2024

THIRD YEAR PROJECT

Optimal sizing of battery energy storage systems and reliability analysis using Particle Swarm Optimization Technique

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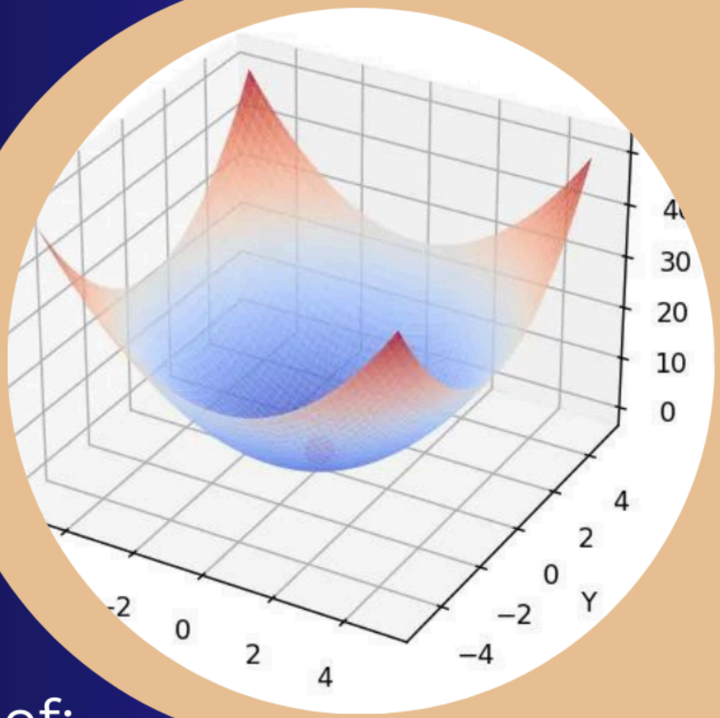

Under the supervision of:
Dr.Kamal Krishna Mandal

Contents

Vision of the Institute:

Faculty of Engineering and Technology, Jadavpur University

To provide young minds an ambience and quality education in Engineering and Technology to contribute towards a better world.

Mission of the Institute:

- To nurture Engineering and Technological potential in undergraduate and post graduate students at their highest standard;
- To take up technological challenges of the State, Nation and beyond for ensuring social security and sustainable development;
- To provide infrastructure at par with international standard for quality training, research and development;
- To encourage collaborative activities across disciplines to take up global challenges;
- To enable young learners with legal and ethical awareness to meet challenges in Industry and academics or for setting up start-up ventures.

Department of Power Engineering

Vision of the department

To emerge as a globally recognized department in imparting quality education to produce successful Power Engineers.

Mission of the department

- To provide the students with the state of art of enabling technologies related to energy and power engineering to meet the global challenges
- To generate skilled human resources for sustainable development of the energy and allied sectors
- To facilitate the students to choose career in the industry, research and development, and entrepreneurship
- To impart legal and ethical awareness to the students for the inclusive development of the society

Program Educational Objectives (PEO)

Graduates of Electrical Engineering Program shall

- **PEO1:** Succeed in their career as globally employable power engineers and team leaders.

  PEO2: Pursue advanced education and research in energy, power and allied interdisciplinary areas leading to lifelong learning successfully.

  PEO3: Have ethical values, social commitment and leadership qualities towards application areas of electrical energy.

Program Specific Outcome (PSO)

PSO1: Interdisciplinary Domain Exposure: Interpret problems and apply enabling technologies to develop comprehensive solutions for the energy and power sectors.

PSO2: Economic and sustainable energy resources: Assess and analyze energy resources and formulate optimized solutions for sustainable development.

PSO3: Safe and secured energy: Recognize safety, control and management aspects of new generation energy technology.

Program Outcomes (PO)

PO1. Engineering knowledge: Apply knowledge of mathematics, science, engineering fundamentals and an engineering specialization to the solution of complex engineering problems.

PO2. Problem analysis: Identify, formulate, research literature and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences and engineering sciences.

PO3. Design & Development of Solutions: Design solutions for complex engineering problems and design system components or processes that meet specified needs with appropriate consideration for public health and safety, cultural, societal and environmental considerations.

PO4. Investigation of Complex Problem: using research-based knowledge and research methods including design of experiments, analysis and interpretation of data and synthesis of information to provide valid conclusions.

PO5. Modern Tool Usage: Create, select and apply appropriate techniques, resources and modern engineering and IT tools including prediction and modelling to complex engineering activities with an under- standing of the limitations.

PO6. The Engineer and Society: Apply reasoning informed by contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to professional engineering practice.

PO7. Environment and Sustainability: Understand the impact of professional engineering solutions in societal and environmental contexts and demonstrate knowledge of and need for sustainable development.

PO8. Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms of engineering practice.

PO9. Individual and Team Work: Function effectively as an individual, and as a member or leader in diverse teams and in multi-disciplinary settings.

PO10. Communication: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as being able to comprehend and write effective reports and design documentation, make effective presentations and give and receive clear instructions.

PO11. Project Management and Finance: Demonstrate knowledge and understanding of engineering and management principles and apply these to one’s own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

PO12. Life-long Learning: Recognize the need for and have the preparation and ability to engage in independent and life- long learning in the broadest context of technological change.

CERTIFICATE OF APPROVAL

This is to certify that the project entitled “Optimal sizing of battery energy storage systems and reliability analysis using Particle Swarm Optimization Technique” in partial fulfilment of requirements for the award of B.E. degree in Power Engineering, submitted in the Department of Power Engineering at Jadavpur University, Kolkata, West Bengal is an authentic record of our own work carried out under the supervision of Dr. Kamal Krishna Mandal, Department of Power Engineering.

The matter presented has not been submitted by us in any other University / Institute for the award of B.E. Degree.

The names of the students are as follows: -

1)Somnath Roy(002111501089)
2)Anirban Das(002111501092)
3)Mrinmoy Pakira(302211501009)

This is to certify that the above statement made by the candidates is correct to the best of my knowledge.

DR. Kamal Krishna Mandal
Project Supervisor
Dept. of Power Engineering

Prof.Kamal Krishna Mandal
Head of the Department
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ACKNOWLEDGEMENT

The Third Year project is a major career defining step for any engineering student's life. It provides us with an opportunity to test our skills in the technological fields and put our imagination to innovation. We are thankful to our H.O.D, Dr. Kamal Krishna Mandal for letting us, choose a topic of our interest to work on.

We owe our sincere gratitude to our present H.O.D. and our Project Guide, Dr. Kamal Krishna Mandal for his unparalleled guidance, right from the moment of choosing a project underthe given topic domain to its step by step progress and its completion. His contributiontowards
the compilation progress report is unavoidable as well.

Acknowledge any project funding source of the lab where the students have worked.

Acknowledge any other person who may have helped you in any way during your work.

_Signature____ __Signature___ ___Signature ___

Introduction

Today, fossil fuels such as coal, oil and natural gas are the main sources of electrical energy generation. However, these fuels cause greenhouse gas emissions and environmental pollution. In addition, while the world's energy demand is increasing year by year, fossil fuel reserves are limited and are about to be depleted. Nevertheless, new restrictions are performed by environmental policies to reduce greenhouse gas emissions [1]. The Paris Agreement, which was signed by 192 countries plus the European Union, is a promising example to deal with climate change. Countries that signed the agreement are planning to reduce their greenhouse gas emissions [2]. Renewable energy resources (RESs) such as photovoltaic and wind energy systems are environmentally friendly and good alternatives to fossil fuels since they do not cause any harmful gas emissions. The number of grid-connected RES installations has been increasing year by year. Along with many advantages, these systems have some disadvantages such as intermittency that can cause scheduling, frequency, and voltage regulation problems on the grid [3,4]. Conventional generation systems with fossil fuels have slower responses to regulate frequency deviation in the short term [5]. With the increase in the number and total capacity of the RES installation, these problems and risks to power system stability have become more severe. Installing larger RES systems may overcome this problem [4]. However, it results in high investment costs. Battery energy storage systems (BESS) show up as an effective solution for this problem [3]. A BESS can be advantageous to maintain the balance between supply and demand with its fast dynamic response characteristics compared to conventional generators or other types of energy storage systems [6]. Particularly modern distribution networks are attracting attention for the solution of nano grid (NG) and microgrid (MG) challenges. Hereby, BESSs are considered a significant element of modern MGs and smart grids [7]. The MG is a concept that enables the effective integration of distributed generation (DG) resources [8]. It is a controllable small network that combines RESs, conventional sources and loads in both grid-connected (on-grid) and island mode (off-grid) [9]. Figure 1 demonstrates a typical MG with these two operation modes [10]. Since DGs' power output characteristics are different from conventional generation systems, the MG should handle power quality problems by itself such as unpredicted fluctuation, robustness of reactive power support, resilience and a reliable system. The BESS is a good choice for maintaining resiliency and reliability with fast and adaptable characteristics. BESS can store the remaining power for later use, thus compensating for unexpected power outages and fluctuations in the RES. Although BESSs and PVs have great advantages in the MG system, they also have some disadvantages. Size and cost are gaining importance as high capacity causes increases in cost and size, while low capacity may not be enough to prevent unexpected power problems and may not meet load demand. Consequently, BESS size must be carefully calculated to determine the optimum size for a given system [8]. Moreover, research has shown that BESSs that are optimally sized for the current loads provide the best performance[11]. Thus, system designers need to find the optimal BESS size according to the specific system to obtain an efficient, reliable, and economical MG system [9].

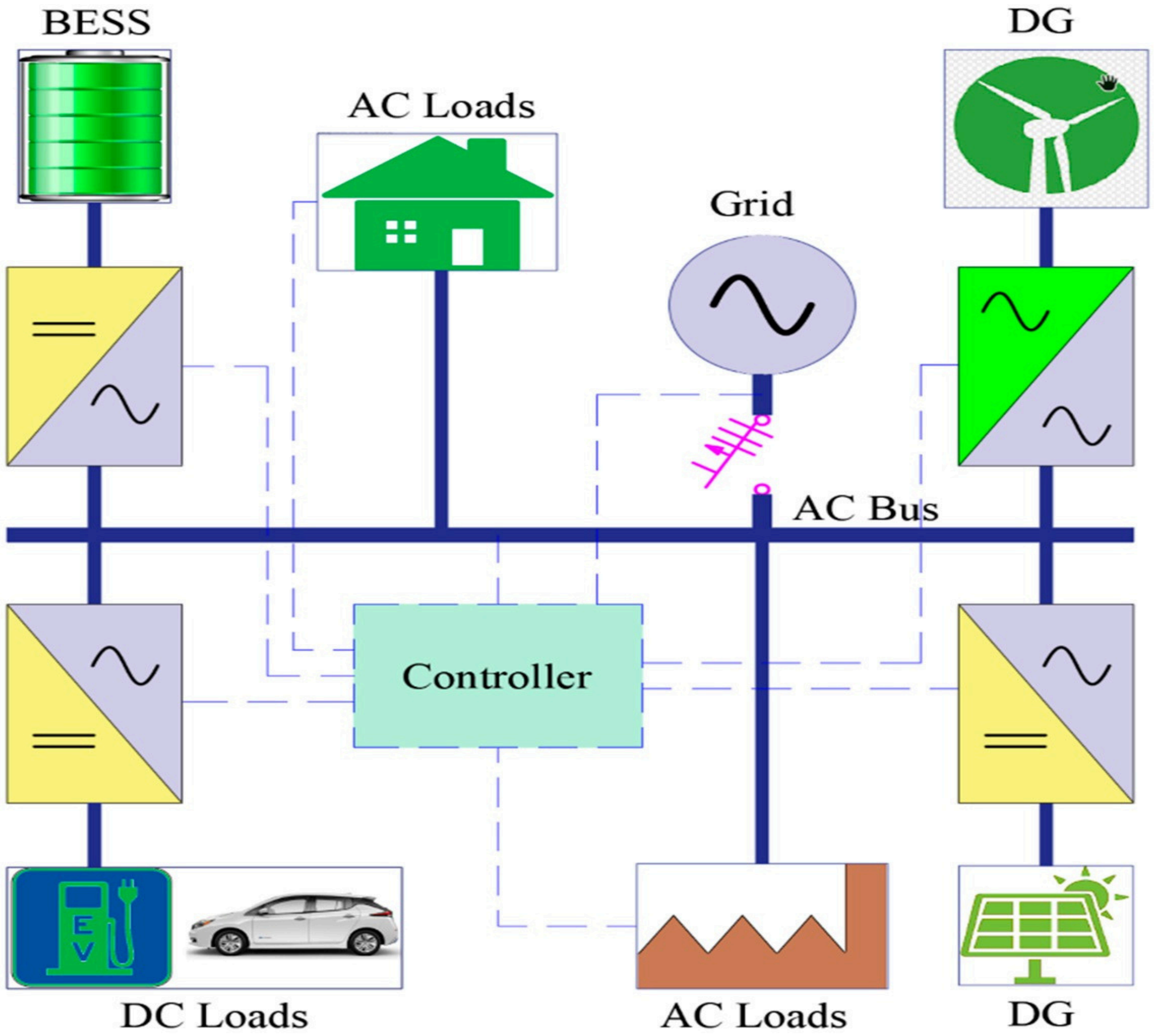


Figure 1. The structure of an AC microgrid.

In the literature, generally, one parameter is kept constant and the other parameter is optimized in PV and BESS optimization studies. In most PV and BESS systems, the PV size is kept constant and the BESS size is optimized. A similar approach is used for structures with an energy management system (EMS), and most of them are proposed for island mode operation. BESS sizing is performed according to the system parameters with various methods. Some of the methods can be performed identically to any sized system [10]. Mathematical-based optimization methods are also used for sizing problems.Dynamic programming (DP) and linear programming (LP) are examples of mathematical methods [10]. DP is used in [12], but it is difficult to apply to large-scale systems [13]. LP optimization is chosen as a simpler method in [13], and it is implemented for a small energy storage system (ESS) in [14]. However, it has some problems when it is applied to large-scale systems. As a result, LP and DP are not good tools for complex systems [10]. As a remedy, different optimization techniques that are named probabilistic methods (PMs) have been developed. The Markov chain decision method (MCDM) is one of them and is used for battery sizing optimization due to its simple structure. Energy storage devices are scheduled optimally with an MCDM [15]. However, probabilistic methods are effective when the number of optimized criteria is less (generally one) [10]. These methods are not suitable for optimizing the two parameters together in interaction with the energy management system in the structure that is the subject of this study. Since RES output is uncertain, metaheuristic approaches are suggested in many applications. Metaheuristic methods give more accurate results on large and nonlinear optimization problems [16,17]. The Genetic Algorithm (GA) is used for cost reduction and optimization of the energy storage system in a hybrid energy system [18]. The bottleneck of GA is that its results are not conclusive [13]. The Bat Algorithm (BA) is used to find the optimum BESS size for a grid-connected low-voltage MG in [19]. The Grey Wolf Optimization (GWO) algorithm is chosen for optimum BESS sizing and decreasing fuel usage, and GWO performance is compared with BA and PSO in [20]. The Artificial Bee Colony algorithm (ABC) is used to calculate of optimal battery size and operation for revenue increase in a hybrid power system. The Grasshopper Optimization Algorithm (GOA) is another method used for optimal battery, PV, wind, and diesel sizing in a microgrid [21]. Particle Swarm Optimization (PSO) has simplicity and ease of use among other metaheuristic optimization algorithms, yet it can present a high convergence rate [8]. Its robustness of convergence comes from being less dependent on setting initial points among other methods.

The PSO algorithm also needs fewer parameters than other metaheuristic algorithms. In addition to these, it needs lower data storage [8]. The PSO-based frequency control method for an off-grid microgrid is implemented to evaluate optimum BESS size and reduction in cost [22]. The PSO algorithm is used to find the optimum battery size and minimum cost for a grid-connected residential system that currently has an available PV system. Similarly, PSO is selected for battery capacity optimization and effective battery installation for an island-mode microgrid. PSO is used for optimal sizing of wind, PV and tidal as a primary and battery as an auxiliary source considering the reliability index. PSO is also proposed to determine optimal BESS with load shedding [5]. The objective of this paper is to enhance frequency control by load shedding, and thus, operation cost. The cost optimization of a PV and BESS system in the grid-connected MG using PSO is proposed. However, this study does not use an energy management system.

In this paper, optimum energy storage and PV size considering cost minimization is determined based on the novel energy management method, and the PSO algorithm is proposed for a grid-connected microgrid. In past studies, various algorithms were used for different systems for optimization. According to the literature study, although the PSO algorithm is a common and well-known algorithm, it has not been used as an optimization algorithm for both PV and BESS sizing. In the majority of studies, one of the parameters is kept constant (mostly PV size), and the remaining parameters (mostly battery size) are optimized. In a limited number of studies, the PSO algorithm is used to determine the optimal size of the PV system and BESS but only for island mode systems. Most of the remaining studies have not used cost minimization as an objective function or energy management system. A limited number of studies used cost minimization as an objective function or energy management system but with different optimization Algorithms. This paper presents cost minimization as an objective function by finding both optimum PV and BESS sizes and proposes a new optimal energy management method for a grid-connected MG. It is applied to a grid-connected microgrid that consists of a PV system with battery storage. MG is allowed to import energy from the grid with a penalty. Thus, by allowing a limited amount of energy to be taken from the grid, it provides a more optimum structure by minimizing the effects of possible instantaneous high power demands. This paper focuses on determining the optimum PV and BESS sizes when the MG supplies energy as much as possible to its loads. The purpose is to create self-sufficient MG with limited grid support by considering cost minimization and defining optimum BESS and PV sizes. Studies are carried out for two different scenarios. In addition, the proposed energy management system with a PSO-based method is compared with GA, which is a well-known optimization algorithm. The results show that the proposed algorithm can achieve optimum PV and BESS size with minimum cost by using the new energy management method with a PSO algorithm. The proposed energy management method provides more flexibility to system designers for various system constraints. This can be accomplished by its configurable parameters. Thus, the new energy management method with PSO can be applied to various systems.

Proposed Algorithm

1. Objective Function

The objective of the optimization problem is finding the optimal size of BESS and to minimize the total cost of the MG, as defined by Eq. (9).

$$\min TC = CR + CBESS + Cexchanged + CRI - CRE \tag{9}$$

where, *TC* represents the total cost of the MG, which is a function of the costs associated with renewable energy *CR*, the battery energy storage system *CBESS* , and the energy exchanged with the main grid *Cexchanged* . Additionally, *CRE* and *CRI* represent the revenue received from exporting energy to the grid and importing energy from the main grid, respectively. The formulation of *CBESS* and *Cexchanged* are presented in Eq. (10) [13] and Eq. (11) respectively.

$$CBESS = PCBESS \times P\_ratedBESS + ECBESS \times E\_ratedBESS \tag{10}$$

$$C_{exchanged} = \sum_{t=1}^{NT} \rho_{i,t} \times EP_t \tag{11}$$

In Eq. (10), the power and energy costs of the BESS are denoted by *PCBESS* and *ECBESS*, respectively. Additionally, *P_ratedBESS* and *E_ratedBESS* represent the rated power and energy of the BESS. In Eq. (11), *EPt* represents the power exchanged with the main grid at time is the price of per KWh energy exchanged with the main grid at time *t* of the day. We denote the energy exported and imported in time period t as *E*export,t and *Eimport,t* , respectively. The revenues from exchanged power with the main grid, *CRE* and *CRI*, in time period t are calculated using Eq. (12) and Eq. (13), respectively, where *R*exp *ort* and *Rimport* represent the export and import tariff rates.

$$CRE = \sum_{t=1}^{NT} E_{\exp ort,t} \times R_{\exp ort} \tag{12}$$

$$CRI = \sum_{t=1}^{NT} E_{import,t} \times R_{import} \tag{13}$$

1

The BESS is modeled based on its constraints. The energy stored in the BESS at time t is calculated using Eq. (14), where the charging and discharging power of the BESS are represented by P^{c}_{BESS} and P^{d}_{BESS}, respectively.

$$E_{BESS,T} = E_{BESS,T-1} + \left(P^{c}_{BESS} \times \eta_c - \frac{P^{d}_{BESS}}{\eta_d} \right) \times \Delta t \nearrow \forall t \in NT \quad (14)$$

where, the efficiency of charging and discharging of the BESS is denoted by η_c and η_d, respectively. The maximum and minimum rated values of the BESS are presented in Eq. (15) and Eq. (16) as constraints, respectively.

$$-P^{R}_{BESS} \leq P_{BESS,t} \leq P^{R}_{BESS} \nearrow \forall t \in NT \quad (15)$$

$$0 \leq E_{BESS,t} \leq E^{R}_{BESS} \nearrow \forall t \in NT \quad (16)$$

Finally, Eq. (17) expresses the constraint on the power exchanged between the main grid and the MG, which is limited by the maximum capacity of the transmission lines that connect them ($P^{max}_{exchanged}$).

$$0 \leq P_t \leq P^{max}_{exchanged} \nearrow \forall t \in NT \quad (17)$$

$$P^{Max}_{exchanged} = \begin{cases} pl^{DTR}_{Max} \\ pl^{STR}_{Max} \end{cases} \quad (18)$$

where, the maximum possible exchanged power is represented by P^{max}_{t}. Moreover, the optimal DC load flow formula (Eq. (18)) considers the maximum transmission capacity, which is defined by either the rating established by the DTR system or the STR system.

PSO Algorithm

The PSO algorithm presents a model of flight patterns of birds and their social behavior for the optimization model, which was proposed by J. Kennedy and R. Eberhart in 1995. Its ties artificial life to the behavior of animal groups, such as bird flocking, fish schooling and swarming theory [30]. The simple explanation of the PSO model can be explained as follows. Each single bird is pointed in the Cartesian Coordinate System (CCS). Their initial location and velocity are assigned randomly. Then, the algorithm is executed with “the nearest proximity velocity match rule”; thus, every bird has the same speed as their closest neighbor. Since iteration maintains in the same direction, all the points will have the same velocity. Because of the simplicity of this structure and not exactly thesame as in real situations, a random variable is added to the speed point. In each iteration, aside from meeting “the nearest proximity velocity match”, each speed will be added with a random variable that provides convergence to the real case. In this model, every bird can find their maximum points. These can only be local maximum points. After every bird meets, in other words, birds finish their movement on the coordinate system, all the maximum points will be found. The highest value of these maximum points is the global maximum point.

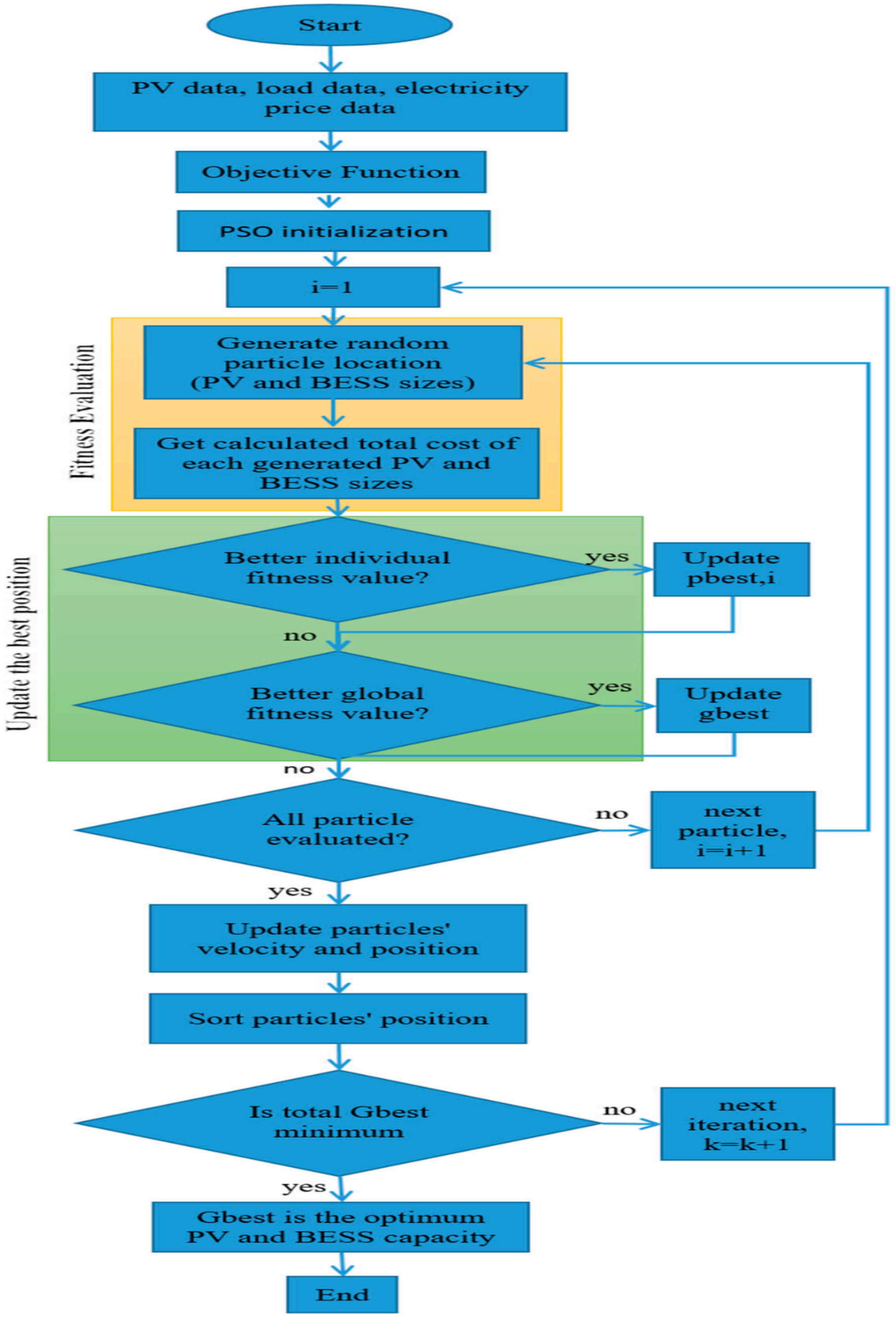
In this study, PSO is used to find the minimum points, meaning minimum cost. Particles represent PV and BESS module counts (or sizes), and they are initialized randomly in the CCS. nPop is the swarm size, and it is defined as 50, which means 50 particles. The maximum iteration, MaxIt, count is set to 100. The inertia coefficient is set to 1. There are two acceleration coefficients, and both of them are selected as 2.5. Each particle’s velocity is zero at the beginning. The objective function, which is explained in the previous section, is called in every iteration to calculate the particle’s total cost. Each particle’s cost is compared with each other’s and the best cost, which is the minimum, is saved as the global best cost. In every iteration, PSO generates random PV and BESS sizes, and their costs are compared with the global best. The lowest value is saved as the new global best. At the end of all iterations’ location, which means PV and BESS sizes, of the global best cost is the optimal point. Each PV and BESS has a position, and these positions have a velocity. The velocity of the kth particle is :

$$v^j_{k,new} = wv^j_{k,old} + c_1 r_1 (x^j_{k,pbest} - x^j_k) + c_2 r_2 \tag{7}$$

where $v^j_{k,new}$ refers to the recent velocity of the kth particle at jth iteration, the w refers to the inertia weight, $v^j_{k,old}$ refers to previous velocity of the kth particle at the jth iteration, c_1 and c_2 are the acceleration constants, and r_1 and r_2 pair are randomly determined numbers between 0 and 1. The position of the kth particle is renewed as below [16]:

$$x^j_{k,new} = x^{j-1}_{k,old} + v^j_{k,new} \tag{8}$$

where $x^{j-1}_{k,old}$ is the previous position of the kth particle from the past iteration [16]. The position x is the size of PV and BESS, and in this study, their minimum value is Var_{Min} = 1 and maximum value is Var_{Max} = 50. Figure 5 shows the flowchart of the applied PSO algorithm.


Start
PV data, load data, electricity price data
Objective Function
PSO initialization
i=1
Fitness Evaluation
Generate random particle location (PV and BESS sizes)
Get calculated total cost of each generated PV and BESS sizes
Update the best position
Better individual fitness value?
yes
Update pbest,i
no
Better global fitness value?
yes
Update gbest
no
All particle evaluated?
no
next particle, i=i+1
yes
Update particles' velocity and position
Sort particles' position
Is total Gbest minimum
no
next iteration, k=k+1
yes
Gbest is the optimum PV and BESS capacity
End

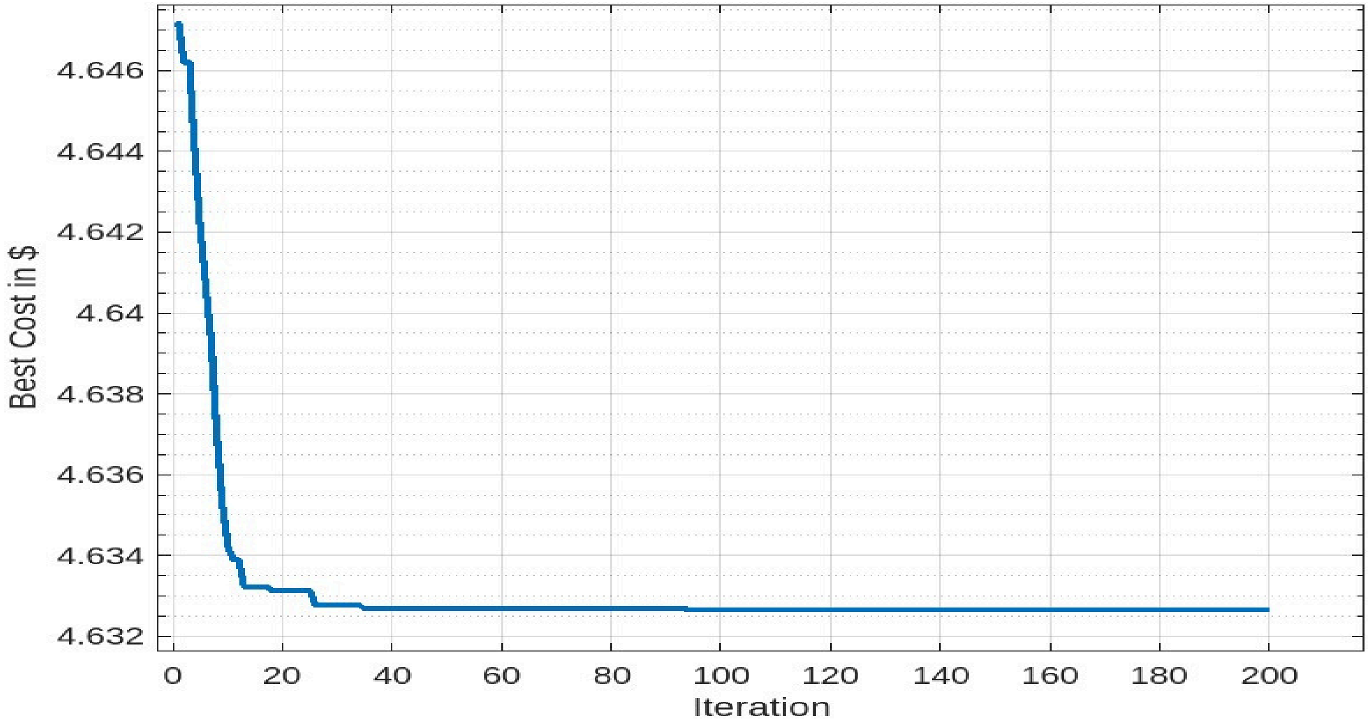
Results and Discussion

First, the PSO algorithm generates a random PV and battery module size between 1 and 50. The first module (or particle) count is equal to npop; thus, it is 50. That is, 50 parameters are spread out to different locations randomly at the beginning. In each iteration, this spreading continues with different velocities depending on c1, c2, w, and Wdamp (damping ratio) values. These values affect the speed and accuracy of the parameter reaching the optimum point. They can be close to the optimum point at the end, but they may take a long time to reach the optimum point due to their slowness. Contrarily, they can find the optimum point fast, but accuracy may need to be guaranteed.

The PSO parameters are chosen to obtain faster and more accurate results. The population size is set to 50, the maximum number of iterations is set to 200, c1 and c2 are set to 2.5, and Wdamp is set to 0.99. The number of battery and PV modules is limited from 1 to 50. Then, the novel energy management algorithm calculates total PV and BESS power outputs and how much energy is needed from the grid to supply loads. Here, providing uninterrupted power to the loads is the main concern. For this purpose, the energy management algorithm can demand energy from the grid. However, it should be a limited time and level that is defined by the grid total cost parameter at the system design stage. If the MG loads cannot be supplied by any source, there will be a large increase in the total cost. This effect is controlled by another parameter such as the penalty parameter, and thus, the cost increases. The algorithm selects an optimum level of the PV system and BESS capacity to supply the load with the energy required in a day. After the energy management algorithm is calculated for daily total average PV and BESS energy output, the total energy cost can be found. The calculated energy cost is compared by the PSO algorithm for every particle, which equals npop = 50, along with iterations. The best particle cost over 50 particles (npop count) is found, and this is called the “particle best cost”. This is saved for the next iteration. The particle's best cost can be updated with a new value at the next iteration by a particle that holds a lower cost. Thus, after all iterations are completed, the best updated “particle best cost” value will be the “global best”. This shows the calculated optimum PV and BESS size with minimum cost with defined constraints. The best particle costs between each of the 50 particles inside an iteration and every best cost throughout the iterations can be seen below in Figure 6.

At the first iterations, the PSO algorithm generates lower PV and BESS module counts, which means that the PV and the BESS particles are far from the optimum point. (Cost can be seen on the second y-axis in Figure 6. The y1-axis and y2-axis scales are different). Since loads are supplied mostly from the grid, the cost is increasing. After the maximum grid cost is exceeded, the total system cost increases faster due to the penalty factor, and the system can obtain supply mostly from renewable energy resources (because increasing the rate of renewable energy use decreases the system's total cost).

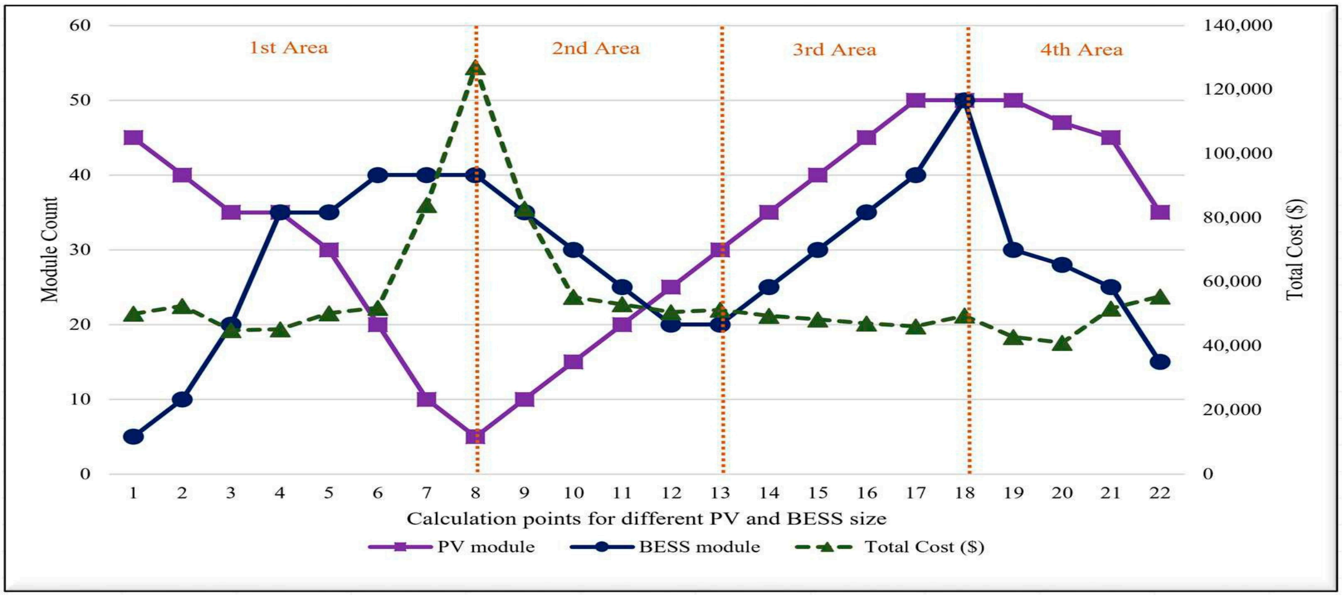
Source Code: [*https://github.com/SomnathRoy-JU25/PSO-CODE*](https://github.com/SomnathRoy-JU25/PSO-CODE)



6 . Best Cost vs Iteration Graph

The *total cost variation of the system according to different PV and battery sizes and penalty factors* are given in Figure 7(a), and (b), respectively. At the first point in Figure 7(a), there are 45 PV modules and five battery modules. The total system cost at this point is USD 49.993. In the first area (depicted in Figure 7a), while the number of PV modules is decreasing, the number of battery modules is increasing. It should be considered that the energy cost penalty highly affects the total system cost. The total system cost is increasing slowly until the sixth calculation point. Then, when the number of PV modules is too low, the system cost increases rapidly. At the eighth calculation point, there are five PV modules and 40 battery modules, and this is the highest cost in the figure, which is USD 127.040. At this point, there are not enough PV modules to supply the loads, and there are not enough PV modules to charge this amount of battery modules. Thus, the loads are supplied from the grid for a longer period. At this longer period, as an option, the cost can be increased excessively or the maximum limit can be set to prevent taking more energy from the grid.

In this study, the maximum level of energy cost that can be taken from the grid has been determined. After reaching the maximum allowable grid supply limit cost, the energy management algorithm cuts off the electricity. Eventually, the total cost will be high in this situation. In the second area, while the number of PV modules has increased, the number of battery modules is low. In this case, the total cost is decreasing because there will be more PV modules to generate energy to supply the loads in the daytime. PV modules can also charge batteries when the number of PV and battery modules is closer to the optimum point. Thus, BESS can supply the loads at night when there is no PV energy. In the third area, both the number of PV and battery modules are increased. The total cost decreases, but at the 18th point, it increases again due to the increased number of battery modules. In the fourth calculation area, both the numbers of PV and battery modules are decreased, and the total cost also starts to decrease. Finally, the number of PV and battery modules reaches the optimum point, such that the total cost is at the lowest value at the 20th point. There are 47 PV modules and 28 battery modules. The total system cost is USD 40.972 at the 20th point. The same study was carried out for case 2. It can be seen from Figure 7b that the cost of the system for 24 PV modules and 28 batteries is USD 24.186. This means that the loads of the MG can be fully supplied by PV and BESS in the daytime, and they can be supplied by BESS most of the night. Therefore, MG can be supplied mostly by its RES, and its dependency on the grid is low. However, the total system cost rises as the number of battery and PV modules continues to decrease because the system needs to import more energy from the grid, which increases the grid supply cost. Another reason is that as the number of both PV and battery modules continues to decrease, the longer the blackout durations occur and thus the penalty cost increases.



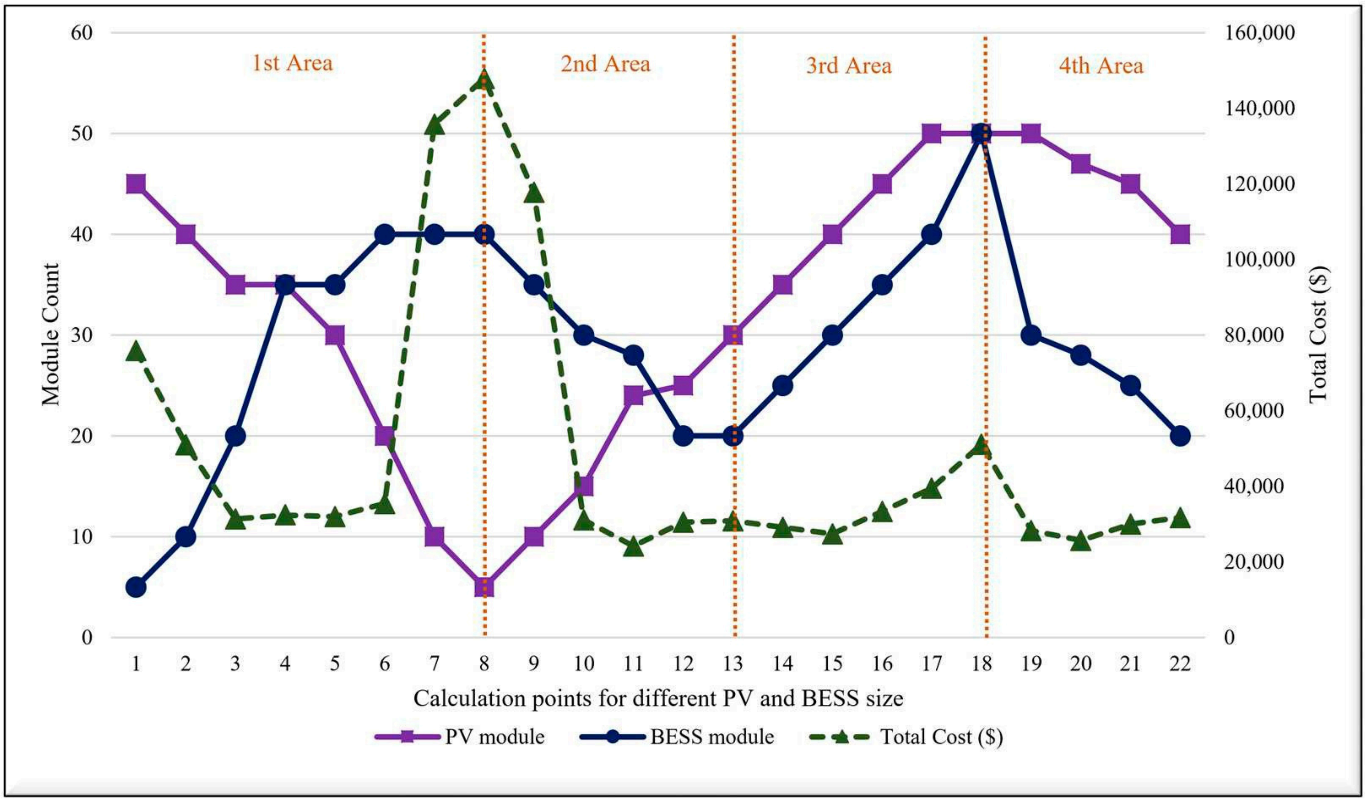


Figure 7. System total cost for various PV and BESS module combinations: (a) case 1 and (b) case 2.

As can be seen, this process is not simple, such as defining the number of PV and battery modules regarding the known changing load demand. PV generation changes according to irradiation and weather conditions. There is an allowed grid supply limit that is defined at the system design stage. Therefore, the energy management algorithm should decide when to charge and discharge the batteries, and when to obtain energy from the grid by considering cost. Eventually, the results show that the proposed optimization algorithm correctly determines the optimum PV and BESS size within the defined constraints. The proposed energy management system with the PSO algorithm has some advantages and superiorities. It also needs only a few initial parameters. In addition, it can be used with different algorithms. Furthermore, the constraints and parameters used in the energy management strategy are also configurable such that they can be easily adapted for different systems. The flexible nature of the proposed approach is its most important strength.

Application of PSO Algorithm

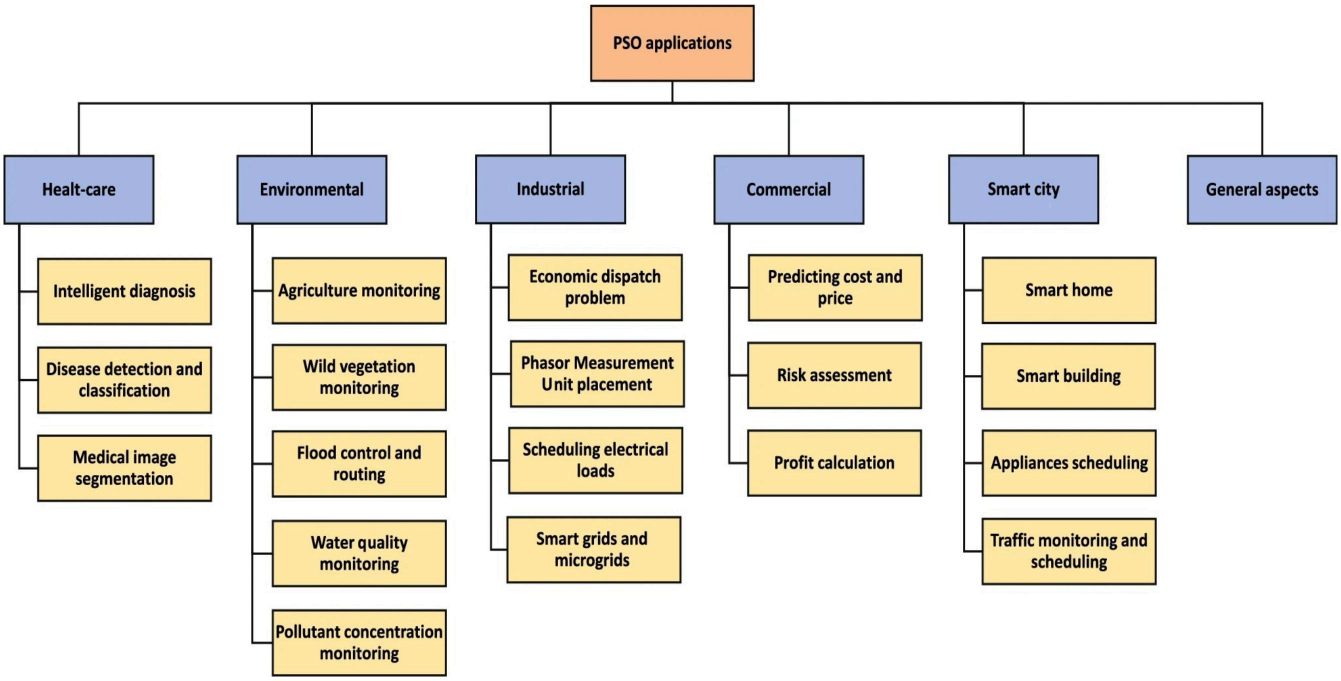


Figure: The taxonomy of PSO applications

The figure demonstrates a comprehensive taxonomy of the PSO applications in different domains, including healthcare, environmental, industrial, commercial, smart city, and general aspects. Each category of PSO applications is likely to face some issues that should be highlighted to develop thriving solutions, enabling further efficient and viable PSO implementation in future real-world applications. Consequently, studies focusing on some pivotal issues are reviewed to prop PSO applications in a particular context associated with these issues. For example, in environmental applications, the main contexts, such as economic emission dispatch, parameter identification of PhotoVoltaics (PV), pollution forecasting, segmentation and classification of plants, flood control and routing, water quality monitoring, and many other issues, are floated in different aspects of environmental PSO applications. Thus, this paper presents a taxonomy based on diverse categories of PSO applications in selected research studies in which special subjunctives are addressed and discussed. Considering the concerns and challenges in various types of PSO applications, I first addressed different categories in the PSO applications. Then I reported the main subjects which have been paid special attention in each category. PSO applications have some general concerns, so a division in the taxonomy, namely “general aspects”, was adopted to refer to the studies that introduced a proposal to cope with a particular challenge in any general type of PSO applications. In other words, a new conceptual approach is introduced based on the studies shown as being of general aspects, thus promoting the development of any type of PSO application.

In addition, various research will be compared from several sides, such as key subjects, case studies, strengths, shortcomings, and special outputs.

Conclusions

This study presents a PSO-based algorithm with a new energy management strategy to find the optimum PV and BESS size for a grid-connected MG. The MG can operate in island mode and, if necessary, in grid-connected mode with some limitations. The MG structure is designed in such a way that it can demand energy from the grid when there is not enough energy in the PV system and BESS. However, the amount of demanded energy is limited by the system authorities. The aim is to find an optimum PV and BESS size by considering the defined energy cost. This allows the microgrid to be supported from the grid in critical situations, although supplying loads from the RES has priority, regardless of whether the system will demand energy from the grid and/or the amount of energy to be demanded from the grid can be configured with the proposed energy management method.

Therefore, the energy management algorithm can be reconfigured and used for various systems and different constraints. To validate the proposed approach, various calculations are carried out for different PV and BESS sizes. Furthermore, to prove the effectiveness of the new energy management method with PSO, it has been compared with GA. Results show that the PSO-based algorithm with the energy management strategy can determine the optimum PV and BESS size, with the minimum cost defining the system constraints. Consequently, PV and battery sizes have been optimized together with the proposed PSO algorithm and novel energy management system. The effectiveness of the system is also explained by comparing the results with different algorithms.

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