Journal of Energy and Safety Technology
JEST
RESEARCH ARTICLE Open Access

SIZING ALGORITHM OF SOLAR-POWERED WATER PUMPING SYSTEM FOR DOMESTIC APPLICATION USING PARTICLE SWARM OPTIMIZATION

Hong Jing Siang[1], Siti Maherah Hussin[2*], Norzanah Rosmin[3], Dalila Mat Said[4], Amirjan Nawabjan[5], Madihah Md Rasid[6]

[1,5,6] Department of Electrical Power Engineering, Universiti Teknologi Malaysia (UTM), Johor, Malaysia
[2,3*,4] Centre of Electrical Energy System (CEES), Faculty of Electrical Engineering, Universiti Teknologi Malaysia (UTM), Johor, Malaysia

Corresponding author: sitimaherah@utm.my

Article History

Received:	Received in revised form:	Accepted:	Published Online:
March 15, 2023	May 28, 2023	May 29, 2023	June 30, 2023

Abstract

Due to some issues faced in rural areas such as increasing water demand, the limited reach of electricity, as well as the scarcity of fossil fuel and its negative impact on the environment, renewable energy water pumping systems emerges as an excellent solution to solve those problems. In this case, the components in the renewable energy water pumping system ought to be optimized to improve the effectiveness of the system. This study was aimed at developing and analyzing an optimization model for the sizing of solar-powered water pumping systems for domestic applications. The sizing algorithm was developed using Particle Swarm Optimization (PSO) in MATLAB software. As a result of the optimization, a summary of the main findings was provided, which include the optimal values for the number of solar panels, water tank capacity, and water pump power that minimize system costs and fulfill the water demand simultaneously. To investigate the performance of the proposed algorithm, several case studies have been evaluated by varying the total dynamic head (TDH) and water demands. In summary, TDH value primarily affects the number of PV panels and pump power, leaving the water tank capacity unchanged. However, the variations in water demand can impact all three parameters: the number of PV panels, water tank capacity, and water pump power. Overall, by applying the PSO method in the sizing algorithm of a solar-powered water pumping system, the cost could be minimized, and it would be able to cover the cost of water storage that supports the water demand of a certain application.

Keywords: optimization; particle swarm optimization; solar-powered water pumping system; sizing algorithm; water demand

© 2023 Penerbit UTM Press. All rights reserved

1.0 INTRODUCTION

Solar PV power is utilized in a significant way for pumping water. In Algeria, particularly in rural areas, there is a significant potential to harness the power of solar and wind energy to drive water pumping systems using photovoltaic and wind sources. The presence of water, ample solar radiation, and wind make Hybrid Renewable Energy Water Pumping Systems (HREWPS) an ideal solution, and a primary source for water supply in the region [1]. The use of solar energy for water pumping is mostly done through PV-based and WT-based systems, which are the most popular ways of utilizing solar energy [2]. The advantage of using a combination of energy sources is that it increases the reliability of the system and reduces dependence on any single source of energy [3]. Despite its importance, solar pumping systems have not seen widespread adoption due to the high initial cost. This can be seen by the relatively low number of solar pumping systems that have been installed globally, which is around 60000 [4]. In India, the number of installed solar pumping systems is even lower, at just 5000 [5]. Therefore, it is important to properly size such systems to determine the optimal configuration (number of water pumps, wind turbines, PV panels, and the capacity of the water tank) that makes the HREWPS more cost-effective.

Generally, the optimum sizing of a PV system can be divided into four methods which are intuitive methods, analytical methods, numerical methods, and intelligent methods [6]. Among those four approaches, intuitive methods are considered the simplest as they are implemented based on the computation of system size. These methods often lead to under-sizing or over-sizing of systems as the effects of subsystems and uncertainties are ignored [7]. In this case, they are more suitable to be used to obtain an initial prediction of the system size [8]. In [9], a simple graphical construction is applied by the author to determine the optimum configuration of PV and wind generators. Ould Bilal used a simple calculation method for the sizing of a hybrid solar-wind-battery system while considering the minimization of the annualized cost and loss of load probability (LOLP) [10]. In [11], a simple sizing of a standalone PV power system for Dhaka is proposed by Bhuiyan et al. Besides, Chel et al also proposed a simplified method to size a building integrated PV system as well as the consideration of life cycle cost assessment [12].

For the numerical methods, they are focused on the system components like the PV module, wind turbine, and motor pump as well as the simulation of the power produced using weather data, water velocity, and the state of charge of the water tank. Eventually, the system performance and its reliability would be evaluated by considering the load demand. In terms of outcome, numerical methods provide more accurate results, and hence long-term meteorological data is required. Analytical methods are relatively simpler than numerical methods as they depend on is reliability curves. However, analytical methods are locally-dependent which means they are not applicable to an unconsidered location in the model [13,14]. Hence, intense computation is required to obtain the reliability curve which will eventually raise the difficulties of implementation.

Artificial intelligent methods such as machine learning, metaheuristic, artificial neural network and fuzzy logic are also can be used for sizing optimization approach [15,16]. In [17], Bouzidi reviewed studies related to the development of a design method. He then made the conclusion that less attention has been paid to the sizing of the water tank storage, which significantly affects the system performance and expenses. Particle Swarm Optimization (PSO) is a heuristic technique that was first introduced by Kennedy and Eberhart in 1995. [18] It is a type of metaheuristic procedure, which is a global optimization algorithm that blends two techniques: exploration and exploitation. PSO is based on the principle of simulating the social behavior of birds flocking [19-21]. PSO is a type of evolutionary technique that starts by initializing a swarm of particles and then updates the velocity and position of each particle according to its fitness evaluations. In PSO, the inertia weight is adapted to control the velocity of particles, allowing them to move iteratively toward the best solution. Due to its heuristic nature, PSO is well-suited for solving nonlinear and nonconvex constrained problems and finding global optima. Traditional model-solving algorithms can have some limitations such as an inflexible iteration process, lack of flexibility, and longer computation time [22].

In [23], the authors introduce an enhanced PSO-GWO algorithm, building upon the foundations of the PSO algorithm. By integrating the best position of individual experience from PSO, the proposed algorithm incorporates this information into the Grey Wolf Optimization (GWO) algorithm. By incorporating the strengths of both PSO and GWO, the proposed algorithm aims to improve the overall optimization performance and search capabilities in solving complex optimization problems. The Particle Swarm Optimization (PSO) algorithm has been widely adopted for its efficient global search capabilities, strong robustness, and ability to resist interference [24]. Authors in [25] focus on the application of the Particle Swarm Optimization (PSO) technique to determine the duty cycle for a DC-DC Cuk converter. The update mechanism for the duty cycle differs between PSO and conventional techniques. In the proposed approach, the particle size adjusts automatically in response to changing irradiance conditions, thereby facilitating the capture of the highest maximum power output. Additionally, the study conducts an analysis of the steady-state and dynamic behaviour of a Brushless DC (BLDC) motor-based water pump system integrated with the Cuk converter. The results demonstrate that employing PSO yields superior performance compared to the conventional Proportional and Integral (P&O) method, particularly in terms of faster tracking speed. [26] introduces a Fuzzy Inertia Weight-based Particle Swarm Optimization (PSO) Maximum Power Point Tracking (MPPT) technique. The proposed approach is designed to ensure system stability and deliver effective control performance, particularly in the presence of high nonlinearities and dynamics within the system. By incorporating Fuzzy-based dynamic inertia weights, the technique extends the search space nonlinearity for accurate tracking of the maximum power operating point (MPPT). As a result, the Fuzzy Logic Controller (FLC) integrated with PSO ensures faster tracking performance, reduces steady-state oscillations and improves overall efficiency. [27] focuses on the determination of optimal component sizes for an isolated Solar-Battery Micro-Grid (SB-MG). The objective is to determine component sizes that meet predefined standards for the percentage of unserved energy while minimizing the Levelized Cost of Energy (LCOE). To solve the optimization problem, the authors employ the Butterfly-PSO algorithm. The algorithm's effectiveness lies in finding the optimal component sizes that satisfy both the energy reliability requirements and cost considerations in the context of the isolated SB-MG.

Additionally, PSO requires only a small number of parameters to be adjusted, and similar parameters can be applied to different applications, making it an attractive option for optimizing nonlinear functions [28]. PSO has been extensively studied and documented in many research studies [29,30,31]. The PSO approach was chosen in this study due to its characteristic of high accuracy which means that it could have better results in a cheaper and faster way. Furthermore, the implementation of the PSO approach only required very few algorithms and it simplified the development process as well as debugging stage.

Optimum sizing of PV systems is an algorithm adopted to find the best system configuration such as the number of PV panels and the capacity of a water tank. This algorithm plays an important role to make a system economically feasible (low and affordable cost) and technically reliable (able to fulfill the water demand). Once the PV system is properly optimized, it can guarantee the sufficiency of water demand for the end users and model the electricity required for the desired water pumping performance. However, there are several assumptions made in this study to reduce the complexity of the sizing algorithm and ease of traceability. For example, factors like partial shading, PV configuration, and the connection between grid systems are not considered in this case. Besides, the mean value of irradiance was determined from the input hourly irradiance data, and the water flow rate, Q was obtained from the mean value of water demand, D. By doing so, only the non-zero inputs will be covered while calculating the energy generated by solar panels and energy consumed by the water pump to maintain Q at its value (mean value of D). The initial remaining water is set at 5 m^3 so that the minimum water tank storage could be the same or more than this value (depending on water demand, and water flow rate from the water pump).

This paper is composed of four sections. Section 2 discusses the proposed sizing optimization model, while Section 3 describes the optimization results where several case studies have been considered. Finally, conclusions are presented in Section 4.

2.0 THE PROPOSED SIZING OPTIMIZATION MODEL

The proposed solar-powered water pumping system is illustrated in Figure 1. It consists of PV panels, a water pump, and a water storage tank. The total dynamic head is defined as the vertical height between the water pump and the water storage tank. The main purpose of this water pump is to lift water from the lower elevation of the river to the higher elevation where the storage tank is located. The flow rate of the water pump depends on various factors including the desired water demand, the distance between the river and the storage tank, and the total dynamic head.

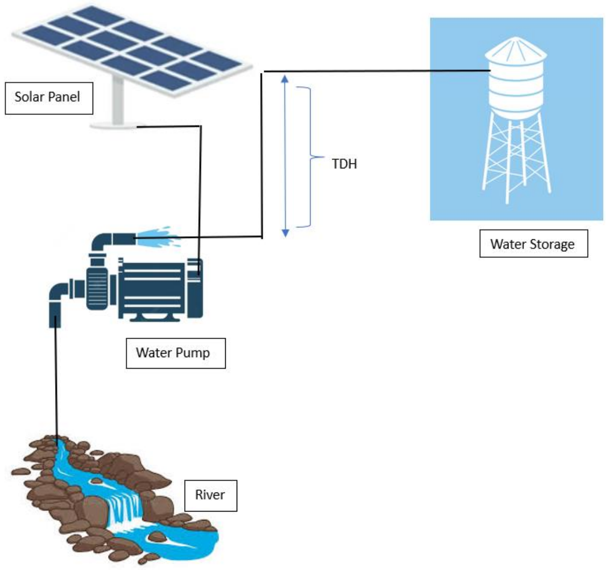

Figure 1. Illustration of the proposed water pumping system.

The main objective of the proposed algorithm is to minimize the overall system cost as stated in equation (1). C_{PV}, C_V, and C_{Watt} are the cost for solar panels, water tank storage and water pump, which are set to a certain value of RM 677/unit, RM320/ m^3, and RM 6/Watt, respectively. Meanwhile, N_{PV}, R_{tank} and $P_{maxpump}$ are represent the number of PV panels, remaining water tank, and maximum power pump, correspondingly. These parameters are the output of the optimization process.

$$f(N_{PV}, R_{tank}, P_{maxpump}) = min(C_{PV}N_{PV} + C_V R_{tank} + C_{watt}P_{maxpump}) \quad (1)$$

The following are the mathematical formulations involved in this sizing algorithm. Equation (2) is related to the calculation of power output from the PV panel, where it is involved the efficiency of solar panels, η_{PV}, and hourly irradiance data, G_{ave}. In this case, the surface area of a single PV panel, A_{PV} is considered as 1.6 m^2. Equation (3) shows the calculation of the remaining water in the tank. This calculation involved the value of water flow rate, Q and water demand, D. The maximum remaining water, R_{tank} and the minimum remaining water, R_{min} are determined respectively from the hourly remaining water in water storage, $C_{res}(t)$ as shown in the equation (4) and equation (5). Equations applied from (1) to (5) are referred to [32]. Meanwhile, equation (6) from [33] illustrates the calculation of the maximum power pump required for the proposed system. Meanwhile, equation (6) illustrates the calculation of the maximum power pump required for the proposed system. It is determined by the value of water density, $\boldsymbol{p}$, acceleration due to gravity, g, total dynamic head, TDH, water flow rate, and the efficiency of water pump, $\boldsymbol{N_{WP}}$.

$$P_{PV} = \eta_{PV} \times A_{PV} \times G_{ave} \times N_{PV} \tag{2}$$

$$(t+1) = C_{res}(t) + Q - D(t) \tag{3}$$

$$R_{tank} = max(\,C_{res}(t)\,) \tag{4}$$

$$R_{min} = min(\,C_{res}(t)\,) \tag{5}$$

$$P_{maxpump} = p * g * TDH * \; Q / \, N_{WP} \tag{6}$$

The above mathematical equations are then formulated in the particle swarm optimization (PSO) algorithm for the optimization purpose**.** Figure 2 illustrates the general overview of the PSO process. In the initialization stage, all PSO parameters such as the number of particles, maximum iteration, learning factors, and initial inertia values are defined. For example, the number of particles is set as 100, and the maximum iteration is set as 50. Both learning factors, c1, and c2 are set as 2. In the declaration of objective and system constraints, the maximum and minimum number of solar panels are declared as 200 and 10 respectively. The remaining water in the water storage must be more than or equal to zero whereas the power generated by solar panels needs to be larger than the power consumed by the water pump operation. Personal best (Pbest) and Global best (Gbest) of interested variables like the number of PV panels, the water tank capacity, the power required for water pump operation, and the respective system cost will be consistently updated and stored from iteration to iteration. The system will examine whether the stopping criteria are met at the end of every iteration. If the stopping criteria are met, the output parameters such as the optimized number of PV panels, water tank capacity, power generated by PVs, the power required for water pump operation, and system cost will be displayed. Otherwise, the optimization will proceed to the mutation process and repeat the former process.

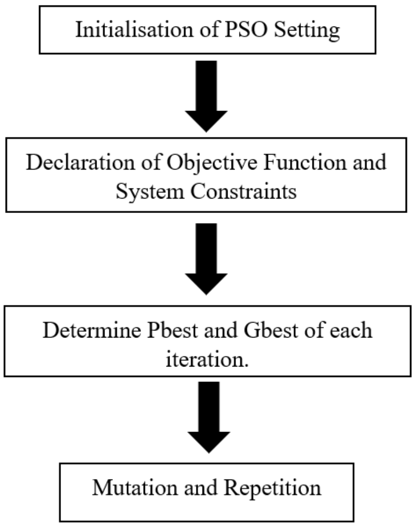

Figure 2. Implementation of PSO in the Sizing Algorithm (Flowchart)

3.0 RESULTS AND DISCUSSION

To evaluate the performance of the proposed algorithm, two (2) case studies have been performed: Case 1: Fixed Demand while TDH is varied and Case 2: Varied Demand while TDH is fixed. Results and analyses for both cases are available in sub-section 3.1 and 3.2, respectively.

3.1 Case 1: Fixed Demand while TDH is varied.

The purpose of Case 1 is to investigate the effects of TDH on the performance of the proposed sizing algorithm of the proposed solar-powered water pumping system. This is important as TDH is one of the critical factors in sizing the water pumping system. It represents the total resistance that the pump must overcome to enable the water flows from the source to the tank smoothly. To see how various values of TDH would affect the system sizing, three different values of TDH were considered: 25 m, 50 m, and 100 m. Hence, Case 1 will be divided into three cases as listed below:

Case 1: Fixed demand and Varies TDH Value
- Case 1(a): TDH is equal to 25 meters.
- Case 1(b): TDH is equal to 50 meters.
- Case 1(c): TDH is equal to 100 meters.

The optimization results for these three cases are summarized in Table 1. From Table 1, it can be observed that the suggested number of PV panels for these three cases is 10, 14, and 28, respectively. As the number of PV panels increases, the total cost also increases, as it is directly proportional to the number of installed PV panels. Similarly, the capacity of the pump power increases as the TDH value increases, as more power is required to overcome the higher resistance. From this result, it shows that higher TDH will give a significant impact on the number of PV panels and the capacity of the pump power.

Table 1. Optimization Result of Cases 1(a),1(b) and 1(c)

Case	**Case 1(a) (TDH=25 m)**	**Case 1(b) (TDH=50 m)**	**Case 1(c) (TDH=100 m)**
Cost (RM)	106537.50	204893	405666
No of PV	10	14	28
Maximum water tank, Rtank (m^3)	12.875	12.875	12.875
Power Required for Water Pump, Ppump (kW)	0.664	1.328	2.657

As can be seen from the same table, the maximum water in the storage tank, Rtank, has been remained unchanged which it consistently remains at 12.875 m3. This is due to the characteristics of the water pump storage system, which is independent of the variation in TDH at the water pump. As long as the water flow rate, Q, Hourly Water Demand, D, and the remaining water in the storage tank, Cres, are fixed, the maximum water tank, Rtank will keep constant from case to case.

3.2 Case 2: Varied Demand while TDH is fixed.

The purpose of the second study, Case 2 is primarily focused to investigate the effects of different water demands on the proposed system. To illustrate this case, three levels of water demand are considered: lower, medium, and higher. Hence, Case 2 will be divided as three cases below:

Case 2: Varies Demand and Fixed TDH Value
- Case 2(a): Lower Demand.
- Case 2(b): Medium Demand.
- Case 2(c): Higher Demand.

The load profiles for these three demand cases are demonstrated in Figure 3, meanwhile the results of the proposed optimization sizing are summarized in Table 2. From the presented table, it can be seen that the proposed number of PV panels for Case 2(a), Case 2(b), and Case 2(c) are 14, 43, and 88, respectively. The result indicates that the fluctuation in water demand significantly influences the system sizing, as it directly impacts the dimensions of PV panels, water tank capacity, and water pump power. As the water demand gradually increases from lower to higher levels, the corresponding water flow rate, Q, also increases as it is depend on the mean water demand, D. Consequently, the energy required by the water pump to achieve the desired water flow rate of Q also rises. Consequently, it becomes necessary to increase the number of solar panels to support the increased demand for both power and water. In Case 2(a) and Case 2(c), the water demand, D, is concentrated during the time periods of 18:00-20:00 pm and 16:00-18:00 pm, respectively. In contrast, for Case 2(b), the peak water demand occurs two times between 8:00-9:00 am and 17:00-18:00 pm. Therefore, the maximum water tank capacity for Cases 2(a) and Case 2(c) is higher, as these conditions allow for water storage in advance, taking advantage of the relatively lower demand during earlier periods. This leads to the result that the maximum remaining water in the tank storage, Rtank, for Cases 2(a) and Case 2(c) is higher compared to Case 2(b). In summary, it can be noted that a comprehensive understanding of water demand enables the selection of appropriate pump sizes and system capacities. It helps avoid undersized or oversized systems, optimizing water supply while minimizing energy consumption and costs. Besides that, considering future demand patterns also would help the designer to design a proper system by taking account the factor of reasonable scale for future expansion.

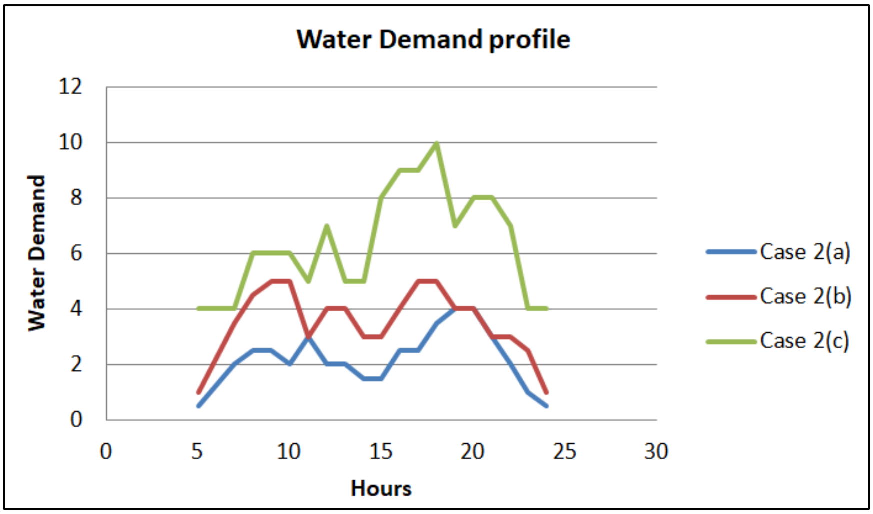

Figure 3. Water Demand Profile

Table 2. Optimization Result of Case 2 (a), Case 2(b) and Case 2(c)

Case	Case 2(a)	Case 2(b)	Case 2(c)
Cost (RM)	204893	613222.43	1259939.81
No of PV	14	43	88
Maximum water tank, Rtank (m3)	12.875	12.25	19.83
Power Required for Water Pump, Ppump (kW)	1.328	4.029	8.292

3.0 CONCLUSION

This paper presents the proposed sizing algorithm for the solar-power water pumping system for domestic applications based on Particle Swarm Optimization (PSO) approach. The main objective of the optimization model is to minimize the overall system cost and at the same time restricted to several constraints. The output of the optimization is in terms of the system cost, number of PV panels, water tank storage capacity, and water pump capacity. Several case studies have been evaluated to test the proposed optimization model by varying the values of the total dynamic head (TDH) and water demands. It can be concluded that these values have a great impact on the system sizing. In summary, proper identification of the water demand and correct selection of the TDH value are crucial steps in determining the system sizing to avoid issues of over-design or under-design.

References

[1] Y. Bakelli, et al., "Optimal sizing of photovoltaic pumping system with water tank storage using LPSP concept," Solar Energy, vol. 85, pp. 288-294, 2011/02/01/ 2011.
[2] J. K. Kaldellis, et al., "Experimental validation of autonomous PV based water pumping system optimum sizing," Renewable Energy, vol. 34, pp. 1106-1113, 2009/04/01/ 2009.
[3] C. Gopal, et al., "Renewable energy source water pumping systems—A literature review," Renewable and Sustainable Energy Reviews, vol. 25, pp. 351-370, 2013/09/01/ 2013.
[4] Short T. D., Mueller M. A.; 'Solar powered water pumps: problems, pitfalls and potential', International Conference on PEMD, 2002, pp280–285.
[5] Surendra T.S., Subbaraman S. V. V.; 'Solar PV water pumping comes of age in India' IEEE Photovoltaic Specialists Conference, 2002, pp1485 – 1488.
[6] R. Rawat, et al., "A review on modeling, design methodology and size optimization of photovoltaic based water pumping, standalone and grid connected system," Renewable and Sustainable Energy Reviews, vol. 57, pp. 1506-1519, 2016/05/01/ 2016.
[7] T. Khatib, et al., "A review of photovoltaic systems size optimization techniques," Renewable and Sustainable Energy Reviews, vol. 22, pp. 454-465, 2013/06/01/ 2013.

[8] R. Posadillo and R. López Luque, " Approaches for developing a sizing method for stand-alone PV systems with variable demand," Renewable Energy, vol. 33, pp. 1037-1048.
[9] T. Markvart, "Sizing of hybrid photovoltaic-wind energy systems," Solar Energy, vol. 57, pp. 277-281, 1996/10/01/ 1996.
[10] B. Ould Bilal, et al., "Optimal design of a hybrid solar–wind-battery system using the minimization of the annualized cost system and the minimization of the loss of power supply probability (LPSP)," Renewable Energy, vol. 35, pp. 2388-2390, 2010/10/01/ 2010.
[11] M. M. H. Bhuiyan and M. Ali Asgar, "Sizing of a stand-alone photovoltaic power system at Dhaka," Renewable Energy, vol. 28, pp. 929-938, 2003/05/01/ 2003.
[12] A. Chel, et al., "Simplified method of sizing and life cycle cost assessment of building integrated photovoltaic system," Energy and Buildings, vol. 41, pp. 1172-1180, 2009/11/01/ 2009.
[13] A. Kaabeche, et al., "Sizing optimization of grid-independent hybrid photovoltaic/wind power generation system," Energy, vol.36, pp. 1214-1222, 2011/02/01/ 2011.
[14] M. G. Molina and E. J. Espejo, "Modeling and simulation of gridconnected photovoltaic energy conversion systems," International Journal of Hydrogen Energy, vol. 39, pp. 8702-8707, 2014/05/27/ 2014.
[15] A. Mellit, et al., "Modeling and simulation of a stand-alone photovoltaic system using an adaptive artificial neural network: Proposition for a new sizing procedure," Renewable Energy, vol.32, pp. 285-313, 2007/02/01/ 2007.
[16] D. H. Muhsen, et al., "Technoeconomic study and optimal sizing of a standalone photovoltaic water pumping system," International Transactions on Electrical Energy Systems, vol. 27, p. e2355, 2017.
[17] B. Bouzidi, "New sizing method of PV water pumping systems," Sustainable Energy Technologies and Assessments, vol. 4, pp. 1-10, 2013/12/01/ 2013.
[18] L. Tarantino and A. Giorgio, "Prognostic evaluation of abdominal echography in typhoid fever," G. Mal. Infett. Parassit., vol. 46, no. 10, pp. 1942–1948, 1994.
[19] J. Kennedy, R. C. Eberhart, and Y. Shi, Swarm Intelligence. San Mateo, CA, USA: Morgan Kaufmann, 2001.
[20] K. E. Parsopoulos and M. N. Vrahatis, Particle Swarm Optimization and Intelligence: Advances and Applications, vol. 1. Hershey, PA, USA: Inf. Sci. Ref., 2010.
[21] O. Gandhi, C. D. Rodr´ıguez-Gallegos, and D. Srinivasan, "Review of optimization of power dispatch in renewable energy system," in Proc. IEEE Innov. Smart Grid Technol., Asia, 2016, pp. 250–257.
[22] S. Sinha and S. S. Chandel, "Review of recent trends in optimization techniques for solar photovoltaic-wind based hybrid energy systems," Renewable and Sustainable Energy Reviews, vol. 50, pp. 755–769, 2015.
[23] Q. Zhang, X. Xu, T. Wang, H. Sun, C. Yang and H. Pan, "Optimal Configuration of Wind/Solar/Diesel /Storage Microgrid Capacity Based on PSO-GWO Algorithm," IECON 2022 – 48th Annual Conference of the IEEE Industrial Electronics Society, Brussels, Belgium, 2022, pp. 1-5, doi: 10.1109/IECON49645.2022.9968359.
[24] E. Riccietti, S. Bellavia, and S. Sello, "Sequential linear programming and particle swarm optimization for the optimization of energy districts," Engineering Optimization, vol. 51, no. 1, pp. 84–100, 2018.
[25] K. K. Jha and M. N. Anwar, "Solar Photovoltaic based Brushless DC Motor Driven Water Pumping System using PSO-MPPT Algorithm," 2019 54th International Universities Power Engineering Conference (UPEC), Bucharest, Romania, 2019, pp. 1-6, doi: 10.1109/UPEC.2019.8893591.
[26] M. S, M. S and Vinothkumar, "Artificial Intelligent Parameter based PSO for Maximum Power Point Tracking of PV Systems under PSC," 2021 IEEE 17th International Colloquium on Signal Processing & Its Applications (CSPA), Langkawi, Malaysia, 2021, pp. 86-91, doi: 10.1109/CSPA52141.2021.9377286.
[27] P. Paliwal, "Determining optimal component sizes for an isolated solar-battery micro-grid using Butterfly PSO," 2021 1st International Conference on Power Electronics and Energy (ICPEE), Bhubaneswar, India, 2021, pp. 1-6, doi: 10.1109/ICPEE50452.2021.9358614.
[28] M. Joana, R. P. V. Faria, I. B. R. Nogueira, J. M. Loureiro, and A. M. Ribeiro, "Optimization strategies for chiral separation by true moving bed chromatography using particles swarm optimization (PSO) and new parallel PSO variant," Computers and Chemical Engineering, vol. 123, pp. 344–356, 2019.
[29] Ngo, V. Q., Al-Haddad, K., & Nguyen, K. K. (2020). Particle Swarm Optimization – Model Predictive Control for Microgrid Energy Management. 2020 Zooming Innovation in Consumer Technologies Conference (ZINC). doi:10.1109/zinc50678.2020.9161790
[30] B Wang, F., Zhang, H., & Zhou, A. (2020). A Particle Swarm Optimization Algorithm for Mixed-Variable Optimization Problems. Swarm and Evolutionary Computation, 100808. doi:10.1016/j.swevo.2020.100808
[31] Nemouchi W, Amrane Y, Nemouchi H.(2021). Optimal sizing design of stand- alone hybrid system using a Fuzzy PSO, 5th International Conference on Artificial Intelligence in Renewable Energetic Systems IC-AIRES2021.
[32] A. Nekkache, B. Bouzidi, A. Kaabeche and Y. Bakelli, "Hybrid PV-Wind based water pumping system optimum sizing: a PSO-LLP-LPSP optimization and cost analysis," 2018 International Conference on Electrical Sciences and Technologies in Maghreb (CISTEM), Algiers, Algeria, 2018, pp. 1-6, doi: 10.1109/CISTEM.2018.8613606.
[33] M. Elrefai, R. A. Hamdy, A. ElZawawi and M. S. Hamad, "Design and performance evaluation of a solar water pumping system: A case study," 2016 Eighteenth International Middle East Power Systems Conference (MEPCON), Cairo, Egypt, 2016, pp. 914-920, doi: 10.1109/MEPCON.2016.7837005.