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Research Article

Metaheuristic Techniques for Optimizing Economic and Energy Management in Nano Grids: A Comprehensive Review

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ABSTRACT

The emergence of Nano grids with integration of renewable energy bases gives an alternative to economic and energy management of small nodes of large grid systems for sustainable environmental development. The concept of Nano grid has become a critical zone of research for mitigation of climatic changes especially when integration with existing power systems. Nano grids are small-scale restricted energy systems that combine renewable energy homes and drive storages for demand-side management with advance energy security and lessen costs. In Nano grids, there are various challenges like distribution of renewable energy, minimization of operational costs, enhancement of grid stability, and assurance of sustainable energy management. In order to manage the structure and economic energy optimization, there is requisite of artificial intelligence designed algorithms that address the complex challenges related to generation, distribution and consumption of energy within Nano grids. This paper spectacle the literature review of metaheuristic techniques and their evolution in economic and energy management of Nano grids along with their comparative performance and emerging trends in the field. Additionally, the review identifies gaps in current research like unit commitment in hybrid models, integration of conventional with RES systems and real-time data processing for dynamic decision-making. Finally, this literature review provides a comprehensive understanding of various metaheuristic techniques that contribute to the operative economic and energy management of Nano grids, with offering insights for future research and practical solicitations in the energy sector.

Keywords: Nano Grids, Energy Management, Economic Optimization, Meta-Heuristic Techniques, Energy Management Services (EMS),Renewable Energy Sources(RES).

1. Introduction

Today's modern societies are heavily contingent on electricity supply especially on local distribution grids in which power is allocated among small units. According to Indian energy statistics, this reliance has been growing over the past years because of advancement in living conditions. However, electric power systems have not seen significant upgrades for decades. With the development of new enabling grid technologies that include ICT, microchip smart digital meters with energy storage devices, innovative concepts are emerging in contemporary power systems. One of the most prominent concept is the development of Nano grid concept, which is a small modern power grid structure based on distributed energy resources (DER). The Nano grid is basically being a part of large micro grid integrated with renewable energy sources (RES) along with enhanced power electronics and ICT technologies. The Nano grids are basically used in small industrial and domestic distributions for fulfillment of self-sustainable power demand. Daniel Burmester et.al provides deep insights on Nano grid structure in which various techniques and topologies are being premeditated including controlling of power, heat recovery in storage devices, and distribution of loads for grid structure which operate as single controllable entity [1]. Additionally, a comparative analysis of Nano grid and micro grid concepts is presented by S. Jamal et al. in which the various considerations taken into account like minimization of energy costing, emission reduction, grid connections, types of energy generation, voltage levels in distribution systems, load management, and

metering [2]. He also proposes a classification of various metaheuristic techniques used in energy management of various grid structures in connection with renewable energy resources like PV, Wind and battery.
Thanks to their segmental nature, Nano grids can function independently or in conjunction with the main electrical grid along with RES models. They typically have lower financial commitments, require fewer technical skills to operate, and rely more on automation technology [3]. These benefits make Nano grids an effective solution for gradually fulfillment of residential power need and modernization of existing power grids. Other advantages of establishing Nano grids include the integration of local renewable resources and reducing consumer dependency on managing traditional micro grids [4]. Despite these benefits, planning a cost-effective Nano grid is a complex process due to the horde of alternatives in various parameters consideration at every decision level. Each decision in the planning process that affects the system's capacities in a competitive energy trading market. Planning is guided by specific goals and constraints, which encompass technical, environmental, geographical, social, and regulatory factors. Uncertainties also play a crucial role, posing risks that system planners must mitigate or manage. Qian Hu in [5] identifies various sources of uncertainty in the energy trading system on decision-making process that includes various modeling uncertainties in exploration, and uncertainties in interpreting results. Research authors in [6] discussed about cost-effective designing and its uncertainties in Nano grids. The focus of researcher is to optimize the multiple energy resources Nano grids with low carbon emissions for sustainable environment in future. Beyond these uncertainties and constraints, objectives, there is main focus on two primary goals and that are cost efficiency and customer satisfaction. In a grid, consumer satisfaction is linked to reliability and quality along with minimizing the environmental impact. It is widely accepted that investment in Nano grids, renewable power sources and energy-efficient technologies is essential to reduce the generation costing and emissions in environment. These investments can enhance the system but also affect its economic viability. The economic feasibility of renewable energy resources hinges on various factors like cost of energy, infrastructure requirements, initial investments, power operational and controlling costs, grid-connection fees, taxes, and grants [7]. Substantial funds are also necessary to improve reliability and supply quality, yet every project faces unique economic constraints, particularly during the design phase. Therefore, the Nano grid provides the optimal solution for designing of grid structure that leads to better distribution and economic trade-off for energy market. A Nano grid often integrates a mix of traditional and renewable energy technologies due to which there is various design configurations and topologies involved in designing process especially in DC Nano grids [8]. Several authors have previously reviewed the various platforms for designing and planning of Nano grid technologies. For instance, Paolillo et al. in [9] introduce commonly available tools for Nano grid energy system. The author deals show the planning, categorization and operational optimization along with simulation, for grid structure. Some of other tools, like HOMER, DER-CAM, MATLAB, MARKAL, RETScreen, and H2RES, are suitable for Nano grid designing and planning [10]. Additionally, Mahmud et al. in [11] provide a comprehensive comparison of different analysis and simulation software tools for designing and evaluating renewable energy integration projects, which also includes smart grid integration like CEN-CENELEC-ETSI. As the Nano grid planning and designing process can be viewed as a series of optimization problems, various software challenges have been explored at different planning levels in the technical literature [12]. In order to optimize the energy and economic problem of Nano grids, numerous revisions have studied on optimization and applications of Nano grid tools, particularly centering on renewable energy sources.
In review [13], Baños et al. assess various optimization methods used for different renewable energy sources like solar energy, wind power, hydropower, bioenergy, geothermal energy, and hybrid systems. The author provides a comprehensive overview of various constraints for resource allocation problems in renewable energy sources. They also present a list of optimization tools, a conflicting objectives matrix, and a review of optimization techniques. Numerous optimization practices have been applied not only to renewable energy sources but also to community energy management systems such as controller designing, load peak management [14][15][16]. Different energy community systems may require distinct optimization techniques due to varying system of load constraints (primarily technical, environmental, and economic) and uncertainties. The advent of new computational optimization approaches and algorithms has opened up fresh methodologies to plan and sort out the dimensional challenges. The coexistence of widely used mathematical optimization techniques with newer ones makes reviewing Nano grid planning problems increasingly appealing of Nano grids
This manuscript mainly deals with review of optimization techniques that are being implemented for structural advancement and economic energy management of Nano grids. The structure of paper is arranged in following manner. Section 1 is about the introduction of recent Nano grid technology in which various software’s and hardware’s are being introduced. Section 2 gives a comprehensive detail about structural parameters of Nano Grids and its various renewable resources integration for energy management along with overview of optimization techniques. There are various intelligent algorithms which deal in employment of energy cost function and minimization of losses. Section 3 presents the literature survey of designing and implementation of intelligent algorithm for both economic and energy

management of Nano grids along with research gaps in this field. Section 4 is about the conclusion and future work in energy management of Nano grids area.

2. Overview of Nano Grids: Background and Development

A Nano grid is a small grid distribution structure designed especially for a single home-based or small edifice that capable of linking or disengaging from other power sources via a gateway. It operates on local energy generation to stream nearby loads, with multiple options for energy storage and control systems. Nano grids serve as restricted energy solutions which manage and distribute power inside a specific area, usually a single construction or a small community. Unlike power grids that cover extensive areas and serve copious users, Nano grids are more self-reliant and often operate independently. From economic point of view, Nano grids provide a reliable and sustainable solution for economic energy management [17]. The Microgrid/Nano grid systems integration includes various renewable energy framework options like PV/DG panels, BES and wind turbines and more but alongside there are many issues related to conventional energy sources. One of prime consideration in grid distribution is the storage of energy that helps in the capture of excess energy generated during low-demand periods and can be released during peak demand intervals [18]. The authors in [19] detailed about controlling systems that play vital role in balancing of energy production along with storage and consumption for ensuring the efficient and reliable operation. Another key component is load management which involves the monitoring and regulation of power loads to optimize energy and maintain stability of system for better usage. Nano grids operate mainly in two modes that are in isolation mode also known as islanded mode and connect grid-tied mode that provide additional support for trading of excess energy posterior to the main grid. Kalair et. al in [20] showed the demean side management and controllable behavior of Nano grids systems work on solar roof top integrated smart Nano grid. The prosed model makes them suitable for wide range of applications from individual households to small communities. They safeguard a dependable energy supply, particularly in isolated or underserved areas and enhance the energy security by maintaining set-up process independently during larger grid failures. Their sustainability is a significant advantage, as they provide assistance in reduction of carbon emissions through consumption of renewable energy sources. Additionally, they are cost-effective that lowers the energy expenditures over period through local renewable generation and efficient energy management [21].

For outlining of grid structure, the distribution and generation of power structures can be complex due to various interpretations and distinctions as per existing literature. As noted in several sources, a Nano grid can be likened to a micro grid for optimal power distribution. There are some similarities as well differences in modes of operations between micro grids and Nano grids that set them apart. Essentially, a Nano grid perform similar as a micro grid because both energy systems can operate in isolated or grid connected modes. They can function both as DC and AC in hybrid power erections, but literature tends to accentuate DC systems in the perspective of Nano grids. Both utilizes a power source often renewable and various conventional loads. The terms "small power" and "intricacy" used to describe Nano grids can be slightly elusive as small power range to be in the few watts up to 5 kw, while others recommend a range of 100 kw. As research progresses, the complication of controlling strategies, optimization methods and structural designing in Nano grids is also evolving [22][23]. While it is normally accepted that Nano grids structures are usually less powerful and composite in nature as compared to micro grids, this can create some indistinctness in their definitions. Another stance defines a Nano grid as "a single dominion for energy, charge, fidelity, value, and administration," which bring into line with the general consensus but refines the discrepancy by signifying that local based generation is not essentially part of the Nano grid itself. This wider definition can include systems like Power over Ethernet and universal control adapters, which customarily wouldn't be classified as Nano grids. While this generality has its advantages, it may obfuscate the original connotation of the term. A clear differentiating feature is being given by Neelesh et. al in [24] of a Nano grid about its association with a PV fed with low voltage dc micro grid (LV-DCMG), in which categorization of Nano grids and micro grids often incorporated at multiple buildings or homes. Although micro grids can technically function a single construction, it is argued that systems limited to one home or building should be classified as Nano grids[25][26].

2.1 Structures and Topologies of Nano grids

Nano grids are condensed energy distribution systems which are designed mainly to manage local power generation, storage, and consumption at a confined level, usually for a single home or small community. Their configuration along with some key components is being incepted by Amin et. al in [27] in work is done collectively to provide reliable and competent energy management to grid structure. The main elements in Nano grids are

i). Power Generating Bases

- **Renewable Energy Sources (RES)**: Nano grids often unite renewable energy structures such as solar panels, small wind turbines and micro-hydro generator to harvest clean energy and lessen dependency on fossil fuels.

- **Conservative Energy Sources**: In some circumstances, Nano grids may also custom conventional power sources like diesel generator (DG) or the main electric grid, predominantly for backup operation during periods of low generation.

ii). Energy Storage Structures

Batteries: Energy storage is precarious in a Nano grid due to offload characteristics, allowing for the capture of surplus energy produced during low demand periods. There are various types of battery systems (e.g., lithium-ion, lead-acid) that enable energy to be stored and released during peak times or when renewable group is insufficient [28].

- **Other Storage Selections**: Some Nano grids might employ pumped hydro-storage or thermal-storage, depending upon the definite application and availability of resources.

iii). Control Driven Systems

- **Energy Management System (EMS)**: Kalvari et. al showed supervisory control system for Nano grids in which EMS is chief of a Nano grid's operation which coordinates the flow of electricity between all energy resources. It optimizes energy consumption based on real-time data and user requests[29].
- **Smart Sensors and Meters**: These devices provide real data on energy consumption of a unit that enable the EMS to make well-versed decisions about energy distribution and storage management.

iv) . Load Supervision

- **Electric Loads**: Nano grids stream power to a diversity of electrical loads within the home or building, including illumination, appliances and heating element systems. Load supervision involves observing and controlling of power loads to optimize energy usage and improve system stability .
- **Demand Response Mechanisms**: These systems can regulate energy practice in response to resource conditions, such as reduction of consumption during shifting or peak usage of high renewable generation [30].

v). Connectivity Routes

- **Grid Tied Mode**: In this formation, the Nano grid connects to the higher power grid that allows for energy exchange mode. Superfluous generated energy can be retailed back to the main grid for additional revenue or credits.
- **Islanded Mode**: In island mode, the author in [31] described about islanded Nano grid that operates autonomously from the main grid with active converter which is crucial during grid time outages or in control in remote locations. This capability ensures continuous power supply even in case of crises.

vi) . Security Systems

- **Circuit Breakers (CB'S), Relays and Fuses**: These constituents protect the Nano grid structure from overloads and short circuits, ensuring safe mode of operation [32].
- **Surge Protection Expedients**: To safeguard against voltage drops and spikes, surge protection is important part that is integrated into grid system.

The organization of Nano grids is characterized by their segmental components that allows for flexible and efficient energy management at a localized level. By uniting the renewable energy sources (RES), storage solutions and advanced control systems, Nano grids provide a sustainable and resilient energy option principally for isolated or underserved areas. Their capability to activate independently or in concurrence with larger power grids further enriches their versatility and reliability.

2.2 Types of Nano grid Technology

The recent advancements in Nano grid technologies lead to ongoing examination about alternating current (AC) and direct current (DC) power in grid structures. The standardization of AC for the national grid lead to loss of large power due to historic methodological limitations. Therefore, there is need of distributed generators often utilizing DC for supply the energy are frequently discussed. This topic also ascends in the framework of Nano grid literature, as DC power distribution can augment efficiency as detailed by Goikoetxea et. al in [33].

- **DC Basis**: While there are no firm boundaries on the types of resources used, some are more functional than others for e.g. solar, PV module, small wind turbines and batteries typically produce DC output also [34].
- **DC-DC source converter**: Askarian et. al proposed three port bidirectional dc-dc source convertor for Nano grids. This constituent normalizes the input voltage and can assist multiple utilities, such as integration of various renewable and non-renewable sources along with optimization of power output maximum tracking methodology [35]. These types of converter generally attain proficiencies up to 80 to 90.

2.3 Comparison of DC and AC Nano grids

While equating DC and AC Nano grids, proficiency factor is a decisive factor. Due to lesser transformation losses, the DC Nano grid tends to be more competent as compared to AC Nano grid. Werth et. al [36] explained that AC Nano grid faces larger losses during ac-dc conversion process at the load level in total grid system especially in open energy systems. However, the pragmatism of a DC Nano grid pivots on the availability of well-suited consumer demands. Presently, most appliances are considered for AC usage, compelling replacement with DC-attuned options. This grants a challenge especially in view of initial costs which are associated with evolution to a DC system [37]. This summary establishes the clear explanations about structure and classifications for Nano grids that enriches the characteristic and performance in this research field. As skill progresses and the energy scene swings, the prospective for Nano grids grow and play a substantial role in localized energy distribution. Figure.1 shows the basic structure of Nano grid along with renewable energy resources.

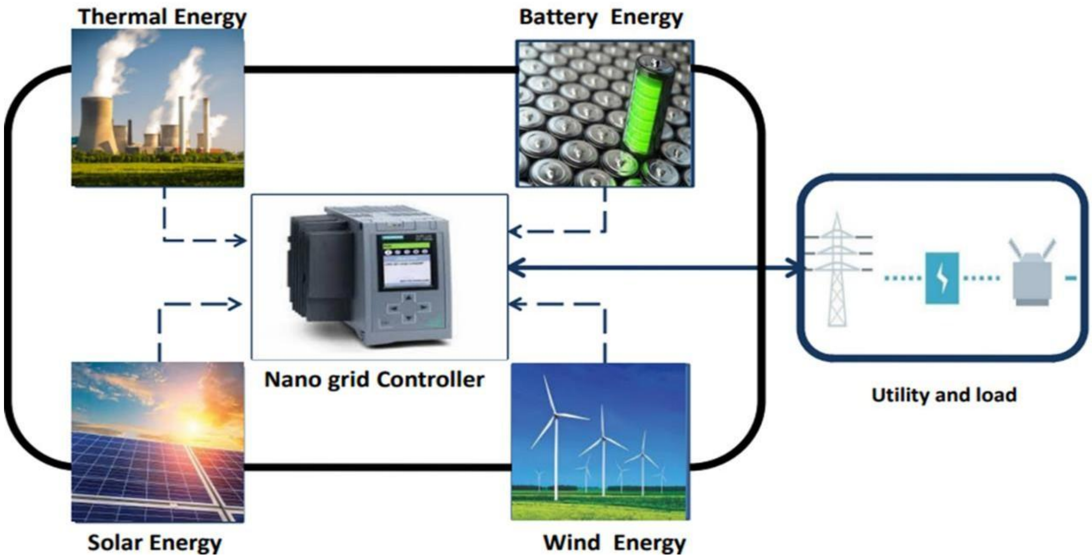

Fig 1: Basic structure of Nano Grid

2.4 Outline of Computational Optimization Techniques

Computational optimization incorporates a range of mathematical techniques that aimed at selecting the optimal solution from a set of available alternatives based on specific region and criteria. The optimization problem involves documentation of best values for an objective function within a defined domain or under a set of particular constraints, that covers wide range of arrays. The expansion of optimization concept and techniques lead to formulations of other constitutes in a significant way of field mathematics. Gunantara et al. in [38] highlight various disciplines involved in computational optimization, including model formulation and mathematical operations for system modeling, research for algorithm design and analysis, and applications in various engineering disciples. Yunfei Cui characterizes the optimization process into various categories of iterative solution, new dominance and Pareto applications in energy saving in all fields. The iterative procedure consisting of an optimizer and a model that involves identifying various objectives, variables, and constraints relevant to a given problem [39]. The multi-objective optimizer invokes the task to model with a specific decision values which calculate the objective function and constraints. This information is then explored and exploited by the optimizer to generate a new set of decision variables. This iterative process continues until the optimization standards specified by the optimization algorithm are being encountered [40]. Among computational optimization techniques are optimization algorithms, iterative methods and meta- heuristic approaches. The optimality of algorithm depends upon the nature of the optimization problem and various taxonomies exist based on decision variables, single and multi-objective functions, and constraints. Osaba et. al outlined practical applications of computational techniques that include several categories like continuous and discrete, stochastic and deterministic, multimodal and multi-objective along with heuristic and metaheuristic optimization [41].

Despite the lexicon, an optimization system does not always promise an optimal solution due to their inherent characteristics which leads to some problems in unfeasible prove. For example, linear programming (LP) optimization demands all unknown variables as integers which is named an integer linear programming (ILP) or else integer programming (IP) problem. In distinction to LP (linear programming), which can be solved efficiently, IP problems are often NP-tough [42]. A. Rong[43] explained the LP Algorithms designed to solve energy problems that require exponential computation time in order to find the optimal solution for tri energy generation system which making them impractical in many situations. Consequently, many scholars have proposed various LP, approximate and convex methods that include heuristic and metaheuristic approaches for addressing the energy optimization challenges [44][45][46][47].

Heuristic methods objective is to identify the fitting solutions among a large set of achievable options with less computational exertion as compared to traditional optimization techniques. They are particularly useful when conventional optimization methods cannot yield an optimal solution. In addition to meta-heuristics, explored the satisfied outputs within discrete search spaces. Further, metaheuristic algorithms can combine multiple heuristic methods into two ways and that one to employed generate an initial solution while second one is to refine that solution. A common way to classify metaheuristic algorithms is to differentiate trajectory paths from population-based approaches in same way bio-inspired classifications are also frequently used [48][49][50].

One of important category known as Population-based metaheuristics (PBMH) influence a group of optimal solutions that evolve over an encoded number of iterations. The generalized framework for PBMH includes the social mutual cooperation, competitiveness and self-adaptive theory among set of populations. The most common examples of PBMH are Genetic algorithms (GA), particle swarm optimization (PSO) and differential algorithm in this category [51][52]. Another important class is Bio-inspired metaheuristics that satirist natural processes to solve optimization problems.

Kar [53] categorize these techniques and explain the different phenomena of algorithms like ant colony, bat algorithm, leaping frog, cuckoo research along with their evolution and intelligence behavior. There is new advancement in classical approach of metaheuristics algorithms that include hybridization and parallel mechanism in order to generate more enhanced results. In Hybrid scheme, the metaheuristic techniques used to combine diverse optimization methodologies within the framework, while in parallel approach, the new approach of execution by many metaheuristics hunts new space concurrently by means of parallel computing routines. Sometimes, the structural and designing complexity of the problem is so inordinate that even advanced metaheuristic models failed to generate precise solution inside standard edgings. In such conditions, the parallel computing propositions provide a feasible solution by consenting wide-ranging problem to be cracked down into minor mechanisms, that enable to provide simultaneous controls and results. One of best application of parallel computing is Monte Carlo model in Nano grid for economic energy dispatch [54][55]. From the brief summary of optimization computations, it can be decided that a broad practical designing and planning of Nano grid is characteristically stochastic, repressed and multi-objective in nature. However, a numeral of writers has engaged in different designing and planning issues of Nano grids. The energy and economic management problems of Nano grids will be surveyed in the ensuing sections with optimal solutions generated by the various meta-heuristic algorithm

3. Energy and Economic Management of Nano Grids using Optimization Techniques

Conventionally, communal energy system designing and planning has focused on minimization of cost objectives. Though, beyond economic factors, the designing process can also be considered for various goals such as total energy distribution, improvement in power quality factor, emission control and sustainability of system. [56].

While individually Nano grid designing and planning process has exclusive restraints and objectives, definite arrangement challenges are usually documented across Nano grids, as illustrious in the technical survey. These challenges include:

i) **Site Problem for Energy Generation and Sizing:** Nano grid plots must be selected at the most appropriate distribution area to meet the request for a specific building or area. This comprises a comprehensive investigation of energy resources availability which is applicable to Nano grid situations. The sizing of generation and distributed elements along with energy storage kit must pay peak loads and cost efficiency into interpretation. The initial designing phase of Nano grid system involves substantial cost of investment and precarious decision making process. It includes the selection of suitable fuel types and sources for the grid system that directly influences the energy and cost efficiency. In summary, this designing and planning stage must discourse main objectives of best site allocation along environmental sustainability.

ii) **Load Scheduling Problem:** This concerns to the allocation of energy sources with grid supply lines to maintain demand standards. During this progression, both existing and probable customer's commitment can be taken into consideration. Consequently, power supply lines or bus systems need to be calculated to serve existing customer areas with minimal power loss. The load scheduling problem aims to minimalize objective cost function with emission dispatch, and maintenance of quality factor along with fulfillment of customer demand. For this, we employed different types of optimization techniques to multiple objectives problems that identify the optimal point of operation for various configurations of Nano grid.

These phases are indispensable mechanisms of any achievability study when designing and planning of Nano grid is taken into account. This section presents a literature survey of metaheuristic optimization techniques that relevant to these set of platforms in addition to mathematical modeling and simulated results.

3.1 Site for Energy Generation and Sizing of resources: Foundation of the Energy Management Problem
Energy Economic concerns play an essential role in the designing and planning of Nano grids to ensure the system's long-term sustainability. The successful positioning of a Nano grid depends on the economic performance of small knots of assorted energy generation tools, storage arrangements and other reliability factors. The key challenges recognized by Mahmoodi et. al
[57] in the technical literature at the strategic designing and planning stage include the selection and sizing of energy loading devices and site selection. The process of creative the optimal energy outputs from generators to minimize overall costs of system is known as the economic load dispatch (ELD) or economic energy dispatch (EED) problem. Both power mix medley and sizing are addressed within this EED framework.
M. Pereira et. Al [58] use economic robust predictive controller model methods to tackle the clustering problem by picking and sizing the various energy and storage sources for designing of grid systems to lessen operational costs. Their designed controller model joins the dynamic and economic trajectory planning technique for tracking a single layer taking into account bounded disturbances. This novel technique provides a review of classical predictive trajectory designing and controlling optimization techniques for Nano grid model. There is another practice for evaluation of EED in Nano grid and that is called Unique identification technique using the coloring system method algorithm. In this method, authors[59] presents power flow coloring steps that gives a unique ID to each energy flow between source and load to determine the power of distinct Nano grid types. Their optimization focuses on condition of power flow without losses while considering the integration of renewable energy source.
S. Eren et al. [60] address the digital control technique for designing problem of Nano grid by applying AC/DC converters which are being used for energy storage systems conditions. This's scheme is designed to incorporate both the time-domain and frequency-domain dynamics to achieve superior transient and steady-state performance along with dropping curves. N. kumar [61] presents a multi-resident cloud based dc nano grid for self-sustaining smart buildings in smart cities. the goal of this optimization is to lessen the capital along with making intelligent decisions with respect to the energy usage of various appliances. the intelligence of Nano grid system can be enhanced by application of smart sensor and advanced optimization technique like machine learning techniques which are being proposed by Y. T. Quek in [62] for load management of dc home system.
Meta-heuristic optimization techniques are commonly used for selecting the power generation mixing and sizing systems. In [63], the authors outline several experiential investigations such as small capacity case system by constructing a 400 l capacity storage tank. The round trip efficiency is quantified by conducting several charging and discharging experiments. The application clues constraints such as capital, auxiliary, functions and fuel costs along with revenues from selling power to the grid. The Maximum Power Point Tracking algorithm is used in [64] to optimize the sizing of renewable energy by instantaneously scheduling thermostatically controlled loads which store thermal energy at the lowest possible annual cost.
Online optimization model for Energy Sharing of Nano grid Clusters is solved by classical approach of Lyapunov optimization method. energy efficiency and the use of renewable energy sources like PV consumption are key elements in minimizing the environmental impact of Nano grids [65][66]. The residential community, numerical experiments show the effectiveness of the proposed method in improving the self-sufficiency of grids. However, as renewable sources are not always obtainable at peak capacity, therefore energy storage becomes an acute component in Nano grid designing and implementation. The sizing problem must, therefore, include hybrid energy storage systems which should be appropriately sized and located to optimize cost-efficiency with environmental sustainability and power quality. E. S. Parizy et al. [67] introduce a method for Control strategy applied to the SPC that presents better performance in terms of dynamic behaviour.
S. Batchelor et al. [67][68]propose linear/ quadratic programming optimization algorithm for the optimal electricity pricing regimes and sizing of energy resources in Nano grids. they employed compromise programming time series forecasting for cost vector to utopia point in solution space for edging the problem as a mixed linear/quadratic programming solved with traditional optimization techniques. H. T. Nguyen et al. [69] introduce uncertainty into a designing of nano grid sizing problem while integrating various resources like a PV/wind hybrid system with energy storage. They consider designing of nano grid along with different phases calculations of voltages and magnitudes in order to achieve globally optimal solutions. There are some other parameters considered for designing of bi-directional Nano grid along with energy storage batteries which are being used to determine the optimum sizing and configuration of a hybrid Nano grids for lessen the environmental pollution.
Many of these conventional optimization methods are now being replaced by intelligent systems for Nano grid designing and planning. Authors in [70] propose dc source allocation optimization to design the future energy generation and

distribution networks in energy sector. To be extremely efficient generated energy and its utilization to its completest extent, K.R. Reddy
[71] introduce ANN FFT optimization algorithm specifically designed for Nano grids. Authors integrate PV arrays with smart Nano grids using artificial intelligence with 11 bus system and multi –level inverter to generate better characteristics. Further, an advanced ANFSI technique is being implemented to design a converter with high power factor and less steady state error. A dual buck-boost ac/dc converter to be used in the united grounding residential configuration. For instance, this tool employs simulation to generate feasible energy management sorted by optimal cost [72]. Another configuration of conventional with RES model is designed in which recent metaheuristic application employed to enhance the energy economic parameter. The proposed algorithm is the integration of Cuckoo Search (CS) and Luus and Jjaakola (LJ) optimizing technique [73]. Another Multi-objective optimization algorithm such as GA optimization is implemented for Optimal Designing of Hybrid PV/Battery Nano grid System in Residential Buildings. FLC based controller with GA is recognized as an important tool for Minimization OF the Total Cost Ownership (TCO) and the Voltage Deviation (VD) in technology operation OF commercial building Nano grids[74][75][75]. There are many advancements in energy management of Nano grids with application of metaheuristics optimization techniques which are incorporated in Table 1 and depict in Figure 2 shows the advancement in articles of Nano grid technology

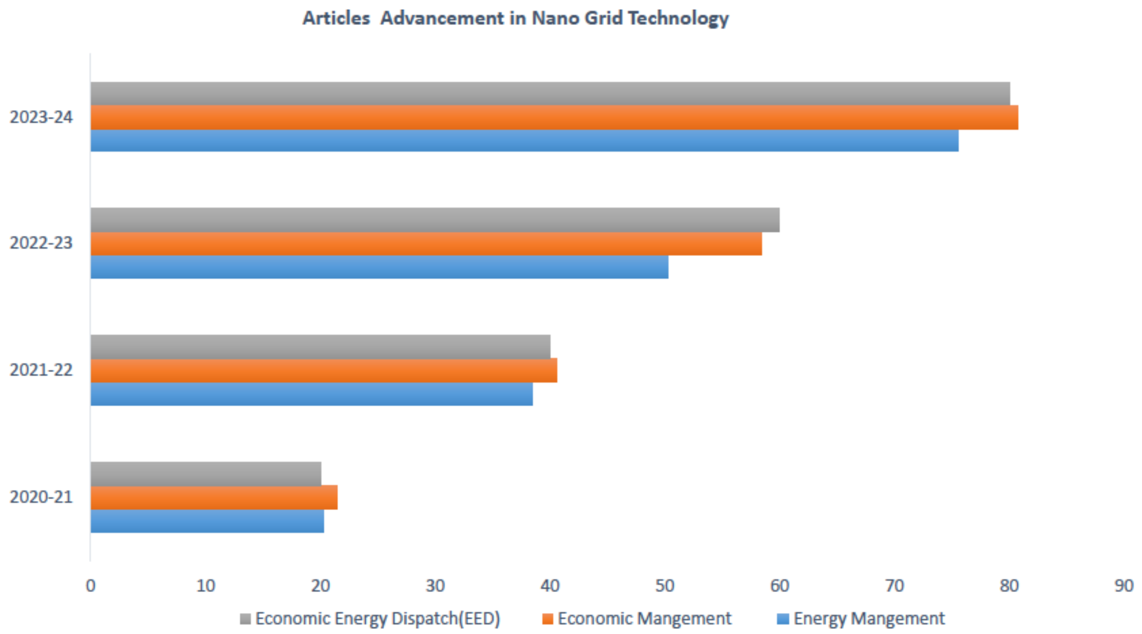

Fig 2: Articles Advancement in Nano Grid Technology

Ref.no	Author	Year	Optimization Techniques	Application in Energy Management of Nano grids
[76]	J. Lyu et.al	2020	Pareto optimisation	Reduction in price-sensitive factor specially in home energy management system and the PAPR value of home Nano grid.
[77]	M. Rawa et al	2020	Harris hawks optimization (HHO)	Proposed optimization framework's effectiveness for grid-connected mgs and allocation of BMS
[78]	A. R. Kalair et. al	2020	EMS controller system	A frequency and voltage relaying based demand side management (DSM) scheme to reduce the load on distribution feeders
[79]	S. Yousaf et.al	2020	Genetic Algorithm (GA) and particle swarm optimization (PSO)	Optimization of the performance of SMC controllers in Nano grids
[80]	R. Namani et.al	2021	A pulse width modulation (PWM)	Dynamic Energy Management for the operation of combined grid-connected with solar photovoltaic
[81]	F. Qayyum et.al	2021	An intelligent cost optimization	Optimal allocation of hybrid renewable energy resources
[82]	C. Samende et.al	2021	Conventional optimization techniques	Algorithm minimizes the power losses by reducing the magnitude of power flow in the Nano- grid at each time instant through battery state of charge balancing
[83]	M. Farmanbar et.al	2021	Sinusoidal wave data acquisition	A network of Nano grids design promoting decentralization
[84]	E. A. Ebrahim et.al	2021	Maximum Power Point Tracking (MPPT)	The SBI-based system is a strong competitor at low-voltage intermittent supply
[85]	R. Ciavarella *et al*	2021	DBS Control	Dc-bus signalling (DBS) used as a distributed decentralized control strategy in in generation sources/storage interface converters.
[86]	S. I. Seleem et.al	2021	Equilibrium optimizer	The effectiveness of EO-PEMFC model to extract fuel cell dynamic model under various operating conditions
[87]	F. Qayyum et.al	2022	Predictive optimization-based	Data Optimization of Nano grid houses.
[88]	P. Muthuvel et.al	2022	Incremental loss consensus algorithm and voltage consensus algorithm.	The power loss minimization problem of solar DC Nano grids
[89]	C. Caputo et.al	2023	Data-driven approach	DRL-based approach for the design and planning of a mobile energy system supply system.
[90]	J. T. N. Bissé *et al*	2024	A fuzzy logic (FLC) centred mechanism with a radial basis function (RBF) neural network	The proposed method is excellent compared with FLC and PI control. It improves response time
[91]	F. Qayyum et.al	2024	RNN	An optimal power management system tailored to Nano grid energy trading
[92]	I. I. Ioannou et.al	2024	Linear Programming,	Distributed AI (DAI) framework as imperative to manage the by the increasing integration of green energy sources into the power system
[93]	G. Brusco et.al	2024	FA-DBS hierarchical control	The power loss problem of multi-port converter-enabled solar DC Nano grids

Table 1: Review of advanced optimization techniques in Energy Management of Nano grids

3.2 Economic Optimization: Energy Economic Dispatch in Nano Grids

There is a developing body of literature on the Nano grid economic dispatch of energy resources using metaheuristic techniques, incorporating not only renewable energy sources (RES) but also conventional energy systems. Generally, the prime considerations in economic dispatch of Nano grids are minimization of costing along with emission dispatch in both operations of generation and storage. Both methodologies target to minimize losses while maintaining value standards.

Authors in [94] present an approach of techno-economic method for cost optimization in Nano grid PV-DG architecture while observing to consistency limits. The proposed method determines the optimal cost per unit of load lines with LCOE consideration of their node locations and potential drop in the way. Kumar N [94] introduce cloud based infrastructure for Nano grid having WT/PV systems that assists as an alternative to traditional power system optimization. The cloud computing approach divides the problem into a 2 modes of data centers for reduction of execution time of RES (Renewable Energy Resources). The goal is to minimize total operational costs, utilizing cloud for storing of information. It also comprises demand forecasts based on local conditions, with nonlinear aspects of cloud infrastructure. Further, for advancement of Nano grid technology infrastructure, online self-governing system is being implemented with optimal selection and formation of grid system in urban building. Online users are connected for trading network and optimize the energy economic dispatch function by self-analysis. Although the Nano grids structure contains various resources parameters, still there is need for enhancement in performance and economic dispatch outputs. In order to improve the existing system, Ding et. Al proposed a well-defined energy strategy for economic energy management of house holding Nano grids [95]. A similar methodology could be smeared in integrated pv-wind-battery Nano grid in which authors present a novel design for optimization of cost objective function by field work. Four different data sets are taken into account for practical demonstration of integrated Nano grid structure. The experiment shows the reduction in leveled cost factor for both solar and wind components. Forcan et. al present the new cloud– fog Optimization technique for load distribution in Nano grid system. In this paper, the cloud fog atmosphere balances the load of 13 bus system data sets. The optimization reduces the CPU processing time as well as total cost factor of Nano grid system. The optimization route integrates limits of bus systems, RES and DG sets [96].

Mohseni et al. [97] propose an approach for transforming the existing optimization algorithm into an advanced for structure development of Nano grids. This includes step by step strategies for performance enhancement of different optimization technologies. The authors also present novel approach for hydrogen sizing and storage distribution in order to make structural modifications for self-sufficient operation. Optimal positions and dimensions for renewable energy resources are recognized by using different metaheuristic techniques likes particle swarm optimization (PSO), bat algorithm (BA), ant colony optimization (ACO), ant lion optimization (ALO), dragonfly algorithm (DM), and genetic algorithms (GA) and also various hybrid optimizations like GA-PSO, NP-HARD, HABC-PSO and more.

In addressing Nano grid controller challenges, some researchers propose an artificial intelligence optimization for enhancing the performance characteristics of controller to multi-objective optimization problems along with sensitivity investigation [98]. For instance, authors in [99] implement a two-stage real coded genetic algorithm (RCGA) in MATLAB to improve PID configurations of controller and minimizing the errors. Similarly, a progressive metaheuristic based programmable controller is being used in for efficient energy management of Nano grids along with two stage distribution systems. The integration of GA with BPSO leads to new advanced controlling technique for energy management and price inspired DR systems. THE first stage uses GA algorithm factors to identify suitable spaces for the local parameters while BPSO leads to global positing of main constraints. The second stage generates a comprehensive result as compared to existing algorithms in order to determine prime dimensions of controller in distributed generators. The simulated simulation prove that proposed hybrid intelligence based technique has surpassed existing approaches in terms of bill cost, PAR, Unit Commitment and emissions parameters [99].

Ban et al. [100] propose another nested routine for addressing multi configurable siting, sizing and comparative analysis in distributed networks of Nano grids. Their main objective is to reduce costing factor associated with integrated linear programming algorithm for 3 different sets of configurations. The proposed nested hybrid technique optimizes integrated(PV/WIND/BESS) Nano grid system capacity from up to 68% by reducing levelized cost of energy(LCOE). The conjunction of genetic algorithm (GA) with PSO algorithm further enhances controller performances of Nano grid with the constrained practice as compared to other techniques in order to find a ISE superior solution for different PID configurations [101].

Different Heuristic approaches have also been active in dealing the remote location problems. For example, Bauchekara et al.

[102] utilize PSO based real application for optimal sizing and cost optimization of desert based Nano grids in Hafr al-Batin city. The authors employed parallel multi-objective PSO (PMOPSO) approach of computing for designing and

economic management of Nano grids. Another concept of metaheuristic optimization technique called Arithmetic Optimization Algorithm (AOA) is used for maximum point tracking interleaved boost convertor for maximizing the benefit to Nano grids. The proposed technique minimize power generation distributed by PV only with different solar conditions to improve duty cycle of solar panel [103]. One of classical approach with modification is used for techno-economic operation of Nano grid. This approach is called Harmony Search (HS) algorithm which is implemented on grid structure having PV/DG for reducing leveled unit energy cost factor [104]. There is introduction of improved pelican optimization algorithm by Davdar et. Al in [105] for three different configurations of Nano grids that is used to reduce the carbon emissions.

In [106], Jirdehi et.al describe an approach for bi-level energy optimization of multiple connected Nano grids loads. This multi objective problem is resolved with help of multiple integer linear programming algorithm MILP in which cost and pollution of a Nano grid framework is being optimized. There is consideration of various parameters like minimizing of cost interconnection, sizing, and siting of renewable energy resources while following global and local positioning criteria. One of main focus for any engineer is to share the energy in such a way that it can be utilized by all resources and this problem can be resolved by predictive optimization. The predictive analysis leads to the distribution of stored energy in peer-to-peer network operation of Nano grid. There is also option of fast charging battery system in Nano grids with intelligent flow management technique proposed by Leonori [107]. There is new approach called ANFIS EMS for energy management of Nano grids and project is called smart Columbus project for fast charging in energy management systems. Alsharif et. al [108] demonstrate the integration of vehicles with grid system with consideration of costing and reliability factor. There is an application of rule based optimization scheme called Improved Ant Lion Optimization (IALO) for cost of energy (COE) optimization of integrated (Solar/Wind/DG) Nano grid system. The proposed algorithm run for 5 parameters size with 500 iterations and generate optimal convergence

The decision and control strategy employed in each Nano grid significantly inspire the energy trading from various scattered generators. For better energy economic dispatch, Quyyam et. al [109] proposed IOT-PSO based orchestration system in which pv and battery is used for trading method. The proposed method generates better trading of per unit energy. One of latest approach called Aquila optimization algorithm (IAO) which is being employed for economic dispatch problem optimization along with bi level energy management of wind and solar Nano grid system [110].

Renjith with co- authors [111] review the energy management challenges in Nano grids, highlighting the coordination and structural optimization of distributed energy resources (DER) using artificial intelligence for modular Nano grid. In this research work, the problem of unit commitment and economic dispersion is being considered and resolved by artificial intelligence optimization technique for solar and wind unified Nano grid. A modern approach for energy management system is illustrated in [112], where a forecasted demand error compensation is optimized using hybrid battery energy systems in nonlinear Nano grids. The complete system model is framed for faster sampling rate within the demand platform.

The motivation behind research in economic and energy optimization for sustainable development is to forge a future where economic growth and environmental sustainability coexist harmoniously. As industrialization and technological advancements intensify the strain on natural resources, it is crucial to integrate economic efficiency and energy optimization to foster sustainable development. Traditional economic models often neglect environmental costs, leading to unsustainable practices that exacerbate climate change and deplete resources. By transitioning to renewable energy sources and enhancing energy efficiency, we can reduce carbon emissions, improve energy security, and generate economic benefits. Interdisciplinary research is essential for developing holistic solutions that inform policy, industry, and community decisions, promoting a culture of sustainability. This research aims not only to address current challenges but also to anticipate and mitigate future risks, ensuring a resilient and sustainable world for future generations.

Table 2 summarizes various optimization techniques used in the economic management of nano-grids. It includes methods like linear programming, genetic algorithms, and particle swarm optimization, highlighting their application areas (e.g., cost optimization, energy scheduling), key features, advantages, limitations, and real-world implementation examples. The table underscores the strengths of each technique while identifying challenges such as computational complexity and handling uncertainty, advocating for advanced hybrid and AI-driven approaches to improve efficiency and reliability.

4. Discussion

Based on the review of relevant literature, several key research gaps have been identified that underscore the need for further exploration in specific areas. Firstly, the application of Artificial Intelligence (AI) in nano-grid systems remains limited in both scope and practical implementation, highlighting an opportunity to expand the role of AI in optimizing and managing these systems. Secondly, the integration of grids, particularly in conjunction with the modeling of Renewable Energy Sources (RES), presents significant challenges. This issue underscores the complexity of achieving seamless interoperability and efficient performance in such systems. Lastly, while integrated and hybrid techniques are gaining attention, their application—especially those involving nature-inspired algorithms—is still in its nascent stages. This limitation points to untapped potential for leveraging advanced computational methods to enhance the efficiency and reliability of grid systems. These gaps collectively pave the way for innovative research aimed at addressing these challenges and advancing the field.

Ref.no	**Author**	**Year**	**Optimization Techniques**	**Application in Economic Management of Nano grids**
[113]	Heidari et. al	2019	Modified Teaching learning based Optimisation (MTLBO) algorithm	Optimization of operating and emission cost of pollution gases
[114]	Yang et. al	2019	article Swarm Optimization (BPSO)	Reduced unit commitment with EVS
[115]	Parizy et,al	2020	Three level optimisation	A distributed three level model of optimization scheme for cost optimal of a prosumer Nano-grid.
[116]	Basu et. al	2021	rd Optimization Algorithm (HOA)	Day ahead scheduling and cost reduced of Nano grids by 2%
[117]	Akpolat et.al	2021	Deep learning Algorithms	Sensor control in DC Nano grids
[118]	Makhlouf i et. al	2021	Logarithmic PSO	Maximum Point tracker and minimize prediction error in PV Nano Grid systems
[119]	Yadav et. al	2022	Hybrid PSO	Parameter optimization of nano grid with PV
[120]	Bitar et. al	2023	Hybrid Algorithms	Energy management systems and integration
[121]	Kumar et. al	2023	Grasshopper–Black Hole Optimization (G–BHO)	Sanitization and Restoration of IIoT data
[122]	Nagaraju et. al	2024	Al based cloud computing	Optimal reduction in various parameters along with link predicti
[123]	Alhasnawi et. al	2023	Butterfly Optimization Algorithm (BOA)	Economic optimization on average all over the grid networks
[124]	Sharma et.al	2023	Coot-bird optimization (CBO)	RMSE value reduced
[125]	Moradi et.al	2023	Multiple Integer linear programming(MLP)	Reducing EV charging and interfacing time for cost optimization
[126]	Abadi et.al	2023	Adaptive Model Predictive Control	Optimal costing for designing of nano grid at building level
[127]	Odonka r et.al	2024	ANFIS	Economic Energy optimization of integrated MG/ NG
[128]	Di Florio et.al	2024	Dynamic life cycle assessment	Optimal power cost optimization for residential hybrid DC Nano grid

Table 2 Review of optimization techniques in economic management of Nano grids

5. **Conclusion and Future Scope**

This paper presents the application and patterns of metaheuristic techniques in economic and energy management of Nano grids with significant potential in solving the complexities associated with the operation and optimization of various distributed energy systems. The various artificial intelligent techniques and their hybrid realizations presented in this paper offer proficient solutions for optimization of energy generation, distribution and storage formulations while minimalizing the cost factor and ensuring grid stability. However, in spite of the promising results, several challenges remain in operational Nano grids due to which there is need of more advanced robust and adaptive optimization models that can knob the dynamic nature and varying demand patterns of renewable energy sources. Future research work should be focus on the convergence and characteristics development of hybrid metaheuristic approaches that incorporate real-time data analytics and machine learning with AI to enhance decision-making process for system efficiency. Additionally, a better accent on scalability and real-world simulations of these models is essential for their pervasive implementation.

References:

[1] D. Burmester, R. Rayudu, W. Seah, and D. Akinyele, "A review of nanogrid topologies and technologies," *Renew. Sustain. Energy Rev.*, vol. 67, pp. 760–775, 2017, doi: 10.1016/j.rser.2016.09.073.

[2] S. Jamal and N. M. L. Tan, "A Review of Energy Management and Power Management Systems for Microgrid and Nanogrid Applications," 2021.

[3] D. Santoro *et al.*, "Local Power Distribution—A Review of Nanogrid Architectures, Control Strategies, and Converters," *Sustain.*, vol. 15, no. 3, 2023, doi: 10.3390/su15032759.

[4] K. R. Naik, B. Rajpathak, A. Mitra, and M. Kolhe, "A Review of Nanogrid Technologies for Forming Reliable Residential Grid," *Proc. 2020 IEEE 1st Int. Conf. Smart Technol. Power, Energy Control. STPEC 2020*, 2020, doi: 10.1109/STPEC49749.2020.9297757.

[5] Q. Hu, Z. Zhu, S. Bu, K. Wing Chan, and F. Li, "A multi-market nanogrid P2P energy and ancillary service trading paradigm: Mechanisms and implementations," *Appl. Energy*, vol. 293, 2021, doi: 10.1016/j.apenergy.2021.116938.

[6] M. Di Somma *et al.*, "Multi-Energy Nanogrids for Residential Applications," 2020.

[7] D. Akinyele, "Techno-economic design and performance analysis of nanogrid systems for households in energy-poor villages," *Sustain. Cities Soc.*, vol. 34, pp. 335–357, 2017, doi: 10.1016/j.scs.2017.07.004.

[8] A. Vazquez, K. Martin, M. Arias, and J. Sebastian, "On bidirectional DC nano-grids: Design considerations and an architecture proposal," *Energies*, vol. 12, no. 19, pp. 1–20, 2019, doi: 10.3390/en12193715.

[9] A. Paolillo, D. L. Carni, M. Kermani, L. Martirano, and A. Aiello, "An innovative Home and Building Automation design tool for Nanogrids Applications," *Proc. - 2019 IEEE Int. Conf. Environ. Electr. Eng. 2019 IEEE Ind. Commer. Power Syst. Eur. EEEIC/I CPS Eur. 2019*, no. June 2019, 2019, doi: 10.1109/EEEIC.2019.8783878.

[10] G. Mendes, C. Ioakimidis, and P. Ferrão, "On the planning and analysis of Integrated Community Energy Systems: A review and survey of available tools," *Renew. Sustain. Energy Rev.*, vol. 15, no. 9, pp. 4836–4854, 2011, doi: 10.1016/j.rser.2011.07.067.

[11] K. Mahmud, A. K. Sahoo, E. Fernandez, P. Sanjeevikumar, and J. B. Holm-Nielsen, "Computational Tools for Modeling and Analysis of Power Generation and Transmission Systems of the Smart Grid," *IEEE Syst. J.*, vol. 14, no. 3, pp. 3641–3652, 2020, doi: 10.1109/JSYST.2020.2964436.

[12] M. Rahimian, L. D. Iulo, and J. M. P. Duarte, "A Review of Predictive Software for the Design of Community Microgrids," *J. Eng. (United Kingdom)*, vol. 2018, 2018, doi: 10.1155/2018/5350981.

[13] R. Baños, F. Manzano-Agugliaro, F. G. Montoya, C. Gil, A. Alcayde, and J. Gómez, "Optimization methods applied to renewable and sustainable energy: A review," *Renew. Sustain. Energy Rev.*, vol. 15, no. 4, pp. 1753–1766, 2011, doi: 10.1016/j.rser.2010.12.008.

[14] O. A. Al-Shahri *et al.*, "Solar photovoltaic energy optimization methods, challenges and issues: A comprehensive review," *J. Clean. Prod.*, vol. 284, 2021, doi: 10.1016/j.jclepro.2020.125465.

[15] G. Barone *et al.*, "Providing Balancing Services," 2021.

[16] S. Leonori, A. Martino, F. M. Frattale Mascioli, and A. Rizzi, "Microgrid Energy Management Systems Design by Computational Intelligence Techniques," *Appl. Energy*, vol. 277, no. June, 2020, doi: 10.1016/j.apenergy.2020.115524.

[17] F. Rossi, M. L. Parisi, S. Maranghi, R. Basosi, and A. Sinicropi, "Environmental analysis of a nano-grid: A Life Cycle Assessment," *Sci. Total Environ.*, vol. 700, 2020, doi: 10.1016/j.scitotenv.2019.134814.

[18] D. Kanakadhurga and N. Prabaharan, "Demand side management in microgrid: A critical review of key issues

and recent trends," *Renew. Sustain. Energy Rev.*, vol. 156, no. May 2021, 2022, doi: 10.1016/j.rser.2021.111915.

[19] M. Latifi, A. Rastegarnia, A. Khalili, W. M. Bazzi, and S. Sanei, "A Self-Governed Online Energy Management and Trading for Smart Micro/Nano-Grids," *IEEE Trans. Ind. Electron.*, vol. 67, no. 9, pp. 7484– 7498, 2020, doi: 10.1109/TIE.2019.2945280.

[20] A. R. Kalair, N. Abas, Q. U. Hasan, M. Seyedmahmoudian, and N. Khan, "Demand side management in hybrid rooftop photovoltaic integrated smart nano grid," *J. Clean. Prod.*, vol. 258, 2020, doi: 10.1016/j.jclepro.2020.120747.

[21] M. H. Shwehdi, "Proposed Smart DC Nano-Grid for Green Buildings — A Reflective View," pp. 765–769, 2014.

[22] C. P. Muzzillo, "Metal nano-grids for transparent conduction in solar cells," *Sol. Energy Mater. Sol. Cells*, vol. 169, no. April, pp. 68–77, 2017, doi: 10.1016/j.solmat.2017.04.048.

[23] Y. B. Elias, M. Y. Yousef, A. Mohamed, A. A. Ali, and M. A. Mosa, "Energy management and demand side management framework for nano-grid under various utility strategies and consumer's preference," *Sci. Rep.*, vol. 14, no. 1, p. 25757, 2024, doi: 10.1038/s41598-024-74509-y.

[24] N. Yadav and N. R. Tummuru, "A Real-Time Resistance Based Fault Detection Technique for Zonal Type Low-Voltage DC Microgrid Applications," *IEEE Trans. Ind. Appl.*, vol. 56, no. 6, pp. 6815–6824, 2020, doi: 10.1109/TIA.2020.3017564.

[25] J. Bae, S. Lee, and H. Kim, "Comparative study on the economic feasibility of nanogrid and microgrid electrification: The case of Jeju Island, South Korea," *Energy Environ.*, vol. 32, no. 1, pp. 168–188, 2021, doi: 10.1177/0958305X20923119.

[26] M. F. Zia, E. Elbouchikhi, and M. Benbouzid, "Microgrids energy management systems: A critical review on methods, solutions, and prospects," *Appl. Energy*, vol. 222, no. March, pp. 1033–1055, 2018, doi: 10.1016/j.apenergy.2018.04.103.

[27] M. Ahmed, U. Amin, S. A. Qureshi, and Z. Ahmed, "Implementation of Nanogrids for Future Power System," vol. i, no. 1, pp. 133–139, 2014.

[28] O. Palizban and K. Kauhaniemi, "Energy storage systems in modern grids—Matrix of technologies and applications," *J. Energy Storage*, vol. 6, pp. 248–259, 2016, doi: 10.1016/j.est.2016.02.001.

[29] S. M. Kaviri, H. Hajebrahimi, B. Poorali, M. Pahlevani, P. K. Jain, and A. Bakhshai, "A Supervisory Control System for Nanogrids Operating in the Stand-Alone Mode," *IEEE Trans. Power Electron.*, vol. 36, no. 3, pp. 2914–2931, 2021, doi: 10.1109/TPEL.2020.3015817.

[30] X. Lu, K. Li, H. Xu, F. Wang, Z. Zhou, and Y. Zhang, "Fundamentals and business model for resource aggregator of demand response in electricity markets," *Energy*, vol. 204, 2020, doi: 10.1016/j.energy.2020.117885.

[31] D. Chowdhury, A. S. M. K. Hasan, and M. Z. R. Khan, "Islanded DC Microgrid Architecture with Dual Active Bridge Converter-Based Power Management Units and Time Slot-Based Control Interface," *IEEJ Trans. Electr. Electron. Eng.*, vol. 15, no. 6, pp. 863–871, 2020, doi: 10.1002/tee.23128.

[32] S. Moussa, M. J. Ben Ghorbal, and I. Slama-Belkhodja, "Bus voltage level choice for standalone residential DC nanogrid," *Sustain. Cities Soc.*, vol. 46, no. January, 2019, doi: 10.1016/j.scs.2019.101431.

[33] A. Goikoetxea, J. M. Canales, R. Sanchez, and P. Zumeta, "DC versus AC in residential buildings: Efficiency comparison," *IEEE EuroCon 2013*, pp. 3–7, 2013, doi: 10.1109/EUROCON.2013.6625162.

[34] L. Mackay, N. H. va. der Blij, L. Ramirez-Elizondo, and P. Bauer, "Toward the Universal DC Distribution System," *Electr. Power Components Syst.*, vol. 45, no. 10, pp. 1032–1042, 2017, doi: 10.1080/15325008.2017.1318977.

[35] D. C. Nanogrids *et al.*, "Three-Port Bidirectional DC / DC Converter for," vol. 36, no. 7, pp. 8000–8011, 2021.

[36] A. Werth, N. Kitamura, and K. Tanaka, "Conceptual Study for Open Energy Systems: Distributed Energy Network Using Interconnected DC Nanogrids," *IEEE Trans. Smart Grid*, vol. 6, no. 4, pp. 1621–1630, 2015, doi: 10.1109/TSG.2015.2408603.

[37] F. Schmid, J. Winzer, A. Pasemann, and F. Behrendt, "An open-source modeling tool for multi-objective optimization of renewable nano/micro-off-grid power supply system: Influence of temporal resolution, simulation period, and location," *Energy*, vol. 219, 2021, doi: 10.1016/j.energy.2020.119545.

[38] L. Street, "ce pt us cr ip t Ac ce pt us cr t," vol. 306, pp. 0–19, 2016.

[39] Y. Cui, Z. Geng, Q. Zhu, and Y. Han, "Review: Multi-objective optimization methods and application in energy saving," *Energy*, vol. 125, pp. 681–704, 2017, doi: 10.1016/j.energy.2017.02.174.

[40] R. T. Marler and J. S. Arora, "Survey of multi-objective optimization methods for engineering," *Struct. Multidiscip. Optim.*, vol. 26, no. 6, pp. 369–395, 2004, doi: 10.1007/s00158-003-0368-6.

[41] E. Osaba *et al.*, "A Tutorial On the design, experimentation and application of metaheuristic algorithms to real-World optimization problems," *Swarm Evol. Comput.*, vol. 64, 2021, doi: 10.1016/j.swevo.2021.100888.
[42] Q. Lyu, Z. Lin, Y. She, and C. Zhang, "A comparison of typical ℓp minimization algorithms," *Neurocomputing*, vol. 119, pp. 413–424, 2013, doi: 10.1016/j.neucom.2013.03.017.
[43] A. Rong and R. Lahdelma, "An efficient linear programming model and optimization algorithm for trigeneration," *Appl. Energy*, vol. 82, no. 1, pp. 40–63, 2005, doi: 10.1016/j.apenergy.2004.07.013.
[44] I. Quesada and I. E. Grossmann, "An LP/NLP based branch and bound algorithm for convex MINLP optimization problems," *Comput. Chem. Eng.*, vol. 16, no. 10–11, pp. 937–947, 1992, doi: 10.1016/0098-1354(92)80028-8.
[45] M. Ali, J. Jokisalo, K. Siren, and M. Lehtonen, "Erratum to 'Combining the Demand Response of direct electric space heating and partial thermal storage using LP optimization' (Electr. Power Syst. Res. (2014) 106 (160–167))," *Electr. Power Syst. Res.*, vol. 107, p. 268, 2014, doi: 10.1016/j.epsr.2013.10.011.
[46] L. Moretti, M. Astolfi, C. Vergara, E. Macchi, J. I. Pérez-Arriaga, and G. Manzolini, "A design and dispatch optimization algorithm based on mixed integer linear programming for rural electrification," *Appl. Energy*, vol. 233–234, pp. 1104–1121, 2019, doi: 10.1016/j.apenergy.2018.09.194.
[47] C. Still and T. Westerlund, "A linear programming-based optimization algorithm for solving nonlinear programming problems," *Eur. J. Oper. Res.*, vol. 200, no. 3, pp. 658–670, 2010, doi: 10.1016/j.ejor.2009.01.033.
[48] A. Gogna and A. Tayal, "Metaheuristics: Review and application," *J. Exp. Theor. Artif. Intell.*, vol. 25, no. 4, pp. 503–526, 2013, doi: 10.1080/0952813X.2013.782347.
[49] A. H. Gandomi, X. S. Yang, S. Talatahari, and A. H. Alavi, "Metaheuristic Algorithms in Modeling and Optimization," *Metaheuristic Appl. Struct. Infrastructures*, pp. 1–24, 2013, doi: 10.1016/B978-0-12-398364-0.00001-2.
[50] M. Abdel-Basset, L. Abdel-Fatah, and A. K. Sangaiah, *Metaheuristic algorithms: A comprehensive review*. 2018. doi: 10.1016/B978-0-12-813314-9.00010-4.
[51] B. Liu, L. Wang, Y. Liu, and S. Wang, "A unified framework for population-based metaheuristics," *Ann. Oper. Res.*, vol. 186, no. 1, pp. 231–262, 2011, doi: 10.1007/s10479-011-0894-3.
[52] H. Garg, "A hybrid GSA-GA algorithm for constrained optimization problems," *Inf. Sci. (Ny).*, vol. 478, pp. 499–523, 2019, doi: 10.1016/j.ins.2018.11.041.
[53] A. K. Kar, "Bio inspired computing - A review of algorithms and scope of applications," *Expert Syst. Appl.*, vol. 59, pp. 20–32, 2016, doi: 10.1016/j.eswa.2016.04.018.
[54] C. Gamarra and J. M. Guerrero, "Computational optimization techniques applied to microgrids planning: A review," *Renew. Sustain. Energy Rev.*, vol. 48, pp. 413–424, 2015, doi: 10.1016/j.rser.2015.04.025.
[55] X. Zhang, Z. Xu, and T. Yu, "A Cyber-Physical-Social System with Parallel Learning for Distributed Energy Management of a Microgrid," *Int. Conf. Innov. Smart Grid Technol. ISGT Asia 2018*, vol. 165, pp. 1294– 1298, 2018, doi: 10.1109/ISGT-Asia.2018.8467970.
[56] M. Mohammad, D. Shankar, T. Vinesh, L. Ravi, and Yvette Shaan Li Susaipan, "Sustainable Nano Grid Design with Solar Wind Hybrid System for Off-Grid Rural Electrification," *Solid State Technol.*, vol. 63, no. 1s, pp. 993–1002, 2020, [Online]. Available: https://solidstatetechnology.us/index.php/JSST/article/view/788
[57] M. Mahmoodi, P. Shamsi, and B. Fahimi, "Economic dispatch of a hybrid microgrid with distributed energy storage," *IEEE Trans. Smart Grid*, vol. 6, no. 6, pp. 2607–2614, 2015, doi: 10.1109/TSG.2014.2384031.
[58] M. Pereira, D. Munoz De La Pena, and D. Limon, "Robust economic model predictive control of a community micro-grid," *2016 IEEE 55th Conf. Decis. Control. CDC 2016*, vol. 100, pp. 2739–2744, 2016, doi: 10.1109/CDC.2016.7798676.
[59] S. Javaid, T. Kato, and T. Matsuyama, "Power Flow Coloring System over a Nanogrid with Fluctuating Power Sources and Loads," *IEEE Trans. Ind. Informatics*, vol. 13, no. 6, pp. 3174–3184, 2017, doi: 10.1109/TII.2017.2733550.
[60] S. Eren, M. Pahlevani, A. Bakhshai, and P. Jain, "A Digital Current Control Technique for Grid-Connected AC/DC Converters Used for Energy Storage Systems," *IEEE Trans. Power Electron.*, vol. 32, no. 5, pp. 3970–3988, 2017, doi: 10.1109/TPEL.2016.2582901.
[61] N. Kumar, A. V. Vasilakos, and J. J. P. C. Rodrigues, "A multi-tenant cloud-based DC nano grid for self-sustained smart buildings in smart cities," *IEEE Commun. Mag.*, vol. 55, no. 3, pp. 14–21, 2017, doi: 10.1109/MCOM.2017.1600228CM.
[62] Y. T. Quek, W. L. Woo, and T. Logenthiran, "Smart Sensing of Loads in an Extra Low Voltage DC Pico-Grid Using

Machine Learning Techniques," *IEEE Sens. J.*, vol. 17, no. 23, pp. 7775–7783, 2017, doi: 10.1109/JSEN.2017.2723925.

[63] S. Javaid, Y. Kurose, T. Kato, and T. Matsuyama, "Cooperative Distributed Control Implementation of the Power Flow Coloring over a Nano-Grid with Fluctuating Power Loads," *IEEE Trans. Smart Grid*, vol. 8, no. 1, pp. 342–352, 2017, doi: 10.1109/TSG.2015.2509002.

[64] G. Venkataramani *et al.*, "Experimental investigation on small capacity compressed air energy storage towards efficient utilization of renewable sources," *J. Energy Storage*, vol. 20, no. March, pp. 364–370, 2018, doi: 10.1016/j.est.2018.10.018.

[65] D. Burmester, R. Rayudu, and W. K. G. Seah, "Use of maximum power point tracking signal for instantaneous management of thermostatically controlled loads in a DC Nanogrid," *IEEE Trans. Smart Grid*, vol. 9, no. 6, pp. 6140–6148, 2018, doi: 10.1109/TSG.2017.2704116.

[66] N. Liu *et al.*, "Online energy sharing for nanogrid clusters: A lyapunov optimization approach," *IEEE Trans. Smart Grid*, vol. 9, no. 5, pp. 4624–4636, 2018, doi: 10.1109/TSG.2017.2665634.

[67] E. S. Parizy, H. R. Bahrami, and K. A. Loparo, "A Decentralized Three-Level Optimization Scheme for Optimal Planning of a Prosumer Nano-Grid," *IEEE Trans. Power Syst.*, vol. 35, no. 5, pp. 3421–3432, 2020, doi: 10.1109/TPWRS.2020.2982278.

[68] S. Batchelor, E. Brown, J. Leary, N. Scott, A. Alsop, and M. Leach, "Solar electric cooking in Africa: Where will the transition happen first?," *Energy Res. Soc. Sci.*, vol. 40, no. March, pp. 257–272, 2018, doi: 10.1016/j.erss.2018.01.019.

[69] H. T. Nguyen, A. S. Al-Sumaiti, K. Al Hosani, and M. S. Elmoursi, "Multifunctional Control of Wind-Turbine Based Nano-Grid Connected to Distorted Utility-Grid," *IEEE Trans. Power Syst.*, vol. 37, no. 1, pp. 576–589, 2022, doi: 10.1109/TPWRS.2021.3093713.

[70] X. Wu, X. Hu, Y. Teng, S. Qian, and R. Cheng, "Optimal integration of a hybrid solar-battery power source into smart home nanogrid with plug-in electric vehicle," *J. Power Sources*, vol. 363, pp. 277–283, 2017, doi: 10.1016/j.jpowsour.2017.07.086.

[71] K. Rajeshwar Reddy, M. Sai Kumar, B. Rajender, and B. Kothapalli, "Integrating the Pv arrays to the smart nano grid using an artificial intelligence," *Int. J. Innov. Technol. Explor. Eng.*, vol. 8, no. 12, pp. 2593–2596, 2019, doi: 10.35940/ijitee.K2078.1081219.

[72] F. Blaabjerg, L. Xiangkun, W. Weimin, W. Houqing, G. Ning, and C. Hnery Shu-hung, "energies Two- Terminal Output Voltage for DC Nano-Grid the," *Energies*, vol. 12, no. 20, p. 3808, 2019.

[73] C. Murugesan and C. N. Marimuthu, "Cost optimization of PV-diesel systems in nanogrid using cuckoo search algorithm and its application in mobile towers," *Int. J. Emerg. Technol.*, vol. 11, no. 3, pp. 328–335, 2020.

[74] A. Ghaznavi and S. M. T. Almodarresi, "A novel robust hierarchical consensus algorithm with application in dc nanogrids coordination," *Int. J. Nonlinear Anal. Appl.*, vol. 10, no. 2, pp. 97–110, 2019, doi: 10.22075/IJNAA.2019.4178.

[75] I. Worighi, T. Geury, M. El Baghdadi, J. Van Mierlo, O. Hegazy, and A. Maach, "Optimal design of hybrid PV-Battery system in residential buildings: End-user economics, and PV penetration," *Appl. Sci.*, vol. 9, no. 5, 2019, doi: 10.3390/app9051022.

[76] J. Lyu, T. Ye, M. Xu, G. Ma, Y. Wang, and M. Li, "Price-sensitive home energy management method based on Pareto optimisation," *Int. J. Sustain. Eng.*, vol. 14, no. 3, pp. 433–441, 2021, doi: 10.1080/19397038.2020.1822948.

[77] M. Rawa *et al.*, "Optimal allocation and economic analysis of battery energy storage systems: Self- consumption rate and hosting capacity enhancement for microgrids with high renewable penetration," *Sustain.*, vol. 12, no. 23, pp. 1–25, 2020, doi: 10.3390/su122310144.

[78] A. R. Kalair, N. Abas, M. Seyedmahmoudian, S. Rauf, A. Stojcevski, and N. Khan, "Duck curve leveling in renewable energy integrated grids using internet of relays," *J. Clean. Prod.*, vol. 294, 2021, doi: 10.1016/j.jclepro.2021.126294.

[79] S. Yousaf, A. Mughees, M. G. Khan, A. A. Amin, and M. Adnan, "A comparative analysis of various controller techniques for optimal control of smart nano-grid using GA and PSO algorithms," *IEEE Access*, vol. 8, pp. 205696–205711, 2020, doi: 10.1109/ACCESS.2020.3038021.

[80] R. Namani, S. Subramaniam, S. M. Samikannu, and M. Gurusamy, "A simple control strategy and dynamic energy management for the operation of combined grid-connected and standalone solar photovoltaic applications," *J. King Saud Univ. - Eng. Sci.*, no. xxxx, 2022, doi: 10.1016/j.jksues.2021.12.009.

[81] F. Qayyum, F. Jamil, S. Ahmad, and D. H. Kim, "Hybrid renewable energy resources management for optimal

energy operation in nano-grid," *Comput. Mater. Contin.*, vol. 71, no. 2, pp. 2091–2105, 2022, doi: 10.32604/cmc.2022.019898.

[82] C. Samende, S. M. Bhagavathy, and M. McCulloch, "Distributed State of Charge-Based Droop Control Algorithm for Reducing Power Losses in Multi-Port Converter-Enabled Solar DC Nano-Grids," *IEEE Trans. Smart Grid*, vol. 12, no. 6, pp. 4584–4594, 2021, doi: 10.1109/TSG.2021.3089362.

[83] M. Farmanbar, K. Parham, O. Arild, and C. Rong, "A widespread review of smart grids towards smart cities," *Energies*, vol. 12, no. 23, 2019, doi: 10.3390/en12234484.

[84] E. A. L. I. Ebrahim, A. M. Ali, J. T. St, Q. El-nozha, and C. Governorate, "Performance and Tracking Control of Three-Phase Induction-Motor Drive Fed from a DC-Modified Nano-grid 2 The Proposed Rig," vol. 16, pp. 8–21, 2021, doi: 10.37394/232016.2021.16.2.

[85] R. Ciavarella *et al.*, "Modeling of an energy hybrid system integrating several storage technologies: The DBS technique in a nanogrid application," *Sustain.*, vol. 13, no. 3, pp. 1–35, 2021, doi: 10.3390/su13031170.

[86] S. I. Seleem, H. M. Hasanien, and A. A. El-Fergany, "Equilibrium optimizer for parameter extraction of a fuel cell dynamic model," *Renew. Energy*, vol. 169, pp. 117–128, 2021, doi: 10.1016/j.renene.2020.12.131.

[87] F. Qayyum, H. Jamil, F. Jamil, and D. Kim, "Predictive Optimization Based Energy Cost Minimization and Energy Sharing Mechanism for Peer-to-Peer Nanogrid Network," *IEEE Access*, vol. 10, pp. 23593–23604, 2022, doi: 10.1109/ACCESS.2022.3153837.

[88] P. Muthuvel, S. A. Daniel, and S. K. Paul, "Engineering Science and Technology , an International Journal Sizing of PV array in a DC nano-grid for isolated households after alteration in time of consumption Grid tied inverter / system Solar array MPPT converter PMDC Grinder BLDC mixer DC freezer PM," *Eng. Sci. Technol. an Int. J.*, vol. 20, no. 6, pp. 1632–1641, 2017, [Online]. Available: https://doi.org/10.1016/j.jestch.2017.12.006

[89] C. Caputo, M. A. Cardin, P. Ge, F. Teng, A. Korre, and E. Antonio del Rio Chanona, "Design and planning of flexible mobile Micro-Grids using Deep Reinforcement Learning," *Appl. Energy*, vol. 335, no. December 2022, 2023, doi: 10.1016/j.apenergy.2023.120707.

[90] J. T. N. Bissé *et al.*, "Qualitative performance improvement of a hybrid power supply at the DC common coupling point using a neuro-fuzzy method," *Sci. African*, vol. 24, no. May, p. e02229, 2024, doi: 10.1016/j.sciaf.2024.e02229.

[91] F. Qayyum, H. Jamil, N. Iqbal, and D. H. Kim, "IoT-orchestrated optimal nanogrid energy management: Improving energy trading performance and efficiency via virtual operations," *Int. J. Electr. Power Energy Syst.*, vol. 155, no. November 2023, 2024, doi: 10.1016/j.ijepes.2023.109668.

[92] I. I. Ioannou, S. Javaid, C. Christophorou, V. Vassiliou, A. Pitsillides, and Y. Tan, "A Distributed AI Framework for Nano-Grid Power Management and Control," *IEEE Access*, vol. 12, no. March, pp. 43350– 43377, 2024, doi: 10.1109/ACCESS.2024.3377926.

[93] G. Brusco, D. Menniti, A. Pinnarelli, N. Sorrentino, and J. C. Vasquez, "Flexible and Advanced DBS: A distributed control strategy for a DC[sbnd]Nanogrid," *Electr. Power Syst. Res.*, vol. 233, pp. 17–20, 2024, doi: 10.1016/j.epsr.2024.110439.

[94] O. Turan, A. Durusu, and R. Yumurtaci, "Driving Urban Energy Sustainability: A Techno-Economic Perspective on Nanogrid Solutions," *Energies*, vol. 16, no. 24, 2023, doi: 10.3390/en16248084.

[95] Y. Ding, Z. Wang, S. Liu, and X. Wang, "Energy Management Strategy of PV Grid-Connected Household Nano-Grid System," *IEEE Power Energy Soc. Gen. Meet.*, vol. 2019-August, pp. 3–7, 2019, doi: 10.1109/PESGM40551.2019.8973404.

[96] M. Forcan and M. Maksimović, "Simulation Modelling Practice and Theory Cloud-Fog-based approach for Smart Grid monitoring," *Simul. Model. Pract. Theory*, vol. 101, no. June 2019, p. 101988, 2020, [Online]. Available: https://doi.org/10.1016/j.simpat.2019.101988

[97] S. Mohseni and A. C. Brent, "Economic viability assessment of sustainable hydrogen production, storage, and utilisation technologies integrated into on- and off-grid micro-grids: A performance comparison of different meta-heuristics," *Int. J. Hydrogen Energy*, vol. 45, no. 59, pp. 34412–34436, 2020, doi: 10.1016/j.ijhydene.2019.11.079.

[98] Z. Shi *et al.*, "Artificial intelligence techniques for stability analysis and control in smart grids: Methodologies, applications, challenges and future directions," *Appl. Energy*, vol. 278, no. May, 2020, doi: 10.1016/j.apenergy.2020.115733.

[99] X. Meng, L. Shi, L. Yao, Y. Zhang, and L. Cui, "ur na l P re of," *Colloids Surfaces A Physicochem. Eng. Asp.*, no. Iii, p. 124658, 2020, [Online]. Available: https://doi.org/10.1016/j.colsurfa.2020.124658

[100] M. Ban, J. Yu, M. Shahidehpour, and D. Guo, "Optimal sizing of PV and battery-based energy storage in an off-

grid nanogrid supplying batteries to a battery swapping station," *J. Mod. Power Syst. Clean Energy*, vol. 7, no. 2, pp. 309–320, 2019, doi: 10.1007/s40565-018-0428-y.

[101] I. A. Khan, A. S. Alghamdi, T. A. Jumani, A. Alamgir, A. B. Awan, and A. Khidrani, "Salp swarm optimization algorithm-based fractional order pid controller for dynamic response and stability enhancement of an automatic voltage regulator system," *Electron.*, vol. 8, no. 12, 2019, doi: 10.3390/electronics8121472.

[102] H. R. E. H. Bouchekara *et al.*, "Optimal sizing of hybrid photovoltaic/diesel/battery nanogrid using a parallel multiobjective PSO-based approach: Application to desert camping in Hafr Al-Batin city in Saudi Arabia," *Energy Reports*, vol. 7, pp. 4360–4375, 2021, doi: 10.1016/j.egyr.2021.07.015.

[103] A. F. Mirza, M. Mansoor, K. Zerbakht, M. Y. Javed, M. H. Zafar, and N. M. Khan, "High-efficiency hybrid PV-TEG system with intelligent control to harvest maximum energy under various non-static operating conditions," *J. Clean. Prod.*, vol. 320, no. July, 2021, doi: 10.1016/j.jclepro.2021.128643.

[104] A. Askarzadeh, "Distribution generation by photovoltaic and diesel generator systems: Energy management and size optimization by a new approach for a stand-alone application," *Energy*, vol. 122, pp. 542–551, 2017, doi: 10.1016/j.energy.2017.01.105.

[105] A. A. Dadvar, J. Vahidi, Z. Hajizadeh, A. Maleki, and M. Reza Bayati, "Experimental study on classical and metaheuristics algorithms for optimal nano-chitosan concentration selection in surface coating and food packaging," *Food Chem.*, vol. 335, no. March 2020, 2021, doi: 10.1016/j.foodchem.2020.127681.

[106] M. A. Jirdehi and S. Ahmadi, "The optimal energy management in multiple grids: Impact of interconnections between microgrid–nanogrid on the proposed planning by considering the uncertainty of clean energies," *ISA Trans.*, vol. 131, pp. 323–338, 2022, doi: 10.1016/j.isatra.2022.04.039.

[107] S. Leonori, G. Rizzoni, F. M. Frattale Mascioli, and A. Rizzi, "Intelligent energy flow management of a nanogrid fast charging station equipped with second life batteries," *Int. J. Electr. Power Energy Syst.*, vol. 127, no. September 2020, 2021, doi: 10.1016/j.ijepes.2020.106602.

[108] A. Alsharif, C. W. Tan, R. Ayop, M. N. Hussin, and A. L. Bukar, "Sizing Optimization Algorithm for Vehicle- to-Grid System Considering Cost and Reliability Based on Rule-Based Scheme," *Elektr. J. Electr. Eng.*, vol. 21, no. 3, pp. 6–12, 2022, doi: 10.11113/elektrika.v21n3.353.

[109] F. Qayyum, H. Jamil, N. Iqbal, and D. H. Kim, "IoT Orchestration-Based Optimal Energy Cost Decision Mechanism with ESS Power Optimization for Peer-to-Peer Energy Trading in Nanogrid," *Smart Cities*, vol. 6, no. 5, pp. 2196–2220, 2023, doi: 10.3390/smartcities6050101.

[110] Y. Zhou, Z. Chen, Z. Gong, P. Chen, and S. Razmjooy, "The improved aquila optimization approach for cost-effective design of hybrid renewable energy systems," *Heliyon*, vol. 10, no. 6, 2024, doi: 10.1016/j.heliyon.2024.e27281.

[111] P. N. Renjith, B. S. Alfurhood, K. V. Prashanth, V. S. Patil, N. Sharma, and A. Chaturvedi, "Coordination of modular nano grid energy management using multi-agent AI architecture," *Comput. Electr. Eng.*, vol. 115, no. February, pp. 1–8, 2024, doi: 10.1016/j.compeleceng.2024.109112.

[112] S. Liao, "Jou rna lP," *Econ. Lett.*, p. 111045, 2023, [Online]. Available: https://doi.org/10.1016/j.econlet.2023.111045

[113] M. Heidari, T. Niknam, M. Zare, and S. Niknam, "Integrated battery model in cost-effective operation and load management of grid-connected smart nano-grid," *IET Renew. Power Gener.*, vol. 13, no. 7, pp. 1123– 1131, 2019, doi: 10.1049/iet-rpg.2018.5842.

[114] Z. Yang *et al.*, "A binary symmetric based hybrid meta-heuristic method for solving mixed integer unit commitment problem integrating with significant plug-in electric vehicles," *Energy*, vol. 170, pp. 889–905, 2019, doi: 10.1016/j.energy.2018.12.165.

[115] E. S. Parizy, H. R. Bahrami, and K. A. Loparo, "A Decentralized Three-Level Optimization Scheme for Optimal Planning of a Prosumer Nano-Grid," *IEEE Trans. Power Syst.*, vol. 35, no. 5, pp. 3421–3432, 2020, doi: 10.1109/TPWRS.2020.2982278.

[116] S. Basu and M. Basu, "Horse Herd Optimization Algorithm for Fuel Constrained Day-ahead Scheduling of Isolated Nanogrid," *Appl. Artif. Intell.*, vol. 35, no. 15, pp. 1250–1270, 2021, doi: 10.1080/08839514.2021.1975392.

[117] A. N. Akpolat, E. Dursun, and A. E. Kuzucuoglu, "Deep Learning-Aided Sensorless Control Approach for PV Converters in DC Nanogrids," *IEEE Access*, vol. 9, pp. 106641–106654, 2021, doi: 10.1109/ACCESS.2021.3100857.

[118] S. Makhloufi and S. Mekhilef, "Logarithmic PSO-Based Global/Local Maximum Power Point Tracker for Partially Shaded Photovoltaic Systems," *IEEE J. Emerg. Sel. Top. Power Electron.*, vol. 10, no. 1, pp. 375– 386,

2022, doi: 10.1109/JESTPE.2021.3073058.
[119] “130.pdf.”
[120] M. Bitar, T. El Tawil, M. Benbouzid, V. B. Dinh, and M. Benaouicha, “On Hybrid Nanogrids Energy Management Systems—An Insight into Embedded Systems,” *Appl. Sci.*, vol. 14, no. 4, 2024, doi: 10.3390/app14041563.
[121] M. Kumar *et al.*, “A smart privacy preserving framework for industrial IoT using hybrid meta-heuristic algorithm,” *Sci. Rep.*, vol. 13, no. 1, pp. 1–17, 2023, doi: 10.1038/s41598-023-32098-2.
[122] N. Sonti, M. S. S. Rukmini, and V. P. Reddy, “Enhancing nano grid connectivity through the AI-based cloud computing platform and integrating recommender systems with deep learning architectures for link prediction,” *Bull. Polish Acad. Sci. Tech. Sci.*, vol. 72, no. 4, pp. 1–11, 2024, doi: 10.24425/bpasts.2024.150113.
[123] B. N. Alhasnawi *et al.*, “A novel economic dispatch in the stand-alone system using improved butterfly optimization algorithm,” *Energy Strateg. Rev.*, vol. 49, no. February, 2023, doi: 10.1016/j.esr.2023.101135.
[124] A. Sharma *et al.*, *Performance investigation of state - of - the - art metaheuristic techniques for parameter extraction of solar cells / module Particle Swarm Optimization with Adaptive Inertia Weight Control Differential Evolution with Integral Mutation Parallel Swarm algorithm*. 2023.
[125] S. Moradi, V. Vahidinasab, and G. Zizzo, “International Journal of Electrical Power and Energy Systems Optimal nanogrid planning at building level,” vol. 153, no. August, 2023.
[126] S. A. G. K. Abadi, T. Khalili, S. I. Habibi, A. Bidram, and J. M. Guerrero, “Adaptive control and management of multiple nano-grids in an islanded dc microgrid system,” *IET Gener. Transm. Distrib.*, vol. 17, no. 8, pp. 1799–1815, 2023, doi: 10.1049/gtd2.12556.
[127] E. N. Odonkor, A. O. Akumu, and P. M. Moses, “ANFIS-based power management and islanding detection utilizing permeation rate(γ) and relaxation parameter(ζ) for optimal operation of multiple grid-connected microgrids,” *e-Prime - Adv. Electr. Eng. Electron. Energy*, vol. 9, no. July, 2024, doi: 10.1016/j.prime.2024.100682.
[128] G. Di Florio *et al.*, “Dynamic life cycle assessment of an on-field tested DC-nanogrid for the environmental evaluation of Renewable Energy Communities,” *Energy Reports*, vol. 13, no. July 2024, pp. 477–490, 2025, doi: 10.1016/j.egyr.2024.12.018.