.org/10.1680/jener.19.00034

[29] Erdinc, O.; Uzunoglu, M. Optimum design of hybrid renewable energy systems: Overview of different approaches. Renew. Sustain. Energy Rev. 2012, 16, 1412–1425. https://doi.org/10.1016/j.rser.2011.11.011

[30] Upadhyay, S.; Sharma, M. A review on configurations, control and sizing methodologies of hybrid energy systems. Renew. Sustain. Energy Rev. 2014, 38, 47–63. https://doi.org/10.1016/j.rser.2014.05.057

[31] Lin, Y.-H.; Lin, M.-D.; Tsai, K.-T.; Deng, M.-J.; Ishii, H. Multi-objective optimization design of green building envelopes and air conditioning systems for energy conservation and CO_2 emission reduction. Sustain. Cities

Soc. 2020, 64, 102555. https://doi.org/10.1016/j.scs.2020.102555

[32] Al-Othman, A.; Tawalbeh, M.; Martis, R.; Dhou, S.; Orhan, M.; Qasim, M.; Olabi, A.G. Artificial intelligence and numerical models in hybrid renewable energy systems with fuel cells: Advances and prospects. Energy Convers. Manag. 2022, 253, 115154. https://doi.org/10.1016/j.enconman.2021.115154

[33] Kaur, H.; Gupta, S.; Dhingra, A. Analysis of hybrid solar biomass power plant for generation of electric power. Mater. Today: Proc. 2021, 48, 1134–1140. https://doi.org/10.1016/j.matpr.2021.08.080

[34] Kumar, R.; Channi, H.K. A PV-Biomass off-grid hybrid renewable energy system (HRES) for rural electrification: Design, optimization and techno-economic-environmental analysis. J. Clean. Prod. 2022, 349, 131347. https://doi.org/10.1016/j.jclepro.2022.131347

[35] Kirim, Y.; Sadikoglu, H.; Melikoglu, M. Technical and economic analysis of biogas and solar photovoltaic (PV) hybrid renewable energy system for dairy cattle barns. Renew. Energy 2022, 188, 873–889. https://doi.org/10.1016/j.renene.2022.02.082

[36] Alam, M.S.; Chowdhury, T.A.; Dhar, A.; Al-Ismail, F.S.; Choudhury, M.S.H.; Shafiullah, M.; Hossain, M.I.; Hossain, M.A.; Ullah, A.; Rahman, S.M. Solar and Wind Energy Integrated System Frequency Control: A Critical Review on Recent Developments. Energies 2023, 16, 812. https://doi.org/10.3390/en16020812

[37] Sankarkumar, R.S.; Natarajan, R. Energy management techniques and topologies suitable for hybrid energy storage system powered electric vehicles: An overview. Int. Trans. Electr. Energy Syst. 2021, 31, e12819. https://doi.org/10.1002/2050-7038.12819

[38] Rekioua, D.; Bensmail, S.; Bettar, N. Development of hybrid photovoltaic-fuel cell system for stand-alone application. Int. J. Hydrogen Energy 2014, 39, 1604–1611. https://doi.org/10.1016/j.ijhydene.2013.03.040

[39] Ibrahim, H.; Ilinca, A.; Perron, J. Energy storage systems—Characteristics and comparisons. Renew. Sustain. Energy Rev. 2008, 12, 1221–1250. https://doi.org/10.1016/j.rser.2007.01.023

[40] Rekioua, D. Energy Management for PV Installations. Adv. Renew. Energ. Power Technol. 2018, 1, 349–369. https://doi.org/10.1016/B978-0-12-812959-3.00011-3

[41] Serir, C.; Rekioua, D.; Mezzai, N.; Bacha, S. Supervisor control and optimization of multi-sources pumping system with battery storage. Int. J. Hydrogen Energy 2016, 41, 20974–2098. https://doi.org/10.1016/j.ijhydene.2016.05.096

[42] Mebarki, N.; Rekioua, T.; Mokrani, Z.; Rekioua, D. Supervisor control for stand-alone photovoltaic/hydrogen/battery bank system to supply energy to an electric vehicle. Int. J. Hydrogen Energy 2015, 40, 13777–13788. https://doi.org/10.1016/j.ijhydene.2015.03.024

[43] Mokrani, Z.; Rekioua, D.; Rekioua, T. Modeling, control and power management of hybrid photovoltaic fuel cells with battery bank supplying electric vehicle. Int. J. Hydrogen Energy 2014, 39, 15178–15187. https://doi.org/10.1016/j.ijhydene.2014.03.215

[44] A.A. Khan, A. F. Minai (2023)"A Strategic Review: The Role of Commercially Available Tools for Planning, Modeling, Optimization, and Performance Measurement of Photovoltaic Systems", Energy Harvesting and Systems (EHS), ISSN: 2329-8766, https://doi.org/10.1515/EHS-2022-0157

[45] Aktas, A.; Kircicek, Y. Solar Hybrid Systems: Design and Application, Academic Press: Cambridge, MA, USA, 2021; pp. 1–356. https://doi.org/10.1016/B978-0-323-88499-0.00014-8

[46] Khan, A.A.; Minai, A.F.; Pachauri, R.K.; Malik, H. Optimal Sizing, Control and Management Strategies for Hybrid Renewable Energy Systems: A Comprehensive Review. Energies 2022, 15(17), 6249. https://doi.org/10.3390/en15176249

[47] Ansori, A.; Yunitasari, B.; Soeryanto; Muhaji. Environmentally Friendly Power Generation Technology with Solar PV-Biogas in Rural Areas of Eastern Java. IOP Conf. Series: Earth Environ. Sci. 2019, 239, 012030. https://doi.org/10.1088/1755-1315/239/1/012030

[48] Das B K and Zaman F 2019 Performance analysis of a PV/ Diesel hybrid system for a remote area in Bangladesh: Effects of dispatch strategies, batteries, and generator selection. Energy 169: 263–276. https://doi.org/10.1016/j.energy.2018.12.014

[49] Shezan SKA, Julaia S, Kibria MA, Ullah KR, Saidur R, Chong WT, et al. Performance analysis of an off-grid wind-PV (photovoltaic)-diesel-battery hybrid energy system feasible for remote areas. J Clean Prod. 2016;125:121–32. https://doi.org/10.1016/j.jclepro.2016.03.014

[50] Al Mahbub CMA, Kundu MS, Azad PA, Iqbal MT. Design and analysis of a hybrid power system for McCallum, NL, Canada. Eur J Electr Eng Comput Sci. 2023; 7.1:47–55. https://doi.org/10.24018/ejece.2023.7.1.487

[51] Erasmus M, Tabet F. Comparative analysis of hybrid renewable energy systems for off-grid applications in Southern Cameroons. Renew Energy. 2019; 135:41–54. https://doi.org/10.1016/j.renene.2018.11.105

[52] Baig MJA, Iqbal MT, Jamil M, Khan J. Design and analysis of an isolated DC-microgrid for a remote community in Pakistan. 2021 IEEE 12th Annual Ubiquitous Computing, Electronics & Mobile Communication Conference (UEMCON). IEEE; 2021. https://doi.org/10.1109/UEMCON53757.2021.9666665

[53] Fazelpour F, Soltani N, Rosen MA. Feasibility of satisfying electrical energy needs with hybrid systems for a medium-size hotel on Kish Island, Iran. Energy. 2014; 73:856–65. https://doi.org/10.1016/j.energy.2014.06.097

[54] Ansari, M.S.; Jalil, M.F.; Bansal, R. A review of optimization techniques for hybrid renewable energy systems. Int. J. Model. Simul. 2022, 1–14. https://doi.org/10.1080/02286203.2022.2119524

[55] Bansal, A.K. Sizing and forecasting techniques in photovoltaic-wind based hybrid renewable energy system: A review. J. Clean. Prod. 2022, 369, 133376. https://doi.org/10.1016/j.jclepro.2022.133376

[56] Abd El-Sattar, H.; Kamel, S.; Hassan, M.H.; Jurado, F. Optimal sizing of an off-grid hybrid photovoltaic/biomass gasifier/battery system using a quantum model of Runge

Kutta algorithm. Energy Convers. Manag. 2022, 258, 115539. https://doi.org/10.1016/j.enconman.2022.115539

[57] A. A. Khan, A. F. Minai, L. Devi, Q. Alam and R. K. Pachauri, "Energy Demand Modelling and ANN Based Forecasting using MATLAB/Simulink," 2021 International Conference on Control, Automation, Power and Signal Processing (CAPS), 2021, pp. 1-6, https://doi.org/10.1109/CAPS52117.2021.9730746

[58] Khan A. A. et al 2024. Feasibility and Techno-Economic Assessment of a 128kWp Grid-Tied SPV System using HOMER Pro. J. Phys.: Conf. Ser. 2777 012008. https://doi.org/10.1088/1742-6596/2777/1/012008

[59] A. F. Minai, M.A. Husain, M. Naseem, A.A. Khan, (2021). Electricity Demand Modeling Techniques for Hybrid Solar PV System. International Journal of Emerging Electric Power System (IJEEPS), ISSN: 1553-779X, 2021. https://doi.org/10.1515/ijeeps-2021-0085

[60] M. Kumar, A. F. Minai, A. A. Khan and S. Kumar, "IoT based Energy Management System for Smart Grid," 2020 International Conference on Advances in Computing, Communication & Materials (ICACCM), 2020, pp. 121-125, https://doi.org/10.1109/ICACCM50413.2020.9213061

[61] Kumar, P.; Pal, N.; Sharma, H. Optimization and techno-economic analysis of a solar photo-voltaic/biomass/diesel/battery hybrid off-grid power generation system for rural remote electrification in eastern India. Energy 2022, 247, 123560. https://doi.org/10.1016/j.energy.2022.123560

[62] Yuan, J.; Xu, J.; Wang, Y. Techno-economic study of a distributed hybrid renewable energy system supplying electrical power and heat for a rural house in China. IOP Conf. Series: Earth Environ. Sci. 2018, 127, 012001. https://doi.org/10.1088/1755-1315/127/1/012001

[63] Nuvvula, R.S.S.; Devaraj, E.; Teegala, S.K. A hybrid multiobjective optimization technique for optimal sizing of BESS-WtEsupported multi-MW HRES to overcome ramp rate limitations on thermal stations. Int. Trans. Electr. Energy Syst. 2021, 31, e13241. https://doi.org/10.1002/2050-7038.13241

[64] Babaei, R.; Ting, D.S.-K.; Carriveau, R. Feasibility and optimal sizing analysis of stand-alone hybrid energy systems coupled with various battery technologies: A case study of Pelee Island. Energy Rep. 2022, 8, 4747–4762. https://doi.org/10.1016/j.egyr.2022.03.133

[65] Rezaei, M.; Dampage, U.; Das, B.K.; Nasif, O.; Borowski, P.F.; Mohamed, M.A. Investigating the Impact of Economic Uncertainty on Optimal Sizing of Grid-Independent Hybrid Renewable Energy Systems. Processes 2021, 9, 1468. https://doi.org/10.3390/pr9081468

[66] Bakht, M.P.; Salam, Z.; Bhatti, A.R.; Sheikh, U.U.; Khan, N.; Anjum, W. Techno-economic modelling of hybrid energy system to overcome the load shedding problem: A case study of Pakistan. PLoS ONE 2022, 17, e0266660. https://doi.org/10.1371/journal.pone.0266660

[67] Ali, F.; Ahmar, M.; Jiang, Y.; AlAhmad, M. A techno-economic assessment of hybrid energy systems in rural Pakistan. Energy 2020, 215, 119103. https://doi.org/10.1016/j.energy.2020.119103

[68] Li, G.; Yuan, B.; Ge, M.; Xiao, G.; Li, T.; Wang, J.-Q. Capacity configuration optimization of a hybrid renewable energy system with hydrogen storage. Int. J. Green Energy 2022, 19, 1583–1599. https://doi.org/10.1080/15435075.2021.2018323

[69] Román, V.B.; Baños, G.E.; Solís, C.Q.; Flota-Bañuelos, M.; Rivero, M.; Soberanis, M.E. Comparative study on the cost of hybrid energy and energy storage systems in remote rural communities near Yucatan, Mexico. Appl. Energy 2022, 308, 118334. https://doi.org/10.1016/j.apenergy.2021.118334

[70] Das, U.; Mandal, S.; Bhattacharjee, S.; Nandi, C. A review of different configuration of hybrid energy systems with case study analysis. Int. J. Environ. Sustain. Dev. 2021, 21, 116. https://doi.org/10.1504/IJESD.2022.119387

[71] Feng, L.; Zhang, X.; Li, X.; Li, B.; Li, Y.; Xu, Y.; Guo, H.; Zhou, X.; Chen, H. Performance analysis of hybrid energy storage integrated with distributed renewable energy. Energy Rep. 2022, 8, 1829–1838. https://doi.org/10.1016/j.egyr.2021.12.078

[72] Debnath, D.; Ray, S. Hybrid Energy System for an Academic Institution: A Case Study. In Renewable Energy Optimization, Planning and Control. Studies in Infrastructure and Control; Khosla, A., Aggarwal, M., Eds.; Springer: Singapore, 2021; pp. 31–39. https://doi.org/10.1007/978-981-16-4663-8_3

[73] Cebotari, S.; Benedek, J. Renewable Energy Project as a Source of Innovation in Rural Communities: Lessons from the Periphery. Sustainability 2017, 9, 509. https://doi.org/10.3390/su9040509

[74] Poggi, F.; Firmino, A.; Amado, M. Planning renewable energy in rural areas: Impacts on occupation and land use. Energy 2018, 155, 630–640. https://doi.org/10.1016/j.energy.2018.05.009

[75] Delicado, A.; Figueiredo, E.; Silva, L. Community perceptions of renewable energies in Portugal: Impacts on environment, landscape and local development. Energy Res. Soc. Sci. 2016, 13, 84–93. https://doi.org/10.1016/j.erss.2015.12.007

[76] Xu, D.; Zhou, B.; Chan, K.W.; Li, C.; Wu, Q.; Chen, B.; Xia, S. Distributed Multienergy Coordination of Multimicrogrids with Biogas-Solar-Wind Renewables. IEEE Trans. Ind. Inform. 2018, 15, 3254–3266. https://doi.org/10.1109/TII.2018.2877143

[77] Mohammad-Alikhani, A.; Mahmoudi, A.; Khezri, R.; Kahourzade, S. Multiobjective Optimization of System Configuration and Component Capacity in an AC Minigrid Hybrid Power System. IEEE Trans. Ind. Appl. 2022, 58, 4158–4170. https://doi.org/10.1109/TIA.2022.3160411

[78] Javeed, I.; Khezri, R.; Mahmoudi, A.; Yazdani, A.; Shafiullah, G. Optimal Sizing of Rooftop PV and Battery Storage for Grid-Connected Houses Considering Flat and Time-of-Use Electricity Rates. Energies 2021, 14, 3520. https://doi.org/10.3390/en14123520

[79] Khezri, R.; Mahmoudi, A.; Haque, M.H. Two-Stage Optimal Sizing of Standalone Hybrid Electricity Systems with Time-of-Use Incentive Demand Response. In Proceedings of the 2020 IEEE Energy Conversion Congress and Exposition (ECCE), Detroit, MI, USA, 11–15 October 2020; pp. 2759–2765. https://doi.org/10.1109/ECCE44975.2020.9236381

[80] Zhao, S.; Sun, W.; Li, J.; Gong, Y. Dynamic modeling of a proton exchange membrane fuel cell using chaotic binary shark smell optimizer from electrical and thermal viewpoints. Int. J. Energy Environ. Eng. 2022, 13, 1067–1080. https://doi.org/10.1007/s40095-022-00483-8

[81] Alramlawi, M.; Li, P. Design Optimization of a Residential PV-Battery Microgrid with a Detailed Battery Lifetime Estimation Model. IEEE Trans. Ind. Appl. 2020, 56, 2020–2030. https://doi.org/10.1109/TIA.2020.2965894

[82] Zhang, G.; Wang, W.; Du, J.; Liu, H. A multiobjective optimal operation of a stand-alone microgrid using SAPSO algorithm. J. Electr. Comput. Eng. 2020, 2020, 6042105. https://doi.org/10.1155/2020/6042105

[83] Khezri, R.; Mahmoudi, A.; Aki, H.; Muyeen, S.M. Optimal Planning of Remote Area Electricity Supply Systems: Comprehensive Review, Recent Developments and Future Scopes. Energies 2021, 14, 5900. https://doi.org/10.3390/en14185900

[84] El-houari, H.; Allouhi, A.; Rehman, S.; Buker, M.S.; Kousksou, T.; Jamil, A.; El Amrani, B. Design, simulation, and economic optimization of an off-grid photovoltaic system for rural electrification. Energies 2019, 12, 4735. https://doi.org/10.3390/en12244735

[85] El-Houari, H.; Allouhi, A.; Rehman, S.; Buker, M.; Kousksou, T.; Jamil, A.; El Amrani, B. Feasibility evaluation of a hybrid renewable power generation system for sustainable electricity supply in a Moroccan remote site. J. Clean. Prod. 2020, 277, 123534. https://doi.org/10.1016/j.jclepro.2020.123534

[86] Khezri, R.; Mahmoudi, A.; Aki, H. Optimal planning of solar photovoltaic and battery storage systems for grid-connected residential sector: Review, challenges and new perspectives. Renew. Sustain. Energy Rev. 2021, 153, 111763. https://doi.org/10.1016/j.rser.2021.111763

[87] Khan, A.; Javaid, N. Jaya Learning-Based Optimization for Optimal Sizing of Stand-Alone Photovoltaic, Wind Turbine, and Battery Systems. Engineering 2020, 6, 812–826. https://doi.org/10.1016/j.compeleceng.2020.106682

[88] Sadeghian, O.; Shotorbani, A.M.; Mohammadi-Ivatloo, B. Risk-averse scheduling of virtual power plants considering electric vehicles and demand response. Sched. Oper. Virtual Power Plants 2022, 54, 227–256. https://doi.org/10.1016/b978-0-32-385267-8.00016-0

[89] Kumar, A.; Kumar, K.; Kapoor, N.R. Optimization of renewable energy sources using emerging computational techniques. In Sustainable Developments by Artificial Intelligence and Machine Learning for Renewable Energies; Elsevier: Amsterdam, the Netherlands, 2022; pp. 187–236. https://doi.org/10.1016/B978-0-323-91228-0.00012-4

[90] Paliwal, P. A Technical Review on Reliability and Economic Assessment Framework of Hybrid Power System with Solar and Wind Based Distributed Generators. Int. J. Integr. Eng. 2021, 13, 233–252. https://publisher.uthm.edu.my/ojs/index.php/ijie/article/view/7124

[91] Diab AAZ, Sultan HM, Mohamed IS, Kuznetsov ON, Do TD. Application of different optimization algorithms for optimal sizing of PV/Wind/Diesel/Battery storage stand-alone hybrid microgrid. IEEE Access 2019; 7:119223–45. https://doi.org/10.1109/ACCESS.2019.2936656

[92] Askarzadeh A. Electrical power generation by an optimized autonomous PV/wind/tidal/battery system. IET Renew Power Gener 2016; 11. https://doi.org/10.1049/iet-rpg.2016.0194

[93] Chauhan A, Saini RP. A review on Integrated Renewable Energy System based power generation for stand-alone applications: configurations, storage options, sizing methodologies and control. Renew Sustain Energy Rev 2014; 38:99–120. https://doi.org/10.1016/j.rser.2014.05.079

[94] Nadjemi O, Nacer T, Hamidat A, Salhi H. Optimal hybrid PV/wind energy system sizing: application of cuckoo search algorithm for Algerian dairy farms. Renew Sustain Energy Rev 2017; 70:1352–65. https://doi.org/10.1016/j.rser.2016.12.038

[95] M. Thirunavukkarasu a, Yashwant Sawle b, Himadri Lala a. A comprehensive review on optimization of hybrid renewable energy systems using various optimization techniques. Renewable and Sustainable Energy Reviews 176 (2023) 113192. https://doi.org/10.1016/j.rser.2023.113192

[96] Sadeghi, D.; Ahmadi, S.E.; Amiri, N.; Marzband, M.; Abusorrah, A.; Rawa, M. Designing, optimizing and comparing dis-tributed generation technologies as a substitute system for reducing life cycle costs, CO_2 emissions, and power losses in residential buildings. Energy 2022, 253, 123947. https://doi.org/10.1016/j.energy.2022.123947

[97] Hassan, A.; Al-Abdeli, Y.M.; Masek, M.; Bass, O. Optimal sizing and energy scheduling of grid-supplemented solar PV systems with battery storage: Sensitivity of reliability and financial constraints. Energy 2022, 238, 121780. https://doi.org/10.1016/j.energy.2021.121780

[98] Fotopoulou, M.; Rakopoulos, D.; Stergiopoulos, F.; Voutetakis, S. A Review on the Driving Forces, Challenges, and Applications of AC/DC Hybrid Smart Microgrids. In Smart Grids Technology and Applications; John Wiley & Sons: Hoboken, NJ, USA, 2022. https://doi.org/10.5772/intechopen.101973

[99] Monteiro, V.; Martins, J.S.; Fernandes, J.C.A.; Afonso, J.L. Review of a Disruptive Vision of Future Power Grids: A New Path Based on Hybrid AC/DC Grids and Solid-State Transformers. Sustainability 2021, 13, 9423. https://doi.org/10.3390/su13169423

[100] Bouaouda, A.; Sayouti, Y. Hybrid Meta-Heuristic Algorithms for Optimal Sizing of Hybrid Renewable Energy System: A Review of the State-of-the-Art. Arch. Comput. Methods Eng. 2022, 29, 4049–4083. https://doi.org/10.1007/s11831-022-09730-x

[101] Gbadamosi, S.L.; Nwulu, N.I. Optimal Configuration of Hybrid Energy System for Rural Electrification of Community Healthcare Facilities. Appl. Sci. 2022, 12, 4262. https://doi.org/10.3390/app12094262

[102] Connolly D, Lund H, V Mathiesen B, Leahy M. A review of computer tools for analysing the integration of renewable energy into various energy systems. Appl Energy 2010; 87(4):1059–82. https://doi.org/10.1016/j.apenergy.2009.09.026

[103] Ammari C, Belatrache D, Touhami B, Makhloufi S. Sizing, optimization, control and energy management of hybrid renewable energy system—a review. Energy Built Environ 2022; 3(4):399–411. https://doi.org/10.1016/j.enbenv.2021.04.002

This article has been accepted for publication in IEEE Access. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2025.3535520

[104] Kavadias KA, Triantafyllou P. Hybrid renewable energy systems' optimisation. A review and extended comparison of the most-used software tools. Energies 2021; 14(24). https://doi.org/10.3390/en14248268

[105] Sinha S, Chandel SS. Review of software tools for hybrid renewable energy systems. Renew Sustain Energy Rev 2014; 32:192–205. https://doi.org/10.1016/j.rser.2014.01.035

[106] Khatib T, Ibrahim IA, Mohamed A. A review on sizing methodologies of photovoltaic array and storage battery in a standalone photovoltaic system. Energy Convers Manag 2016; 120:430–48. https://doi.org/10.1016/j.enconman.2016.05.011

[107] Seedahmed, M.M.; Ramli, M.A.; Bouchekara, H.R.; Milyani, A.H.; Rawa, M.; Budiman, F.N.; Muktiadji, R.F.; Hassan, S.M.U. Optimal sizing of grid-connected photovoltaic system for a large commercial load in Saudi Arabia. Alex. Eng. J. 2021, 61, 6523–6540. https://doi.org/10.1016/j.aej.2021.12.013

[108] El Boujdaini, L.; Mezrhab, A.; Moussaoui, M.A.; Jurado, F.; Vera, D. Sizing of a stand-alone PV–wind–battery–diesel hybrid energy system and optimal combination using a particle swarm optimization algorithm. Electr. Eng. 2022, 104, 3339–3359. https://doi.org/10.1007/s00202-022-01529-0

[109] Sahoo, S.; Swain, S.C.; Chowdary, K.V.; Pradhan, A. Cost and Feasibility Analysis for Designing a PV–Wind Hybrid Renewable Energy System (A Case Study for Campus-3, KIIT University, Bhubaneswar). In Innovation in Electrical Power Engineering, Communication, and Computing Technology; Springer: Berlin/Heidelberg, Germany, 2022; pp. 243–253. https://doi.org/10.1007/978-981-16-7076-3_22

[110] Kefif, N.; Melzi, B.; Hashemian, M.; Assad, M.E.H.; Hoseinzadeh, S. Feasibility and optimal operation of micro energy hybrid system (hydro/wind) in the rural valley region. Int. J. Low-Carbon Technol. 2021, 17, 58–68. https://doi.org/10.1093/ijlct/ctab081

[111] Al-Najjar, H.; Pfeifer, C.; Al Afif, R.; El-Khozondar, H.J. Performance Evaluation of a Hybrid Grid-Connected Photovoltaic Biogas-Generator Power System. Energies 2022, 15, 3151. https://doi.org/10.3390/en15093151

[112] Ren, Y et al. Optimal design of hydro-wind-PV multi-energy complementary systems considering smooth power output. Sustain. Energy Technol. Assess. 2022, 50, 101832. https://doi.org/10.1016/j.seta.2021.101832

[113] Pujari, H.K.; Rudramoorthy, M. Optimal design and techno-economic analysis of a hybrid grid-independent renewable energy system for a rural community. Int. Trans. Electr. Energy Syst. 2021, 31, e13007. https://doi.org/10.1002/2050-7038.13007

[114] Hassan, R.; Das, B.K.; Hasan, M. Integrated off-grid hybrid renewable energy system optimization based on economic, environmental, and social indicators for sustainable development. Energy 2022, 250, 123823. https://doi.org/10.1016/j.energy.2022.123823

[115] Olatomiwa, L.; Mekhilef, S.; Huda, A.S.N.; Sanusi, K. Techno-economic analysis of hybrid PV –diesel–battery and PV–wind–diesel–battery power systems for mobile BTS: The way forward for rural development. Energy Sci. Eng. 2015, 3, 271–285. https://doi.org/10.1002/ese3.71

[116] Rehman, S.; Habib, H.U.R.; Wang, S.; Buker, M.S.; Alhems, L.M.; Al Garni, H.Z. Optimal Design and Model Predictive Control of Standalone HRES: A Real Case Study for Residential Demand Side Management. IEEE Access 2020, 8, 29767–29814. https://doi.org/10.1109/ACCESS.2020.2972302

[117] Das, B.K.; Tushar, M.S.H.; Hassan, R. Techno-economic optimisation of stand-alone hybrid renewable energy systems for concurrently meeting electric and heating demand. Sustain. Cities Soc. 2021, 68, 102763. https://doi.org/10.1016/j.scs.2021.102763

[118] Kumar, S.; Sethuraman, C.; Chandru, G. Design of Optimum Sizing for Hybrid Renewable Energy System using HOMER Pro to Meet the Identical Load Demand at Selected Indian Cities. Int. J. Grid Distrib. Comput. 2021, 14, 1589–1607.http://sersc.org/journals/index.php/IJGDC/article/view/36949

[119] Raff, R.; Golub, V.; Kneževi´c, G.; Topi´c, D. Modeling of the Off-Grid PV-Wind-Battery System Regarding Value of Loss of Load Probability. Energies 2022, 15, 795. https://doi.org/10.3390/en15030795

[120] Mubaarak, S.; Zhang, D.; Chen, Y.; Liu, J.; Wang, L.; Yuan, R.; Wu, J.; Zhang, Y.; Li, M. Techno-Economic Analysis of Grid-Connected PV and Fuel Cell Hybrid System Using Different PV Tracking Techniques. Appl. Sci. 2020, 10, 8515. https://doi.org/10.3390/app10238515

[121] Zhu, T.; Wills, R.G.; Lot, R.; Kong, X.; Yan, X. Optimal sizing and sensitivity analysis of a battery-supercapacitor energy storage system for electric vehicles. Energy 2021, 221, 119851. https://doi.org/10.1016/j.energy.2021.119851

[122] Jahangir, M.H.; Javanshir, F.; Kargarzadeh, A. Economic analysis and optimal design of hydrogen/diesel backup system to improve energy hubs providing the demands of sport complexes. Int. J. Hydrogen Energy 2021, 46, 14109–14129. https://doi.org/10.1016/j.ijhydene.2021.01.187

[123] Pandyaswargo, A.H.; Wibowo, A.D.; Onoda, H. Socio-techno-economic assessment to design an appropriate renewable energy system for remote agricultural communities in developing countries. Sustain. Prod. Consum. 2022, 31, 492–511. https://doi.org/10.1016/j.spc.2022.03.009

[124] Goel, S.; Sharma, R. Optimal sizing of a biomass–biogas hybrid system for sustainable power supply to a commercial agricultural farm in northern Odisha, India. Environ. Dev. Sustain. 2019, 21, 2297–2319. https://doi.org/10.1007/s10668-018-0135-x

[125] Al-Ghussain, L.; Ahmad, A.D.; Abubaker, A.M.; Mohamed, M.A. An integrated photovoltaic/wind/biomass and hybrid energy storage systems towards 100% renewable energy microgrids in university campuses. Sustain. Energy Technol. Assess. 2021, 46, 101273. https://doi.org/10.1016/j.seta.2021.101273

[126] Adaramola M, Agelin-Chaab M, Paul S. Analysis of hybrid energy systems for application in southern Ghana. Energy Convers Manag 2014; 88: 284–95. https://doi.org/10.1016/j.enconman.2014.08.029

[127] Anastasopoulou, A.; Butala, S.; Patil, B.; Suberu, J.; Fregene, M.; Lang, J.; Wang, Q.; Hessel, V. Techno-Economic Feasibility Study of Renewable Power Systems for a Small-Scale Plasma-Assisted Nitric Acid Plant in Africa. Processes 2016, 4, 54. https://doi.org/10.3390/pr4040054

[128] Oviroh P, Jen T-C. The energy cost analysis of hybrid systems and diesel generators in powering selected base transceiver station locations in Nigeria. Energies 2018; 11. https://doi.org/10.3390/en11030687

[129] Rezk H, Alghassab M, Ziedan H. An optimal sizing of stand-alone hybrid PV-fuel cell-battery to desalinate seawater at Saudi NEOM city. Processes 2020; 8: 382. https://doi.org/10.3390/pr8040382

[130] Yimen N, Hamandjoda O, Meva'a L, B´enoît N, Nganhou J. Analyzing of a photovoltaic/wind/biogas/pumped-hydro off-grid hybrid system for rural electrification in sub-Saharan Africa—case study of djound´e in northern Cameroon. Energies 2018; 11: 2644. https://doi.org/10.3390/en11102644

[131] Rashid, M.U.; Ullah, I.; Mehran, M.; Baharom, M.N.R.; Khan, F. Techno-Economic Analysis of Grid-Connected Hybrid Renewable Energy System for Remote Areas Electrification Using Homer Pro. J. Electr. Eng. Technol. 2022, 17, 981–997. https://doi.org/10.1007/s42835-021-00984-2

[132] Shah, S.; Mahajan, D.; Varun, R.; Jain, V.; Sawle, Y. Optimal Planning and Design of an Off-Grid Solar, Wind, Biomass, Fuel Cell Hybrid Energy System Using HOMER Pro. In Recent Advances in Power Systems; Springer: Berlin/Heidelberg, Germany, 2022; pp. 255–275. https://doi.org/10.1007/978-981-16-6970-5_20

[133] Pujari, H.K.; Rudramoorthy, M. Optimal design, prefeasibility techno-economic and sensitivity analysis of off-grid hybrid renewable energy system. Int. J. Sustain. Energy 2022, 41, 1466–1498. https://doi.org/10.1080/14786451.2022.2058502

[134] Tay, G.; Acakpovi, A.; Adjei, P.; Aggrey, G.K.; Sowah, R.; Kofi, D.; Afonope, M.; Sulley, M. Optimal sizing and techno-economic analysis of a hybrid solar PV/wind/diesel generator system. IOP Conf. Ser. Earth Environ. Sci. 2022, 1042, 012014. https://doi.org/10.1088/1755-1315/1042/1/012014

[135] Hutasuhut, A.A.; Riandra, J.; Irwanto, M. Analysis of hybrid power plant scheduling system diesel/photovoltaic/microhydro in remote area. J. Phys. Conf. Ser. 2022, 2193, 012024. https://doi.org/10.1088/1742-6596/2193/1/012024

[136] Mahmud, S.; Kaihan, M.K.; Salehin, S.; Ferdaous, M.T.; Nasim, M. Hybrid renewable energy systems for a remote community in a high mountain plateau. Int. J. Energy Environ. Eng. 2022, 13, 1335–1348. https://doi.org/10.1007/s40095-022-00494-5

[137] Babatunde, O.; Denwigwe, I.; Oyebode, O.; Ighravwe, D.; Ohiaeri, A.; Babatunde, D. Assessing the use of hybrid renewable energy system with battery storage for power generation in a University in Nigeria. Environ. Sci. Pollut. Res. 2021, 29, 4291–4310. https://doi.org/10.1007/s11356-021-15151-3

[138] Khan, F.A.; Pal, N.; Saeed, S.H. Optimization and sizing of SPV/Wind hybrid renewable energy system: A techno-economic and social perspective. Energy 2021, 233, 121114. https://doi.org/10.1016/j.energy.2021.121114

[139] Osaretin, C.A.; Iqbal, T.; Butt, S. Optimal sizing and techno-economic analysis of a renewable power system for a remote oil well. AIMS Electron. Electr. Eng. 2020, 4, 132–153. https://doi.org/10.3934/ElectrEng.2020.2.132

[140] Yasin, A.; Alsayed, M. Optimization with excess electricity management of a PV, energy storage and diesel generator hybrid system using HOMER Pro software. Int. J. Appl. Power Eng. (IJAPE) 2020, 9, 267–283. http://doi.org/10.11591/ijape.v9.i3.pp267-283

[141] Anoune, K.; Laknizi, A.; Bouya, M.; Astito, A.; Ben Abdellah, A. Sizing a PV-Wind based hybrid system using deterministic approach. Energy Convers. Manag. 2018, 169, 137–148. https://doi.org/10.1016/j.enconman.2018.05.034

[142] Fathy, A.; Kaaniche, K.; Alanazi, T.M. Recent Approach Based Social Spider Optimizer for Optimal Sizing of Hybrid PV/Wind/Battery/Diesel Integrated Microgrid in Aljouf Region. IEEE Access 2020, 8, 57630–57645. https://doi.org/10.1109/ACCESS.2020.2982805

[143] Moghaddam, M.J.H.; Kalam, A.; Nowdeh, S.A.; Ahmadi, A.; Babanezhad, M.; Saha, S. Optimal sizing and energy management of stand-alone hybrid photovoltaic/wind system based on hydrogen storage considering LOEE and LOLE reliability indices using flower pollination algorithm. Renew. Energy 2019, 135, 1412–1434. https://doi.org/10.1016/j.renene.2018.09.078

[144] Fioriti, D.; Giglioli, R.; Poli, D.; Lutzemberger, G.; Vanni, A.; Salza, P. Optimal sizing of a mini-grid in developing countries, taking into account the operation of an electrochemical storage and a fuel tank. In Proceedings of the 2017 6th International Conference on Clean Electrical Power (ICCEP), Santa Margherita Ligure, Italy, 27–29 June 2017; pp. 320–326. https://doi.org/10.1109/ICCEP.2017.8004834

[145] Sawle, Y.; Gupta, S.; Bohre, A.K. Optimal sizing of standalone PV/Wind/Biomass hybrid energy system using GA and PSO optimization technique. Energy Procedia 2017, 117, 690–698. https://doi.org/10.1016/j.egypro.2017.05.183

[146] Yimen, N.; Tchotang, T.; Kanmogne, A.; Idriss, I.A.; Musa, B.; Aliyu, A.; Okonkwo, E.; Abba, S.; Tata, D.; Meva'A, L.; et al. Optimal Sizing and Techno-Economic Analysis of Hybrid Renewable Energy Systems—A Case Study of a Photovoltaic/ Wind/Battery/Diesel System in Fanisau, Northern Nigeria. Processes 2020, 8, 1381. https://doi.org/10.3390/pr8111381

[147] Emad, D.; El-Hameed, M.A.; Yousef, M.T.; El-Fergany, A.A. Computational Methods for Optimal Planning of Hybrid Renewable Microgrids: A Comprehensive Review and Challenges. Arch. Comput. Methods Eng. 2020, 27, 1297–1319. https://doi.org/10.1007/s11831-019-09353-9

[148] Kharrich, M.; Kamel, S.; Abdeen, M.; Mohammed, O.H.; Akherraz, M.; Khurshaid, T.; Rhee, S.-B. Developed Approach Based on Equilibrium Optimizer for Optimal Design of Hybrid PV/Wind/Diesel/Battery Microgrid in Dakhla, Morocco. IEEE Access 2021, 9, 13655–13670. https://doi.org/10.1109/ACCESS.2021.3051573

[149] Paliwal, P. Techno-Socio-Economic Sizing of Solar–Diesel Generator-Based Autonomous Power System Using Butter-fly-PSO. In Advances in Renewable Energy and

Electric Vehicles; Springer: Berlin/Heidelberg, Germany, 2022; pp. 427–437. https://doi.org/10.1007/978-981-16-1642-6_33

[150] Mohseni, S.; Brent, A.C.; Burmester, D.; Browne, W.N.; Kelly, S. Adding a Computationally-Tractable Probabilistic Dimension to Meta-Heuristic-Based Microgrid Sizing. In Proceedings of the TENCON 2021—2021 IEEE Region 10 Conference (TENCON), Auckland, New Zealand, 7–10 December 2021; pp. 464–469. https://doi.org/10.1109/TENCON54134.2021.9707310

[151] Das, B.K.; Hassan, R.; Islam, S.; Rezaei, M. Influence of energy management strategies and storage devices on the techno-enviro-economic optimization of hybrid energy systems: A case study in Western Australia. J. Energy Storage 2022, 51, 104239. https://doi.org/10.1016/j.est.2022.104239

[152] Udeh, G.T.; Michailos, S.; Ingham, D.; Hughes, K.J.; Ma, L.; Pourkashanian, M. A modified rule-based energy management scheme for optimal operation of a hybrid PV-wind-Stirling engine integrated multi-carrier energy system. Appl. Energy 2022, 312, 118763. https://doi.org/10.1016/j.apenergy.2022.118763

[153] Sharma, R.; Kodamana, H.; Ramteke, M. Multi-objective dynamic optimization of hybrid renewable energy systems. Chem. Eng. Process. Process. Intensif. 2022, 170, 108663. https://doi.org/10.1016/j.cep.2021.108663

[154] Alshammari, N.; Asumadu, J. Optimum unit sizing of hybrid renewable energy system utilizing harmony search, Jaya and particle swarm optimization algorithms. Sustain. Cities Soc. 2020, 60, 102255. https://doi.org/10.1016/j.scs.2020.102255

[155] Maleki, A.; Askarzadeh, A. Comparative study of artificial intelligence techniques for sizing of a hydrogen-based stand-alone photovoltaic/wind hybrid system. Int. J. Hydrogen Energy 2014, 39, 9973–9984. https://doi.org/10.1016/j.ijhydene.2014.04.147

[156] Zhang, Y.; Zhou, H.; Xiao, L.; Zhao, G. Research on Economic Optimal Dispatching of Microgrid Cluster Based on Improved Butterfly Optimization Algorithm. Int. Trans. Electr. Energy Syst. 2022, 2022, 1–16. https://doi.org/10.1155/2022/7041778

[157] Jahannoosh, M.; Nowdeh, S.A.; Naderipour, A.; Kamyab, H.; Davoudkhani, I.F.; Klemeš, J.J. New hybrid meta-heuristic algorithm for reliable and cost-effective designing of photovoltaic/wind/fuel cell energy system considering load interruption probability. J. Clean. Prod. 2021, 278, 123406. https://doi.org/10.1016/j.jclepro.2020.123406

[158] Maleki, A. Design and optimization of autonomous solar-wind-reverse osmosis desalination systems coupling battery and hydrogen energy storage by an improved bee algorithm. Desalination 2018, 435, 221–234. https://doi.org/10.1016/j.desal.2017.05.034

[159] Khezri, R.; Mahmoudi, A.; Haque, M.H. Optimal WT, PV and BES based Energy Systems for Standalone Households in South Australia. In Proceedings of the 2019 IEEE Energy Conversion Congress and Exposition (ECCE), Baltimore, MD, USA, 29 September–3 October 2019; pp. 3475–3482. https://doi.org/10.1109/ECCE.2019.8911902

[160] Lai, C.S.; McCulloch, M.D. Sizing of Stand-Alone Solar PV and Storage System with Anaerobic Digestion Biogas Power Plants. IEEE Trans. Ind. Electron. 2016, 64, 2112–2121. https://doi.org/10.1109/TIE.2016.2625781

[161] Nyeche, E.; Diemuodeke, E. Modelling and optimisation of a hybrid PV-wind turbine-pumped hydro storage energy system for mini-grid application in coastline communities. J. Clean. Prod. 2019, 250, 119578. https://doi.org/10.1016/j.jclepro.2019.119578

[162] Zhang, Y.; Sun, H.; Tan, J.; Li, Z.; Hou, W.; Guo, Y. Capacity configuration optimization of multi-energy system integrating wind turbine/photovoltaic/hydrogen/battery. Energy 2022, 252, 124046. https://doi.org/10.1016/j.energy.2022.124046

[163] Hossain, M.A.; Ahmed, A.; Tito, S.R.; Ahshan, R.; Sakib, T.H.; Nengroo, S.H. Multi-Objective Hybrid Optimization for Optimal Sizing of a Hybrid Renewable Power System for Home Applications. Energies 2023, 16, 96. https://doi.org/10.3390/en16010096

[164] Maleki, A.; Askarzadeh, A. Artificial bee swarm optimization for optimum sizing of a stand-alone PV/WT/FC hybrid system considering LPSP concept. Sol. Energy 2014, 107, 227–235. https://doi.org/10.1016/j.solener.2014.05.016

[165] Su, H.-Y.; Liu, J.-H.; Chu, C.-C.; Lee, S.-H.; Hong, Y.-Y.; Lin, Y.-J.; Liao, C.-J. Developing an Optimal Scheduling of Taiwan Power System with Highly Penetrated Renewable Energy Resources and Pumped Hydro Storages. IEEE Trans. Ind. Appl. 2021, 57, 1973–1986. https://doi.org/10.1109/TIA.2021.3057300

[166] Khemissi, L.; Khiari, B.; Sellami, A. A novel optimal planning methodology of an autonomous Photovoltaic/Wind/Battery hybrid power system by minimizing economic, energetic and environmental objectives. Int. J. Green Energy 2021, 18, 1064–1080. https://doi.org/10.1080/15435075.2021.1891906

[167] Khan A. A., Minai A. F. Metaheuristic Techniques for Power Extraction from PV-Based Hybrid Renewable Energy Sources (HRESs). Photovoltaic Systems Technology. 2024, pp 103-121. https://doi.org/10.1002/9781394167678.ch6

[168] Memon, S.A.; Patel, R.N. An overview of optimization techniques used for sizing of hybrid renewable energy systems. Renew. Energy Focus 2021, 39, 1–26. https://doi.org/10.1016/j.ref.2021.07.007

[169] Zereg, H.; Bouzgou, H. Multi-Objective Optimization of Stand-Alone Hybrid Renewable Energy System for Rural Electrification in Algeria. In Artificial Intelligence and Heuristics for Smart Energy Efficiency in Smart Cities; Springer: Cham, Switzerland, 2021; pp. 21–33. https://doi.org/10.1007/978-3-030-92038-8_3

[170] Samy, M.; Mosaad, M.I.; Barakat, S. Optimal economic study of hybrid PV-wind-fuel cell system integrated to unreliable electric utility using hybrid search optimization technique. Int. J. Hydrogen Energy 2021, 46, 11217–11231. https://doi.org/10.1016/j.ijhydene.2020.07.258

[171] Jahannoush, M.; Nowdeh, S.A. Optimal designing and management of a stand-alone hybrid energy system using meta-heuristic improved sine–cosine algorithm for Recreational Center, case study for Iran country. Appl. Soft Comput. 2020, 96, 106611. https://doi.org/10.1016/j.asoc.2020.106611

[172] Javed, M.S.; Ma, T.; Jurasz, J.; Ahmed, S.; Mikulik, J. Performance comparison of heuristic algorithms for optimization of hybrid off-grid renewable energy systems. Energy 2020, 210, 118599. https://doi.org/10.1016/j.energy.2020.118599

[173] Lorestani, A.; Gharehpetian, G.; Nazari, M.H. Optimal sizing and techno-economic analysis of energy- and cost-efficient standalone multi-carrier microgrid. Energy 2019, 178, 751–764. https://doi.org/10.1016/j.energy.2019.04.152

[174] Ma, T.; Yang, H.; Lu, L.; Peng, J. Technical feasibility study on a standalone hybrid solar-wind system with pumped hydro storage for a remote island in Hong Kong. Renew. Energy 2014, 69, 7–15. https://doi.org/10.1016/j.renene.2014.03.028

[175] Diab, A.A.Z.; Sultan, H.M.; Kuznetsov, O.N. Optimal sizing of hybrid solar/wind/hydroelectric pumped storage energy system in Egypt based on different meta-heuristic techniques. Environ. Sci. Pollut. Res. 2020, 27, 32318–32340. http://doi.org/10.1007/s11356-019-06566-0

[176] Guneser, M.T.; Elbaz, A.; Seker, C. Hybrid Optimization Methods Application on Sizing and Solving the Economic Dispatch Problems of Hybrid Renewable Power Systems. In Applications of Nature-Inspired Computing in Renewable Energy Systems; IGI Global: Hershey, PA, USA, 2022; pp. 136–165. http://doi.org/10.4018/978-1-7998-8561-0.ch008

[177] Suman, G.K.; Guerrero, J.M.; Roy, O.P. Optimisation of solar/wind/bio-generator/diesel/battery based microgrids for rural areas: A PSO-GWO approach. Sustain. Cities Soc. 2021, 67, 102723. https://doi.org/10.1016/j.scs.2021.102723

[178] Liu, B.; Zhou, B.; Yang, D.; Li, G.; Cao, J.; Bu, S.; Littler, T. Optimal planning of hybrid renewable energy system considering virtual energy storage of desalination plant based on mixed-integer NSGA-III. Desalination 2022, 521, 115382. https://doi.org/10.1016/j.desal.2021.115382

[179] Pravin, P.; Luo, Z.; Li, L.; Wang, X. Learning-based scheduling of industrial hybrid renewable energy systems. Comput. Chem. Eng. 2022, 159, 107665. https://doi.org/10.1016/j.compchemeng.2022.107665

[180] Hemeida, A.M.; Omer, A.S.; Bahaa-Eldin, A.M.; Alkhalaf, S.; Ahmed, M.; Senjyu, T.; El-Saady, G. Multi-objective multi-verse optimization of renewable energy sources-based micro-grid system: Real case. Ain Shams Eng. J. 2021, 13, 101543. https://doi.org/10.1016/j.asej.2021.06.028

[181] Yahiaoui, A.; Tlemçani, A. Superior performances strategies of different hybrid renewable energy systems configurations with energy storage units. Wind Eng. 2022, 46, 1471–1486. https://doi.org/10.1177/0309524X221084124

[182] Sun, H.; Ebadi, A.G.; Toughani, M.; Nowdeh, S.A.; Naderipour, A.; Abdullah, A. Designing framework of hybrid photovoltaic bio-waste energy system with hydrogen storage considering economic and technical indices using whale optimization algorithm. Energy 2022, 238, 121555. https://doi.org/10.1016/j.energy.2021.121555

[183] Alturki, F.A.; Awwad, E.M. Sizing and cost minimization of standalone hybrid WT/PV/biomass/pump-hydro storage-based energy systems. Energies 2021, 14, 489. https://doi.org/10.3390/en14020489

[184] Islam, R.; Akter, H.; Howlader, H.O.R.; Senjyu, T. Optimal Sizing and Techno-Economic Analysis of Grid-Independent Hybrid Energy System for Sustained Rural Electrification in Developing Countries: A Case Study in Bangladesh. Energies 2022, 15, 6381. https://doi.org/10.3390/en15176381

[185] Chen, J.; Li, J.; Zhang, Y.; Bao, G.; Ge, X.; Li, P. A hierarchical optimal operation strategy of hybrid energy storage system in distribution networks with high photovoltaic penetration. Energies 2018, 11, 389. https://doi.org/10.3390/en11020389

[186] Cruz, M.R.M.; Fitiwi, D.Z.; Santos, S.F.; Catalão, J.P.S. A comprehensive survey of flexibility options for supporting the low-carbon energy future. Renew. Sustain. Energy Rev. 2018, 97, 338–353. https://doi.org/10.1016/j.rser.2018.08.028

[187] Tsakiris, A. Analysis of hydrogen fuel cell and battery efficiency. In Proceedings of the World Sustainable Energy Days 2019 Young Energy Researchers Conference, Wels, Austria, 27 February–1 March 2019. https://c2e2.unepccc.org/wp-content/uploads/sites/3/2019/09/analysis-of-hydrogen-fuel-cell-and-battery.pdf

[188] Yi, T.F.; Sari, H.M.K.; Li, X.; Wang, F.; Zhu, Y.R.; Hu, J.; Zhang, J.; Li, X. A review of niobium oxides based nanocomposites for lithium-ion batteries, sodium-ion batteries and supercapacitors. Nano Energy 2021, 85, 105955. https://doi.org/10.1016/j.nanoen.2021.105955

[189] Revankar, S.T. Chemical Energy Storage. In Storage and Hybridization of Nuclear Energy: Techno-Economic Integration of Renewable and Nuclear Energy; Academic Press: Cambridge, MA, USA, 2019, pp. 177–227. eBookISBN:9780128139769

[190] Wang, Y.X.; Lai, W.H.; Chou, S.L.; Liu, H.K.; Dou, S.X. Remedies for polysulfide dissolution in room-temperature sodium–sulfur batteries. Adv. Mater. 2020, 32, 1903952. https://doi.org/10.1002/adma.201903952

[191] Xu, Z.; Fan, Q.; Li, Y.; Wang, J.; Lund, P.D. Review of zinc dendrite formation in zinc bromine redox flow battery. Renew. Sustain. Energy Rev. 2020, 127, 109838. https://doi.org/10.1016/j.rser.2020.109838

[192] Lourenssen, K.; Williams, J.; Ahmadpour, F.; Clemmer, R.; Tasnim, S. Vanadium redox flow batteries: A comprehensive review. J. Energy Storage 2019, 25, 100844. https://doi.org/10.1016/j.est.2019.100844

[193] Edalati, P.; Mohammadi, A.; Li, Y.; Li, H.W.; Floriano, R.; Fuji, M.; Edalati, K. High-entropy alloys as anode materials of nickel—Metal hydride batteries. Scr. Mater. 2022, 209, 114387. https://doi.org/10.1016/j.scriptamat.2021.114387

[194] Blumbergs, E.; Serga, V.; Platacis, E.; Maiorov, M.; Shishkin, A. Cadmium recovery from spent Ni-Cd batteries: A brief review. Metals 2021, 11, 1714. http://doi.org/10.3390/MET11111714

[195] Torres, N.N.S.; Scherer, H.F.; Ando Junior, O.H.; Ledesma, J.J.G. Application of neural networks in a sodium-nickel chloride battery management system. J. Control Autom Electr. Syst. 2022, 33, 1188–1197. https://doi.org/10.1007/s40313-021-00847-1

[196] Zhang, Z.; Wang, X.; Li, X.; Zhao, J.; Liu, G.; Yu, W.; Dong, X.; Wang, J. Review on composite solid electrolytes for solid-state lithium-ion batteries Materials Today. Sustainability 2023, 21, 100316. https://doi.org/10.1016/j.mtsust.2023.100316

[197] Belaid, S.; Rekioua, D.; Oubelaid, A.; Ziane, D.; Rekioua, T. Proposed Hybrid Power Optimization for Wind Turbine/Battery System. Period. Polytech. Electr. Eng. Comput. Sci. 2022, 66, 60–71. https://doi.org/10.3311/PPee.18758

[198] Leung, P.; Li, X.; De Leon, C.P.; Berlouis, L.; Low, C.T.J.; Walsh, F.C. Progress in redox flow batteries, remaining challenges and their applications in energy storage. RSC Adv. 2012, 2, 10125–10156. https://doi.org/10.1039/C2RA21342G

[199] Blakers, A.; Stocks, M.; Lu, B.; Cheng, C. A review of pumped hydro energy storage. Prog. Energy 2021, 3, 022003. https://doi.org/10.1088/2516-1083/abeb5b

[200] Akram, U.; Nadarajah, M.; Shah, R.; Milano, F. A review on rapid responsive energy storage technologies for frequency regulation in modern power systems. Renew. Sustain. Energy Rev. 2020, 120, 109626. https://doi.org/10.1016/j.rser.2019.109626

[201] Choudhury, S. Flywheel energy storage systems: A critical review on technologies, applications, and future prospects. Int.Trans. Electr. Energy Syst. 2021, 31, e13024. https://doi.org/10.1002/2050-7038.13024

[202] Borri, E.; Tafone, A.; Comodi, G.; Romagnoli, A.; Cabeza, L.F. Compressed Air Energy Storage—An Overview of Research Trends and Gaps through a Bibliometric Analysis. Energies 2022, 15, 7692. https://doi.org/10.3390/en15207692

[203] Wang, Z.; Fang, G.; Wen, X.; Tan, Q.; Zhang, P.; Liu, Z. Coordinated operation of conventional hydropower plants as hybrid pumped storage hydropower with wind and photovoltaic plants. Energy Convers. Manag. 2023, 277, 116654. https://doi.org/10.1016/j.enconman.2022.116654

[204] Chavan, S.; Rudrapati, R.; Manickam, S. A comprehensive review on current advances of thermal energy storage and its applications. Alex. Eng. J. 2022, 61, 5455–5463. https://doi.org/10.1016/j.aej.2021.11.003

[205] Liu, Z.; Zhao, P.; Yang, A.; Ye, K.; Zhang, R.; Yuan, H.; Wang, X.; Rong, M. A Novel Method for Magnetic Energy Harvesting Based on Capacitive Energy Storage and Core Saturation Modulation. IEEE Trans. Ind. Electron. 2023, 70, 2586–2595. https://doi.org/10.1109/TIE.2022.3172777

[206] Hunt, J.D. et al. Underground Gravity Energy Storage: A Solution for Long-Term Energy Storage. Energies 2023, 16, 825. https://doi.org/10.3390/en16020825

[207] Hassani, H.; Zaouche, F.; Rekioua, D.; Belaid, S.; Bacha, S. Feasibility of a standalone photovoltaic/battery system with hydrogen production. J. Energy Storage 2020, 31, 101644. https://doi.org/10.1016/j.est.2020.101644

[208] Rekioua, D. Energy Storage Systems for Photovoltaic and Wind Systems: A Review. Energies 2023, 16, 3893. https://doi.org/10.3390/en16093893

[209] A. F. Minai, A. A. Khan, M. A. Siddiqui, F. I. Bakhsh, M. A. Hussain and R. K. Pachauri, "Genetic Algorithm Based SPV System with Cascaded H-Bridge Multilevel Inverter," 2023 International Conference on Power, Instrumentation, Energy and Control (PIECON), Aligarh, India, 2023, pp. 1-6, https://doi.org/10.1109/PIECON56912.2023.10085864

[210] Naeem, A.; Hassan, N.U. Renewable Energy Intermittency Mitigation in Microgrids: State-of-the-Art and Future Prospects. In Proceedings of the 2020 4th International Conference on Green Energy and Applications (ICGEA), Singapore, 7–9 March 2020; pp. 158–164. https://doi.org/10.1109/ICGEA49367.2020.239699

[211] Kaldellis, J.; Zafirakis, D. Optimum energy storage techniques for the improvement of renewable energy sources-based electricity generation economic efficiency. Energy 2007, 32, 2295–2305. https://doi.org/10.1016/j.energy.2007.07.009

[212] Hadjipaschalis, I.; Poullikkas, A.; Efthimiou, V. Overview of current and future energy storage technologies for electric power applications. Renew. Sustain. Energy Rev. 2009, 13, 1513–1522. https://doi.org/10.1016/j.rser.2008.09.028

[213] Al-Ghussain, L.; Samu, R.; Taylan, O.; Fahrioglu, M. Sizing renewable energy systems with energy storage systems in microgrids for maximum cost-efficient utilization of renewable energy resources. Sustain. Cities Soc. 2020, 55, 102059. https://doi.org/10.1016/j.scs.2020.102059

[214] Sánchez, A. et al. Towards a new renewable power system using energy storage: An economic and social analysis. Energy Convers. Manag. 2022, 252, 115056. https://doi.org/10.1016/j.enconman.2021.115056

[215] Chand, A.A.; Prasad, K.A.; Mamun, K.A.; Sharma, K.R.; Chand, K.K. Adoption of Grid-Tie Solar System at Residential Scale. Clean Technol. 2019, 1, 224–231. https://doi.org/10.3390/cleantechnol1010015

[216] Fossati, J.P.; Galarza, A.; Martín-Villate, A.; Fontán, L. A method for optimal sizing energy storage systems for microgrids. Renew. Energy 2015, 77, 539–549. https://doi.org/10.1016/j.renene.2014.12.039

[217] Rosenberg, M.; French, T.; Reynolds, M.; While, L. Finding an optimised infrastructure for electricity distribution networks in rural areas—A comparison of different approaches. Swarm Evol. Comput. 2022, 68, 101018. https://doi.org/10.1016/j.swevo.2021.101018

[218] Kumar, N.; Chopra, S.; Chand, A.; Elavarasan, R.; Shafiullah, G. Hybrid Renewable Energy Microgrid for a Residential Community: A Techno-Economic and Environmental Perspective in the Context of the SDG7. Sustainability 2020, 12, 3944. https://doi.org/10.3390/su12103944

[219] Hermann, D.T.; Donatien, N.; Armel, T.K.F.; René, T. Techno-economic and environmental feasibility study with demand-side management of photovoltaic/ wind/ hydroelectricity/ battery/ diesel: A case study in Sub-Saharan Africa. Energy Convers. Manag. 2022, 258, 115494. https://doi.org/10.1016/j.enconman.2022.115494

[220] Kaabeche, A.; Diaf, S.; Ibtiouen, R. Firefly-inspired algorithm for optimal sizing of renewable hybrid system considering reliability criteria. Sol. Energy 2017, 155, 727–738. https://doi.org/10.1016/j.solener.2017.06.070

This article has been accepted for publication in IEEE Access. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2025.3535520

[221] Das, M. et al. Techno-economic optimization of an off-grid hybrid renewable energy system using metaheuristic optimization approaches—Case of a radio transmitter station in India. Energy Convers. Manag. 2019, 185, 339–352. https://doi.org/10.1016/j.enconman.2019.01.107

[222] Maleki, A. et al. Design of a cost-effective wind/photovoltaic/hydrogen energy system for supplying a desalination unit by a heuristic approach. Sol. Energy 2016, 139, 666–675. https://doi.org/10.1016/j.solener.2016.09.028

[223] Ridha, H.M. et al. Sizing and implementing off-grid stand-alone photovoltaic/battery systems based on multi-objective optimization and techno-economic (MADE) analysis. Energy 2020, 207, 118163. https://doi.org/10.1016/j.energy.2020.118163

[224] Kaur, R.; Krishnasamy, V.; Kandasamy, N.K.; Kumar, S. Discrete Multiobjective Grey Wolf Algorithm Based Optimal Sizing and Sensitivity Analysis of PV-Wind-Battery System for Rural Telecom Towers. IEEE Syst. J. 2019, 14, 729–737. https://doi.org/10.1109/JSYST.2019.2912899

[225] Guezgouz, M.; Jurasz, J.; Bekkouche, B.; Ma, T.; Javed, M.S.; Kies, A. Optimal hybrid pumped hydro-battery storage scheme for off-grid renewable energy systems. Energy Convers. Manag. 2019, 199, 112046. https://doi.org/10.1016/j.enconman.2019.112046

[226] Javed, M.S.; Ma, T.; Jurasz, J.; Amin, M.Y. Solar and wind power generation systems with pumped hydro storage: Review and future perspectives. Renew. Energy 2019, 148, 176–192. https://doi.org/10.1016/j.renene.2019.11.157

[227] Nazari, M.E.; Ardehali, M.M.; Jafari, S. Pumped-storage unit commitment with considerations for energy demand, economics, and environmental constraints. Energy 2010, 35, 4092–4101. https://doi.org/10.1016/j.energy.2010.06.022

[228] Zhang, Z.; Feng, L.; Liu, H.; Wang, L.; Wang, S.; Tang, Z. Mo^{6+}–P^{5+} co-doped Li$_2$ZnTi$_3$O$_8$ anode for Li-storage in a wide temperature range and applications in LiNi$_{0.5}$Mn$_{1.5}$O4/Li$_2$ZnTi$_3$O$_8$ full cells. Inorg. Chem. Front. 2021, 9, 35–43. https://doi.org/10.1039/D1QI01077H

[229] Chen, Y. Research on collaborative innovation of key common technologies in new energy vehicle industry based on digital twin technology. Energy Rep. 2022, 8, 15399–15407. https://doi.org/10.1016/j.egyr.2022.11.120

[230] Liu, L.; Tang, Y.; Liu, D. Investigation of future low-carbon and zero-carbon fuels for marine engines from the view of thermal efficiency. Energy Rep. 2022, 8, 6150–6160. https://doi.org/10.1016/j.egyr.2022.04.058

[231] Liu, L.; Wu, Y.; Wang, Y. Numerical investigation on the combustion and emission characteristics of ammonia in a low-speed two-stroke marine engine. Fuel 2021, 314, 122727. https://doi.org/10.1016/j.fuel.2021.122727

[232] Ge, L.; Li, Y.; Li, Y.; Yan, J.; Sun, Y. Smart Distribution Network Situation Awareness for High-Quality Operation and Maintenance: A Brief Review. Energies 2022, 15, 828. https://doi.org/10.3390/en15030828

[233] Li, X.; Wang, H.; Yang, C. Driving mechanism of digital economy based on regulation algorithm for development of low-carbon industries. Sustain. Energy Technol. Assess. 2022, 55, 102909. https://doi.org/10.1016/j.seta.2022.102909

[234] Lu, S.; Guo, J.; Liu, S.; Yang, B.; Liu, M.; Yin, L.; Zheng, W. An Improved Algorithm of Drift Compensation for Olfactory Sensors. Appl. Sci. 2022, 12, 9529. https://doi.org/10.3390/app12199529

[235] Dang, W.; Guo, J.; Liu, M.; Liu, S.; Yang, B.; Yin, L.; Zheng, W. A Semi-Supervised Extreme Learning Machine Algorithm Based on the New Weighted Kernel for Machine Smell. Appl. Sci. 2022, 12, 9213. https://doi.org/10.3390/app12189213

[236] Lu, S.; Yin, Z.; Liao, S.; Yang, B.; Liu, S.; Liu, M.; Yin, L.; Zheng, W. An asymmetric encoder–decoder model for Zn-ion battery lifetime prediction. Energy Rep. 2022, 8, 33–50. https://doi.org/10.1016/j.egyr.2022.09.211

[237] Das, P.; Das, B.K.; Mustafi, N.N.; Sakir, T. A review on pump-hydro storage for renewable and hybrid energy systems applications. Energy Storage 2020, 3, e223. https://doi.org/10.1002/est2.223

[238] Argyrou, M.C.; Christodoulides, P.; Kalogirou, S.A. Energy storage for electricity generation and related processes: Technologies appraisal and grid scale applications. Renew. Sustain. Energy Rev. 2018, 94, 804–821. https://doi.org/10.1016/j.rser.2018.06.044

[239] Nordling, A.; Englund, R.; Hembjer, A.; Mannberg, A. Energy Storage-Electricity Storage Technologies. IVA'S Electr. Crossroads Proj. 2016. Available online: https://issuu.com/iva-publikationer/docs/201604-iva-va_gvalel-ellagring-rap (accessed on 20 June 2023).

[240] Medina, P.; Bizuayehu, A.W.; Catalão, J.P.; Rodrigues, E.M.; Contreras, J. Electrical energy storage systems: Technologies' state-of the-art, techno-economic benefits and applications analysis. In Proceedings of the 2014 47th Hawaii International Conference on System Sciences, Waikoloa, HI, USA, 6–9 January 2014; pp. 2295–2304. https://doi.org/10.1109/HICSS.2014.290

[241] Castillo, A.; Gayme, D.F. Grid-scale energy storage applications in renewable energy integration: A survey. Energy Convers. Manag. 2014, 87, 885–894. https://doi.org/10.1016/j.enconman.2014.07.063

[242] Gallo, A.B.; Simõões-Moreira, J.R.; Costa, H.K.M.; Santos, M.M.; Moutinho dos Santos, E.M. Energy storage in the energy transition context: A technology review. Renew. Sustain. Energy Rev. 2016, 65, 800–822. https://doi.org/10.1016/j.rser.2016.07.028

[243] Zhao, P.; Wang, J.; Dai, Y. Capacity allocation of a hybrid energy storage system for power system peak shaving at high wind power penetration level. Renew. Energy 2015, 75, 541–549. https://doi.org/10.1016/j.renene.2014.10.040

[244] Badreldien, M.M.; Abuagreb, M.; Allehyani, M.F.; Johnson, B.K. Modeling and Control of Solar PV System Combined with Battery Energy Storage System. In Proceedings of the 2021 IEEE Electrical Power and Energy Conference (EPEC), Toronto, ON, Canada, 22–31 October 2021; pp. 373–377. https://doi.org/10.1109/EPEC52095.2021.9621564

[245] Nguyen, T.-T.; Martin, V.; Malmquist, A.; Silva, C.A. A review on technology maturity of small scale energy storage technologies. Renew. Energy Environ. Sustain. 2017, 2, 36. https://doi.org/10.1051/rees/2017039

This article has been accepted for publication in IEEE Access. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2025.3535520

[246] Akinyele, D.O.; Rayudu, R.K. Review of energy storage technologies for sustainable power networks. Sustain. Energy Technol. Assess. 2014, 8, 74–91. https://doi.org/10.1016/j.seta.2014.07.004

[247] Kousksou, T.; Bruel, P.; Jamil, A.; El Rhafiki, T.; Zeraouli, Y. Energy storage: Applications and challenges. Sol. Energy Mater. Sol. Cells 2013, 120, 59–80. https://doi.org/10.1016/j.solmat.2013.08.015

[248] Slaughter, A. Electricity Storage Technologies, Impacts, and Prospects. Deloitte Center for Energy Solutions 2015. Available online: https://www2.deloitte.com/content/dam/Deloitte/us/Documents/energy-resources/us-er-electric-storage-paper.pdf (accessed on 30 June 2023).

[249] Aneke, M.; Wang, M. Energy storage technologies and real-life applications—A state of the art review. Appl. Energy 2016, 179, 350–377. https://doi.org/10.1016/j.apenergy.2016.06.097

[250] Bahramian, P. Integration of Wind Power into an Electricity System Using Pumped Storage: Economic Challenges and Stakeholder Impacts; Queen’s Economics Department Working Paper; Queen’s University, Department of Economics: Kingston, ON, Canada, 2022. https://ideas.repec.org/p/qed/dpaper/4605.html

[251] Du, P.; Lu, N. Energy Storage for Smart Grids: Planning and Operation for Renewable and Variable Energy Resources (VERs); Academic Press: Cambridge, MA, USA, 2014. https://www.harvard.com/book/9780124104914

[252] Hallasmaa, T. Implementation of an Energy Storage for Waste-to-Energy Plant. 2022. Available online: https://urn.fi/URN:NBN:fi:amk-202205169532 (accessed on 01 July 2023).