Analytical review study of the Grid connected Micro grid Energy Management System

Ayat Hussien Saleh[1*] and *Ahmed* Obaid Afta[1]

[1] Electrical Engineering Techniques Department, Technical College /Al-Mussaib , Al-Furat Al-Awsat Technical University Najaf, Iraq

Abstract. As an environmentally friendly method of distributing energy production, the integration of photovoltaic systems into micro grids has drawn in significant focus on. Our goal in doing is to examine features regarding micro grid that is linked to the power grid, with a focus on photovoltaic energy management in particular. Finding the optimal micro grid capacity for the solar system seeks to increase energy efficiency, decrease dependence on main grid, and promote an utilization of green power. The outlined optimization approach evaluates the micro grid's dynamic interactions using state-of-the-art modelling and simulation tools. These components include photovoltaic panels, energy storage systems, alongside the main grid. The refinement method takes into account crucial factors including patterns of load demand, costs of the grid electricity, and variations in solar irradiation. Finding a happy medium between increasing the amount of power generated by renewable sources and decreasing overall energy costs is the objective. That study takes a multi-scenario approach to determining how various micro grid sizes affect overall system efficiency. Using scenario-based simulations and techno-economic criteria, the appropriate size of the photovoltaic system was determined. Factors like payback time, ROI, and system reliability are taken into account here. The study's findings provide light on grid-connected micro grids, particularly in regards to photovoltaic energy management, which is crucial for their planning and implementation. In order to make educated decisions towards more robust and ecologically friendly power systems, stakeholders, lawmakers, and decision-makers can use the optimal micro grid size as a benchmark for future renewable power projects. This paper reviews the relevant literature and proposes a division and performance strategy based on its findings. By classifying energy management into three groups according to grid connection, configuration, and control method, this article provides a description of the performance, application, advantages, and disadvantages of algorithms that may be used as a reference for selecting an appropriate algorithm. Also included is a comparison table for the control strategies that were used to regulate a micro grid system that is connected to the grid.

1 Introduction

Electricity can be generated from intense sunlight through the use of electronic devices called solar panels. Its constituent parts, called solar cells, are quite small. When exposed to light, the components that make up a solar panel,which can be made from semiconductors like silicon-generate voltage, which in turn causes current to flow.The sun's Electricity Generation Technology" contains solar panels and variations on them are becoming increasingly popular in many parts of the globe. It is an excellent alternative to diesel generators and other energy sources that damage the environment and waste non-renewable resources.

*Corresponding author: Ayat.hussien.tcm.23@student.atu.edu.iq

Because it has no limits, solar energy is both abundant and safe for the environment. sources of renewable energy such as wind power with solar batteries electricity are able to operate independently from central distribution and transmission network, thanks to the daily renewal of sunlight. However, there are still significant obstacles to the deployment of solar systems development due to the high cost of photovoltaic materials, PV modules' poor conversion efficiency is another obstacle to solar energy's widespread use [1]. The reliability and security of the power grid are major issues when micro grid load and generation fluctuate [2]. Recent years have seen a rise in the popularity of renewable-source hybrid energy systems due to rising energy demand, fuel pricing, environmental concerns, and fossil fuel depletion [3]. Wind and photovoltaic systems are examples of renewable energy resources (RES) that are environmentally beneficial and a great alternative to fossil fuels because they do not emit hazardous gases [4]. The number of renewable energy systems that are linked to the grid has been increasing on an annual basis. Although these systems have many advantages, they also have some disadvantages, such as being intermittent, which can lead to grid management problems with timetables, electric power [5]-[6]. One must consider various approaches to determine an optimal size of grid connected micro grid (MG) components, including battery energy storage systems (BESSes) and photovoltaic (PV) panels. One method involves a hybrid of the cuckoo search optimization algorithm and optimization using particle swarms (PSO) algorithm. The goal is to minimize energy costs. To test the method's robustness, we compare the results in relation to those that were obtained using optimizing using grey wolf. We find that the method known as GWCSO uses fewer components compared to the GWO method, but overall, the GWO approach yields more optimal BESS and PV sizes. When comparing the GWO and GWCSO algorithms, the former exhibited the least variation across all three measures of cost, annual expense, total NPC, and LCOE [7]. While solar power systems and energy storage devices that use batteries have many advantages in the MG system, they also have some disadvantages. The size and cost of these systems are growing concerns as high capacity increases both. Nevertheless, even with modest capacity, it may not be sufficient to satisfy demand for load and avoid unexpected disruptions in electrical service. Therefore, it is essential to precisely calculate the size of BESS to determine an ideal system-specific dimensions [8]. For this reason, it is crucial for system designers to ascertain the optimal BESS size for each system in order to build MG systems that are effective, reliable, and cost-efficient [9]. Several methods are used to size BESS systems according to the system factors; some of these methods are applicable to systems of any size. Optimization methods based on mathematics are also used to address size concerns; two such methods are linear programming (LP) and dynamic programming (DP) However, there are some problems with systems operating on a huge scale. So, for complex systems, LP and DP aren't good tools [10]. The researches has shown that battery energy storage system perform the best when adequately suited for present loads, and as comprehensive networks are difficult to apply DP, LP optimization is utilized instead [11].

When applied to a decentralized micro grid, the PSO method for frequency regulation finds the ideal battery capacity and the most cost-effective way to power a home's electrical system when coupled with an existing photovoltaic array [12]. In a similar vein, PSO optimally sizes wind, photovoltaic panels as well as as hydropower dams main sources and battery energy storages as additional energy resources by selecting an island mode small grid-based energy storage architecture and optimizing the capacity of batteries given that dependability index. [13]

Here we have a look at a comprehensive evaluation of micro grids' energy management approach, which includes a summary of the pros and cons of the methods mentioned, as well as correlation tables for optimization algorithms. This work is organized as follows: an introduction at the top of the page, three sections on system configuration, EMS, management strategy, and limitations at the bottom of the page, and finally, optimization methods at the end of the page.

2 System Configuration

The micro grid-connected system is illustrated in Figure (1) and consists of the following components: the grid, the load, photovoltaic cells, the AC bus, and BESS. DC-DC converters link the solar panels and batteries to the direct current power distribution system, allowing the PV to continually charge the power along the DC bus. The system of energy management, which is composed of the DC and AC bus monitors the charger's energy level, potential energy from photovoltaic cells, load demand, state of the battery's charge and discharge. It determines when it demands supply of power from the system.

Storage devices are essential for micro grid power balance maintenance through charging and discharging. However, when battery capacity is low, power is inadequate, leading to instability or increased costs for conventional

fuel. On the other hand, when battery capacity is high, prices would rise. Therefore, finding the optimal size or capacity for storage units is crucial for avoiding micro grid transport issues as well as maximizing operating expenses [15, 16].

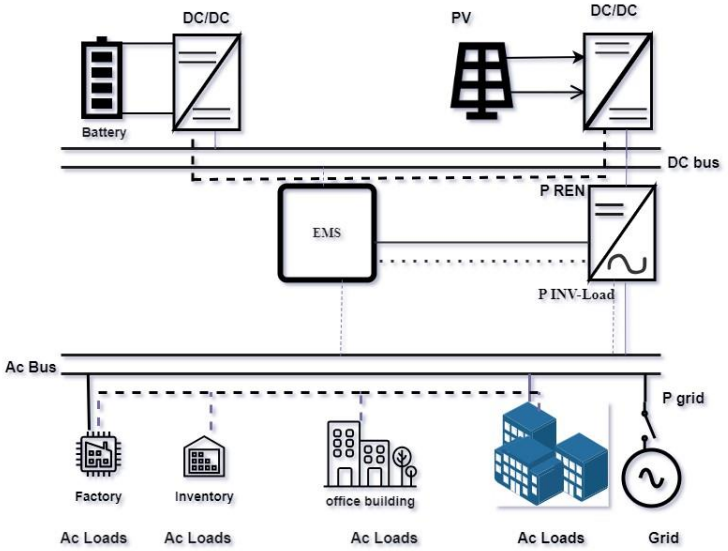

Fig.1. The micro grid's architecture linked [4]

Optimal battery size, optimal amount of conventional petrol used, and total operating expenses can all be achieved through the use of energy-storage devices, which can either add extra power to the electrical grid during blackouts or store extra electricity from renewable sources when demand has low [17]

MGs can function in either an AC-DC or radial (ring) mode [18]. And if the power grid goes down, you can always buy or trade energy. [19]. In spite of their many configurations, micro grids have proven effective in reducing carbon dioxide levels and energy costs, micro grids can operate independently tapping into local resources as well as grid-connected systems tied to a conventional utility grid. [20, 21] However, micro grid storage devices are now needed due to on occasion variable sustainability of energy sources that are photovoltaic (PV) systems. [22].

The type of system used, aims sought, control mechanisms applied, and elements that effect these systems are summarized in Table 1 of earlier research into energy management systems.

Table.1 summarized energy control in micro grids that are connected to the main power grid

The hybrid energy system	renewable energy, hydrogen fuel cells, micro turbines, diesel power plants, batteries, super capacitors, and water reservoirs
Objectives	Cut costs, lessen pollution, lessen peak demand, stabilize the system, stop the central EMS from collapsing, boost grid quality, do away with overvoltage, and boost financial gains.
Factors considered	Issues with renewable energy resources being stochastic, degrading batteries, inaccurate predictions, uncertain demand, and real-time modifications in electricity market prices
Control strategy	Demand response, online/real time, hierarchical, centralized, decentralized

3 Classification of EMS

Referring to Figure (2), the classification for popular management systems for energy from literature, that can be based on connected to the power grid, solving methods, setup, control strategy, and parameter selection methods [23]

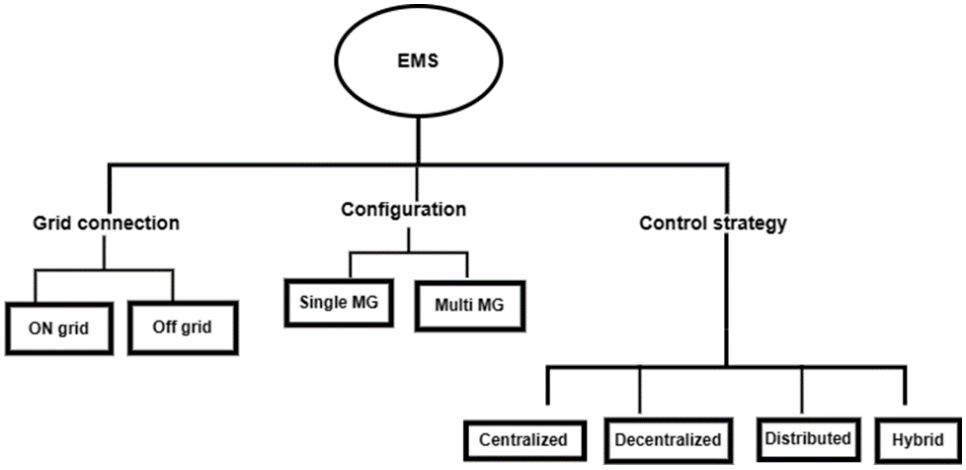

Fig.2. Energy Management System Classification [23]

4 Control STRATEGY

The micro grids are made up of several dispersed generator units and stochastic nature loads, As well as, the additional control algorithms and energy management systems are needed to ensure a steady and economical power flow among every one MG components. The EMS is necessary in distributed generation systems via multiple sources as well as storage devices to determine each unit's operating point as well as regulate the energy is coordinated and flowed among the many departments to ensure an efficient, dependable, and cost-effective operation that maintains a balance between supply and demand [24-26].

In all, four main varieties of control mechanisms used in micro grid energy management: centralized, decentralized, distributed, and hybrid. Under centralized management, individual units have their own set of breakers and control units. receive safety and management command signals from centralized CCU or control unit, which applies algorithms that are based on requirement to ascertain an optimal point of operating by evaluating a myriad of criteria, such as expenses, greenhouse gases, gird supply, resilience, and dependability, among many others. Given the restricted accessibility of local data and the fact that extended MGs are under consideration, it is recommended to use a hierarchical approach instead of a completely centralized or decentralized one. This is because decentralization requires too much synchronization, while problematic as handling large amounts of MGs. Controls can be classified as primary, secondary, or tertiary. Primary control is in charge of tasks such as droop detection, power electronic converter regulation, and islanding prevention. Secondary control is in charge of making sure that EM works reliably, securely, and economically in MGs. Tertiary management is in charge of coordinating several MGs. [27]. The hybrid energy management system integrates the benefits of both decentralized and c entralized control systems, making it more adaptable than either and more cost-effective to run [28]. Decentralized control requires less information systems and critical features of distinct units, which benefits privacy, requires less computational power, and is simple to expand [29]. Without it, a decentralized controller cannot carry out their duties; instead, the central authority in a distributed management system collects resources and relays the best possible outcomes to the various agents working under their supervision. [30]

The two main approaches, centralized and decentralized control systems are summarized in Table 2.

Table.2 Decentralized and centralized approaches summarized.

Decentralized	Centralized
There is a separate controller and data set for each unit. self-organizes through communicating [31],[32]	The centralized controller for processing bulk data bases its decisions on the data made available through communication between the controller and MG components.[34]
Strength, dependability, decreased processing time, increased data accuracy in information exchange, data privacy preserved, and network security strengthened are some of the benefits.[33]	Even though a sluggish connection of data between the control and management units could cause delays and decreased efficiency, it supplies the optimal potential, current, and minimum requirements for the optimization technique [35]

5 Grid Connection

A cost-effective method of managing storage that takes part in the power market to make prompt utilization of the energy storage system capacities in grid connected micro grid for both independent loads with both fixed and variable times [36].

While on the main grid, both the energy production units and load can see a distinct structure in order to distribute economic resources; however, We can't predict the load, just Optimal scheduling can be considered by the generator side, This is main difference between the two [37].

There shouldn't be any ripple effect on the stability of the main grid from include the MG, and MG optimization should reduce fuel prices, emissions of carbon monoxide (GHG), interruptions in power, and emissions of carbon dioxide [38].

6 RESTRICTIONS ON THE GRID

The optimization problem's stated constraints determine the variables' operational ranges.

Distributed Generation (DG) Capacity Restrictions:

There should be no more than the following range for the output operations of each unit's distributed generators: [39]

$$Pmt,\min \leq PMT,t \leq PMT,\max \quad (1)$$
$$Pfc,min \leq P\,FC \;,t \leq PFC,\max \quad (2)$$
$$Ppv,min \leq PPV,t \leq PPV,max \quad (3)$$
$$Pwt,min \leq P\,WT,t \leq P\,WT\;,\max \quad (4)$$

Where:

Pmt , min — minimal microturbine output power

Pfc, min — minimal power that the fuel cell can produce.

P pv, min — little electricity that can be generated using photovoltaic methods.

Pwt, min — limit of the wind turbine's producible power.

And P MT, max — optimal microturbine output power.

Ppv, max — photovoltaic system's maximum power for production.

Pfc, min — optimal fuel cell output power.

Pwt, max — best possible wind turbine output.

Restrictions on the Grid

At every time step, the utility grid's power limits, both maximum and minimum, must be satisfied. [40]

$$PGrid,min \leq P\,Grid,t \leq P\,Grid,max \qquad t=1,.., \qquad (5)$$

Whenever Pgrid, maximum, and minimum: Upper and lower bounds, in kilowatts, of power output utility

P grid,t : power of utility in (KW)

Battery Energy Storage Constraints

The following are descriptions of the steps involved in charging a battery and the steps involved in discharging it[35]:

$$E\ bat(t)\left[E\ PV(t) - E\frac{Load(t)}{\eta}inv\right] \times \eta\ Bch \quad (6)$$

$$E\ bat(t)\ [E\ Load(t)/\eta\ inv - E\ PV(t)] \times \eta\ B \quad (7)$$

Here, E Load(t) represents the load demand at time interval t, and EPV(t) is the energy that was created. η Bch, η Bdch, and η inv are, in that order, the inverter, the efficiency of charging the battery, efficiency of draining the battery.

For the process of recharging modes, the bounds of the BES power are given by the equations (8) and (9), respectively. [17]

$$P\ BES,min \leq P\ BES\ ,t \leq PBES\ ,max \quad t=1,\ldots\ldots,T \quad (8)$$

$$P\ BES\ ,min \leq PBES\ ,t \leq PBES\ ,max \quad t=1,\ldots\ldots,T \quad (9)$$

Microgrid Optimization Techniques

Optimization strategies used in the MGs, greedy algorithms, adaptive programming, not linear simulations, and linear programming (LP) include models that combine deterministic theory, analysis, heuristics, stochastics, along with hybrids [41] Interactive programming and other methods are utilized in the execution of a predefined plan. [42].

EMF optimization, PSO (particle swarm optimization), cuckoo search, explosive blast method, whale optimization, moth swarms, harmony searches, and algorithms for flower pollination powered by artificial intelligence. [43]. All of these are a part of the heuristic, metaheuristic approach; metaheuristic algorithms are based on natural processes that iteratively find the optimal value. [44].

In order to optimize power flow and address energy management issues, a number of versions or adjustments of the algorithms outlined before are employed. [45] [46] [47]. Hybrid systems use both methods, or any mix of the two [42], on the other hand, parallelism can address the issue of it being longer to compute [48].

The pros and cons of well-known optimization techniques, such PSO strength, are It is easy to implement, has a fast computation time, and isn't as dependent on the nature of the target function that initial points, but it is impracticable to real-time applications which makes it tough to establish the appropriate design parameters [49]. While solving problems with equality and inequality, multi-objective optimization produces a set of optimal values instead of just one, all while juggling competing goals [50]. Table (3) provides comparisons between the existing studies.

A close examination of Table 3 provides an idea of the difference between the different algorithms , Numerous research have employed various optimization techniques to achieve the goal of cost minimization in energy management systems. The table 4 below lists the advantages and disadvantages of some optimization algorithms and approaches that are commonly employed

Table 3. The evaluation of previous research

Ref	The optimization algorithm(s)	number of Opt. Criteria	The operation mode	Type of RES	EMS	The intended purpose	The ESS's objective
[51-53]	PSO	More	Grid-connected	PV, BESS	Yes	Maximize the system's return on investment. .	effectiveness in energy usage
[54]	DP	Less	Grid-connected	PV,BESS	No	Discovering the most efficient way to charge and discharge ESSs while keeping operational expenses to a minimum	energy conservation
[55]	LP	Less	Grid - connected	PV ,Wind , BESS	No	Minimizing MG operational expenses and optimizing BESS sizing	great location for shaving
[56-57]	MILP	Less	Grid connected	PV,BESS	Yes	Lessening of annual expenditure Power and expenses associated with battery degradation comprised	energy conservation
[58-59]	MCDP	Less is better in terms of efficacy.	Grid connected	BESS (storage plant)	Yes	Determined to store power references with the largest profit margins	Energy efficiency, renewable power, and energy trading
[60]	ABC	Average	Grid connected	Wind, Hydro ,BESS	No	Enhancing revenue	Saving energy and making money off of energy prices

Table.4 The analysis of typical methods for enhancement

Algorithms	Strength	Weakness
LP	Computing speed and reliability	Making a linear model out of a nonlinear problem is a surefire way to lose big time when dealing with real-world issues [61]
DP	The sensitivity analysis can be inferred from the problem's solution [62]	As the number of functions grows, the number of components also grows exponentially, necessitating additional storage space. [61]

Statistical analysis	A conclusions are more reliable since the model correctly represents the nonlinear characteristics of the system under study.	It is impossible to find the best answers if the computations are not differentiable. Achieving global optimal requires a practical starting point. [61]
Heuristic approach	We managed to find the optimal solution by keeping the nonlinear features and keeping storage and processing time requirements realistic [61]	Local rather than global optima may result from a hidden solution [63-64]
ABCA	Adaptable, versatile, and with little likelihood of early convergence, the results reflect the best possible values on a global scale [66]	increasing the time and memory needed for computation [65]

7 Conclusion

Energy management is the subject of this paper's review, which categorizes the various grid connection types, control strategies, and configurations. We provide a comprehensive literature evaluation of optimization algorithms that take into consideration certain aspects and energy managements in order to ensure a stable economic operation. Additionally, tables are provided that describe the advantages and disadvantages of several optimization strategies. The four control strategies used in this study are distributed, hybrid, centrifugal, and decentralized. This paper presents a thorough literature analysis of EMS methods, taking into account a number of important criteria. This study found and categorized three types of EMS categorization systems that were found to be highly successful. Considerations for the design of grid-connected micro grid size optimization for PV systems and hybrid energy systems include goals, converters, tracking speed, grid integration ability used, sensed factors, and algorithm complexity, among other things. Various tactics are also analyzed and their pros and cons are presented in tables.

A meta-heuristic approach to techno-economic control of PV systems is introduced in this paper, which helps to resolve these challenges. Finally, a more sustainable, reliable, and affordable energy market is within reach when grid-connected micro grids are optimized for PV energy management. The study's findings can inform stakeholder decision-making, leading to advancements in renewable energy technologies and a more environmentally friendly and long-term energy system.

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