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Spider Monkey Optimization Based Optimal Sizing of Battery Energy Storage for Micro-Grid

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Abstract: The ever-increasing need for power in today's environment calls for a secure and effective energy supply network. Distributed renewable options such as Diesel Generator (DG), wind turbine (WT) and photovoltaic (PV) solar energy may be integrated inside a micro grid (MG) to supply electricity to customers in a sensible manner. In order to provide a more efficient and affordable source of electricity, the battery storage device is built into the micro grid. This article identifies the cost-based approach to calculate the optimum size of the Battery energy storage (BES) for MG operations. Some constraints, i.e., the power output of the Distributed Generators (DGs), the power and energy capacity of BES, the charging/discharge performance of BES, the working reserve and the fulfilment of the load requirement, should also be considered. In this article the Spider Monkey (SM) algorithm is a modern evolutionary technology that is used to build correction policies and to execute less costly dispatch. Four different cases have been studied. The results are compared with recently developed Fire Fly (FF) algorithm to corroborate the effectiveness of the proposed algorithm. The results show that the proposed algorithm has low power loss and the operating cost of the proposed SM technique is 0.0129% less than existing FF algorithm based micro-grid system. Here, IEEE 33 bus system performed to prove the effectiveness of the proposed SM algorithm over the FF algorithm.

Keywords: battery energy storage; diesel generator; micro grid; optimal sizing; renewable energy; spider monkey algorithm

1 INTRODUCTION

In recent years, the world has witnessed an exponential growth in its population, culminating in increased demand for electricity; all of that are the major operating forces behind carbon pollution and global warming. However, people are now steadfastly reliant on the usage of fossil fuels, which, by the way, already play a substantial role in the energy supply of the electricity production and transport network. Furthermore, the continuing and unavoidable loss of fossil fuel supplies in recent years has placed considerable strain on authorities and RES (Renewable Energy Sources) producers must take responsibility to replenish energy through renewable energy [1]. The manufacturing sector contributes to green energy development by reducing greenhouse gases from fossil fuels. Renewable energy is one of the alternative energy sources that has grown in importance and relevance. Renewable energy may be utilized again without depletion, and it is eco-friendly, helps to conserve the environment, and reduces health concerns. As a result, renewable energy sources are critical for sustaining human existence while simultaneously reducing carbon dioxide emissions and combating climate change [2-5].

Different renewable energy sources can be used to create hybrid energy systems, such as solar, wind, tidal, and fuel cells. Several studies have been published on the efficiency of hybrid systems that integrate power input from different distributed renewable energy resources by overcoming existing distribution system drawbacks. One of the main benefits of a hybrid power system is its ability to continue to deliver an uninterrupted supply of power to the load at any time, even if one of the energy sources, such as solar energy, is unable to produce electricity and supply it to the load. As a result, guaranteeing a steady supply to the distribution system will ensure the overall sustainability of the power system. Micro grids havealso arisen as a forum for combining Distributed Energy Resources (DER), such as DGs, WTs, micro turbines (MTs), fuel cells (FCs), PVs and Battery energy storage systems (BESSs) through a more organized and functional grid. Depending on the load requirements and market price of electricity, micro grids can operate in insulated or grid-connected modes [6], having the capacity to address the problems of efficiency, sustainability and demand response of the current power network.

Heuristic optimization approaches have received a lot of attention in recent years due to their higher performance in dealing with big and complicated optimization issues compared to quantitative optimization methodologies. A heuristic optimization strategy can take many forms. GM algorithm (GA) [7] and additional methods, including optimization of ant colony (ACO) [7], firefly (FA) [11], Artificial Plant Optimization Algorithm (APOA) [12-16], were several of the earliest strategies. In order to maximize the scale of the hybrid wind turbine, PV and the BESS system, Vrettos and Papathanassiou [17] have been using GA. The multi-target position in this research reduces the costs of generation and maximizes renewable energy deployment. GA has been used by Chen et al. [18] to evaluate the best battery capacity size by optimising the non-linear functional capital cost model. Presented bat algorithm based ideal sizing of battery storage for MG operation, which shows the reduction in total costs is due to the battery energy's ability to store and redispatch excess RES power. Firefly algorithms are approximation solution methods for an optimization process that use the 'educated guess' random elements function in their search process and attempt to improve the efficiency of the solutions at hand by iterations, a randomly generated collection of feasible solutions, by exploring and leveraging the solution space. Although these algorithms do not guarantee maximum efficiency, they are evaluated to have a fair and acceptable solution. Some drawbacks of FF algorithms include their sensitivity to control parameters. Due to its high computational complexity, the convergence speed is slow.

The rest of the document is structured as follows. The mathematical modeling of the MG components are explained in Section 2. The formulation of the problem, objective function and equal and unequal constraints of the proposed MG model and the proposed Spider Monkey algorithm based optimal sizing of MG is briefly presented in Section 4. Section 5 addresses the outcomes of the proposed and existing techniques and the conclusion is eventually provided in Section 6.

2 MATHEMATICAL MODELING OF HYBRID MG SYSTEM

In this work, the renewable energy such as Wind energy, solar photovoltaic (PV) are considered as primary energy sources. Battery energy storage and diesel generator are secondary sources of power for the micro grid where renewable resources cannot satisfy the necessary requirement for power. The AC bus bar is connected to the power sources, and the load is integrated with the opposite side of the AC bus bar. The presented hybrid microgrid system is depicted in Fig. 1. The traditional generator acts as a secondary source of energy and increases the device efficiency by smoothing the production of electricity from alternative energy sources. The mathematical modelling of a Wind Turbine (WT), a Diesel Generator (DG), a photovoltaic system, and a battery storage unit is evaluated further below.

2.1 Wind Turbine Model

The wind turbine performance model calculates the output as a feature of the hourly speed of wind [13]. Following is the equation that defines the relationship between speed and production strength. The wind turbine's power (P_W) at time t is calculated as below:

$$P_W(t)=\begin{cases} 0 & w_h \le w_h \text{ or } w_k - w_{c,a} \\ P_{w,\max}\times\dfrac{w_h - w_{c,i}}{w_{rf}-w_{c,i}} & w_{c,i}\le w_k \le w_{rf} \\ P_{w,\max} & w_{rf}\le w_h \le w_{c,\rho} \end{cases} \tag{1}$$

where, $P_{w,\max}$ - maximum power output of wind turbine, kW; w_h - speed of wind turbine at hour h, m/s; w_{rf} - rated wind speed, m/s; $w_{c,i}$ - cut in wind speed, m/s; $w_{c,\rho}$ - cut out wind speed, m/s.

2.2 Solar PV Model

Solar photovoltaic systems generate energy depending on the amount of solar irradiation and the temperature in the atmosphere at any given time. The power of the PV is provided by [20].

$$PV_{\text{power,out}} = P_{pv}\frac{Z}{Z_{ref}}\cdot \cdot\left[1+k_{temp}\left\{\left(T_{amb}+\left(0.0256\times Z\right)\right)-T_{ref}\right\}\right] \tag{2}$$

where, P_{pv} - rated PV power, kW; Z - solar radiation, W/m^2; Z_{ref} - solar radiation of standard temperature; T_{amb} - ambient temperature of the solar panel; T_{ref} - standard temperature.

2.3 Diesel Generator

A minimum of two generators have been included here. The expense of the generator is measured in terms of power supply The diesel generator's fuel consumption, F_c l/h, is determined by the output power and is specified by the following equation:

$$F_c = p_D \times P_r + q_D \times P_{DG} \tag{3}$$

where, P_r - rated power, P_{DG} - output power of the diesel generator, the consumption curve coefficients are p_D and q_D, which are 0.08145 l/kWh and 0.246 l/kWh, respectively.

2.4 Battery Model

Micro grids have been equipped with battery energy storage systems in order to avoid power discrepancy between demand and supply. The lithium-ion battery has been included in this paper. Due to its high energy capacity, long life cycle, and efficiency, this battery is typically used to store solar and wind energy. [12].

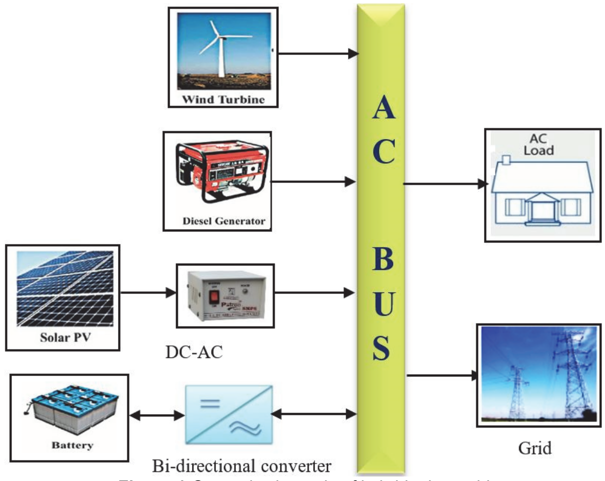

Figure 1 General schematic of hybrid micro grid

In Fig. 2, we study the costs associated with energy storage for various discharge energies and discharge ranges. As a feature of battery capacity and DOD, the charge and discharge expense of the battery is given in Eq. (4). Battery energy TCPD is the feature of the capital expense of the battery and the total operating expense of the battery existence. The ideal size of the battery would reduce the average expense of the micro grid. The cost feature of the battery storage throughout the charging/discharging case has been modeled as

In terms of battery capacity, state of charge (SOC) that signifies the condition of the battery is expressed below.

$$D_{batt}(t) = 1 - SOC_{batt}(t) \tag{4}$$

$$SOC_{batt}(t+1) = SOC_{batt}(t) - \frac{P_{batt}\times \Delta t \times \eta_{batt}^{ch}}{E_{batt}} - -\frac{P_{batt}\times\Delta t}{E_{batt}\times \eta_{batt}^{ch}} \tag{5}$$

where, η_{batt}^{ch} - efficiency of battery charging and discharging, Δt - time interval (1 hour), and η_{batt}^{ch} is battery efficiency.

3 PROBLEM FORMULATION
3.1 Objective Function

The proposed algorithm is used to find an optimum sizing of BESS in a routine economic scheduling of the MG system. Hence, the total expense of the BESS is considered as a crucial element while estimating its capacity. In this proposed research work the objective function is developed to minimize the operating cost (OC) of the system which is further divided in two fundamental factors, such as daily scheduling cost (SCD) and Total Cost Per Day (TCPD). Optimal BESS aimed to reduce these factors in order to reduce the regular operating costs of the micro-grid and BESS average expense per day. The schedule expenses for the day comprise the amount of the expense of DGs supplying electricity to satisfy the demand of load. The battery TCPD is the feature of capital expense of the battery and the total operating expense of the battery existence. The ideal size of the battery would reduce the average expense of the micro grid. The description of the objective function is depicted in the Eq. (6) and the fundamental factors are given in Eq. (10) and Eq. (11).

$$\text{Min}\, F(x) = \sum_{t=1}^{NT} f_t + TCPD_{\text{BES}} + OM_{\text{DG}} \tag{6}$$

where, OM_{DG} - distributed generator's fixed operation and maintenance cost.

$$SCD = \text{Min} \sum_{t=1}^{T} \left(\sum_{j=1}^{N} F_j \left(P_{\text{gen}}(t) \right) \right) + C_{\text{batt}} \tag{7}$$

$$OM_{\text{DG}} = \left(OM_{\text{FC}} + OM_{\text{MT}} + OM_{\text{DG}} + OM_{i_{\text{wt}}} + OM_{i_{\text{PV}}} \right) \times \times NT \tag{8}$$

TCPD (Total Cost Per Day) of battery is expressed in the following equation.

$$TCPD_{\text{BESS}} = \frac{C_{\text{BES,MAX}}}{365} \left(\frac{IR(1+IR)^{LT}}{(1+IR)^{LT} - 1} \right) FC_{\text{BES}} + MC_{\text{BES}} \tag{9}$$

$$f_t = Cost_{\text{grid},t} + Cost_{\text{DG},t} + Cost_{\text{BES},t} + Cost_{\text{PV},t} + + Cost_{\text{WT},t} + SUC_{\text{DG},t} + SDC_{\text{DG},t} \tag{10}$$

where,

$$Cos\,t_{\text{grid},t} = f(x) = \begin{cases} Bid_{\text{grid},t} P_{\text{grid},t} & \text{if } P_{\text{grid},t} > 0 \\ (1-tax)\, Bid_{\text{grid},t} P_{\text{grid},t} & \text{if } P_{\text{grid},t} < 0 \\ 0 & \text{if } P_{\text{grid},t} = 0 \end{cases} \tag{11}$$

Cost of diesel generator can be expressed as Eq. (12)

$$Cost_{\text{DG},\,t} = \sum_{t=1}^{T} \sum_{i=1}^{l} \left[a_j P_{\text{gen}}^2(t) + b_j P_{\text{gen}}(t) + c_j \right] \tag{12}$$

The hourly cost of fuel usage may be calculated by,

$$Cost_{\text{fuel}} = P_{\text{fuel}} . Cost_{\text{DG},\,t} \tag{13}$$

where, $a_j b_j c_j$ - cost coefficients of the j-th generators, P_{fuel} - fuel price.

$$SDC_{\text{DG},t} = Shut_{\text{DG}} \times \max\left(0, U_{\text{DG},t-1}, -U_{\text{DG},t}\right) \tag{14}$$

$$SUC_{\text{DG},t} = Start_{\text{DG}} \times \max\left(0, U_{\text{DG},t} - U_{\text{DG},t-1}\right) \tag{15}$$

where, $SUC_{\text{DG},t}$ - DG's start-up cost, $SDC_{\text{DG},t}$ - DG's shut-down cost, $U_{\text{DG},t}$ - status (on or off) of diesel generator at time t.

The cost of energy supplied by solar *PV* depends on the initial cost and the power production as specified.

$$Cost_{\text{pv},\,t} = \left(\sum_{t=1}^{T} P_{\text{pv,out}(t)} \right) \times IC_{\text{pv}} \times CRF \tag{16}$$

The cost of energy supplied by WT depends on the initial cost and the power production as specified, which is expressed as Eq. (17).

$$Cost_{\text{WT},\,t} = \left(\sum_{t=1}^{T} P_{\text{WT,out}(t)} \right) * IC_{\text{WT}} * CRF \tag{16}$$

where, $P_{\text{WT,out}(t)}$ - output power of the wind turbine, kW; IC_{WT} - wind turbine's initial cost, and *CRF* - capital recovery factor.

$$CRF = \frac{r(1+r)^T}{(1+r)^T - 1} \tag{17}$$

The cost of energy supplied by battery storage system depends on the initial cost and the power production as specified.

$$Cost_{\text{BES},\,t} = \frac{C_{\text{BES}} \times P_{\text{BES}} \times \Delta t}{E_{\text{BES}} \times l_{\text{c}} \left(D_{\text{BES}}(t) \right) \times \eta_{\text{BES}}^2} \tag{18}$$

where, $D_{\text{BES}}(t)$ depth of discharge, P_{BES} - producible power of battery energy storage, Δt - time interval duration, and η_{BES} - efficiency of BES.

Load demand balance

The load demand at any instant might be balanced by the energy generation by DG, PV, and WT sources as well as the power in BES. The energy balance equation of the prescribed system is represented as follows:

$$P_{\text{DG},t} U_{\text{DG},t} + P_{i\text{PV},t} + P_{i\text{wt},t} + P_{\text{BES},t} + P_{\text{grid},t} = P_{\text{Demand},t} \quad t = 1, \ldots, NT \tag{19}$$

where, $U_{\mathrm{DG},t}$ - variables that indicate the on/off status of diesel generator.

3.2 Constraints

3.2.1 Renewable and Non-Renewable Power Constraints

The constraints of the generating system considered in this research works such as DG, PV, WT and BES are written in the following equations.

$$P_{\mathrm{PV,min}} \le P_{\mathrm{PV},t} \le P_{\mathrm{PV,max}} \qquad t = 1,\dots,NT \tag{20}$$

$$P_{\mathrm{WT,min}} \le P_{\mathrm{WT},t} \le P_{\mathrm{WT,max}} \qquad t = 1,\dots,NT \tag{21}$$

$$P_{\mathrm{DG,min}} \le P_{\mathrm{DG},t} \le P_{\mathrm{DG,max}} \qquad t = 1,\dots,NT \tag{22}$$

3.2.2 BES Constraints

$$P^{\min}_{\mathrm{BES},t} \le P_{\mathrm{BES},t} \le P^{\max}_{\mathrm{BES},t} \qquad t = 1,\dots,NT \tag{23}$$

where $P_{\mathrm{BES},t}$ - rated power capacity of BESS, MW, at time t, $P^{\min}_{\mathrm{BES},t}$ - minimum rated power capacity, at time t and $P^{\max}_{\mathrm{BES},t}$ - maximum power rating for BESS at time t.

Discharging mode:

$$\begin{gathered} C_{\mathrm{BES},t+1} = \max\{(C_{\mathrm{BES},t} - \Delta t P_{\mathrm{BES},t}\eta_{\mathrm{discharge}}), C_{\mathrm{BES,min}}\} \\ t = 1,\dots,NT \\ P_{\mathrm{BES},t} \le P_{\mathrm{BES},t} \le \overline{P_{\mathrm{BES},t}} \qquad t = 1,\dots,NT \end{gathered} \tag{24}$$

Charging

$$\begin{gathered} C_{\mathrm{BES},t+1} = \min\{(C_{\mathrm{BES},t} - \Delta t P_{\mathrm{BES},t}\eta_{\mathrm{discharge}}), C_{\mathrm{BES,min}}\} \\ t = 1,\dots,NT \\ P_{\mathrm{BES},t} \le P_{\mathrm{BES},t} \le \overline{P_{\mathrm{BES},t}} \qquad t = 1,\dots,NT \end{gathered} \tag{25}$$

where,

$$\begin{gathered} \overline{P}_{\mathrm{BES},t} = \min\{P_{\mathrm{BES,max}}(C_{\mathrm{BES},t} - C_{\mathrm{BES,min}})\eta_{\mathrm{discharge}} / \Delta t\} \\ t = 1,\dots,NT \end{gathered} \tag{26}$$

$$\begin{gathered} P_{\mathrm{BES},t} = \min\{P_{\mathrm{BES,min}}(C_{\mathrm{BES},t} - C_{\mathrm{BES,max}}) / \eta_{\mathrm{discharge}}\Delta t\} \\ t = 1,\dots,NT \end{gathered} \tag{27}$$

3.2.3 Grid Constraint

The utility's power supply should always be within its minimum and maximum limits and is provided through:

$$P_{\mathrm{grid,min}} \le P_{\mathrm{grid},t} \le P_{\mathrm{grid,max}} \qquad t = 1,\dots,NT \tag{28}$$

3.2.4 Operating Reserve Constraint

The MG system is normally equipped with BESS for storing and retrieving the energy to satisfy the demand whenever the energy generation couldn't meet out the demands. In this research article the battery energy storage (BES) is taken into concern, which is normally fed to the MG system within 10 min as follows:

$$\begin{gathered} P_{\mathrm{FC,min}}U_{\mathrm{FC},t} + P_{\mathrm{MT},t}U_{\mathrm{MT},t} + P_{\mathrm{grid,max}} + \overline{P}_{\mathrm{BES},t}U_{\mathrm{BES},t} \ge \\ OR_t + P_{\mathrm{Demand},t} \qquad t = 1,\dots,NT \end{gathered} \tag{29}$$

where OR_t is normally 10 min.

4 OPTIMIZATION APPROACHES FOR OPTIMAL SIZING OF MG

The aim of this paper is to identify the most cost-effective BES size. Here, the Spider Monkey (SM) algorithm is presented to measure the optimal size of the battery and schedule the generators in the DGs in an economical manner.

This could be achieved through proper scheduling of power delivery with the various energy sources connected in the MG system. Whenever, the load demand is higher than the renewable power generation, the suggested approach must supply electricity from DG or stored energy from battery. The proposed algorithm scans the DOD of battery and converts the same into the cost factor. In general, the DOD of battery is large, while the battery is providing electricity and it is low when the battery is charging. At first the charging discharging status of the battery is predicted by the algorithm and corresponding SOC voltage is measured for each hour. The use of multiple RESs increases device performance and rising energy storage demands relative to a standard RES. The superiority of SM algorithm is proved by comparing the performance with another intelligent approach named FF algorithm.

4.1 Proposed Spider Monkey (SM) Optimization Approach

Spider Monkey (SM) algorithm is one of the promising intelligent algorithms which is framed from the foraging behavior of the spider monkey. In this algorithm the main groups of spider monkeys are split into sub groups with minimum of 3 participants and each subgroup is led by a female monkey to search the food. By proper aggressiveness and territorial behavior, they communicate their intensions, and availability of food with the other group members. The algorithmic steps of the SM algorithm are presented below:

Step 1: Initialization

In this stage the dimension of problem and the size of particles in a solution space are initialized (30). Whereas $SM_{\min j}$ and $SM_{\max j}$ are the minimum maximum bounds of the optimal search location and $U(0, 1)$ is a randomly generated number between [0-1].

$$SM_{ij} = SM_{\min j} + U(0,1) \times (SM_{\max j} - SM_{\min j}) \tag{30}$$

Step 2: Local Leader Phase

In this stage the position of each particle is modernized according to the best position of leader or group members (31). The best position is hereby decided by the fitness values of the particles. Whereas, the LL_{kj} is the local best position in the group.

$$SM_{\text{new}ij} = SM_{ij} + U(0,1) \times (LL_{kj} - SM_{ij}) + \\ + U(-1,1) \times (SM_{rj} - SM_{ij}) \quad (31)$$

Step 3: Global Leader Phase

In this step, the position of the particles is updated based on the overall best position of all groups which is termed as global best position. The below equations are used to update position of particles conferring to the global best solution Eq. (32). Whereas, the GL_{kj} is the global best position in the group. In this step the probability evaluated from the Eq. (33) is used to update the position of particles.

$$SM_{\text{new}ij} = SM_{ij} + U(0,1) \times (GL_{kj} - SM_{ij}) + \\ + U(-1,1) \times (SM_{rj} - SM_{ij}) \quad (32)$$

$$Prob_{\text{new}i} = 0.9 \times \frac{fitness_i}{\max\_fitness} + 1 \quad (33)$$

Step 4: Global Leader (GL) Learning

The particle with the maximum fitness value in the complete solution space replaces the global leader at this stage. If the position of the *GL* is not updated, the global limit count is increased by one.

Step 5: Local Leader (LL) Learning

Similarly to step 4, the particle with the highest fitness value in each group takes over as local leader. If the position of the *LL* is not modernized, the local limitation count is increased by one.

Step 6: Local Leader Decision

The modification of particle positions as well as local leader position will extend until the threshold value known as local leader limit reached. If the desired position is not reached, the particles are updated through random initialization (30) or through the knowledge of local and global leader information based on perturbation value (34).

$$SM_{\text{new}ij} = SM_{ij} + U(0,1) \times (GL_{kj} - SM_{ij}) + \\ + U(0,1) \times (SM_{rj} - LL_{kj}) \quad (34)$$

Step 7: Global Leader Decision Phase

The modification of particle positions as well as global leader position is decided with the threshold value known as global leader limit reached. If it is not reached, then the particles are split in to small groups up to the maximum group number is reached (34). The flow chart of the proposed spider monkey algorithm based on optimal sizing of micro grid.

4.2 SMA Implementation Steps for Optimal BESS Size of MG

SM algorithm optimal size of BESS and the output power of energy sources in order to minimize total MG operation costs are as the following,

Step 1: At the starting, describe all the input data, including operation costs, power output by WT, DG, PV, grid and BESS injected or absorbed power limits, BESS size, power loss, cost data of start-up and shut-down for DG, electrical load demand, and so on.

Step 2: Initialize the particles number (*N*) in spider monkeys (*SM*) and initialize maximum numbers of iterations ($iter_{\max}$) using Eq. (30)

Step 3: Set constraint which is mentioned in Eq. (20) to (29).

Step 4: Choose the best particle from a random sample of *n* spider monkeys by evaluating their fitness using the objective function using Eq. (6).

Step 5: Make iteration $k = 1$

Step 6: Update the position of each particle using Eq. (30) to (32).

Step 7: Assess the output power restrictions of DG, BESS, WT, PV, and grid. Also, verify that each particle's new location meets all the constraints in Eq. (20) to (29).

Step 8: If the restrictions limitations are met, go to the next step; else, return to step 6 and repeat stages 6-8.

Step 9: Assess the fitness function value for each updated particle and calculate its minimum value.

Step 10: Make the location of the search particle to the lowest fitness function as $SM_{\min}$.

Step 11: Increase the number of iterations (*iter*) by one, so *iter*, $k = k + 1$.

Step 12: Evaluate the stopping criterion for convergence. The iterative procedure should be stopped if the maximum number of iterations has been obtained and saving the $SM_{\min}$ objective function value should be performed; otherwise, repeat steps 6-12.

The suggested approach measures the optimum size of the battery. The optimum size of the battery has been determined for the specified approaches to mitigate the expense of arranging the power supplies to the total cost of the micro grid.

5 SIMULATION RESULTS AND DISCUSSIONS

The proposed test method has been evaluated on the regular IEEE 33 bus network as shown in Fig. 2.

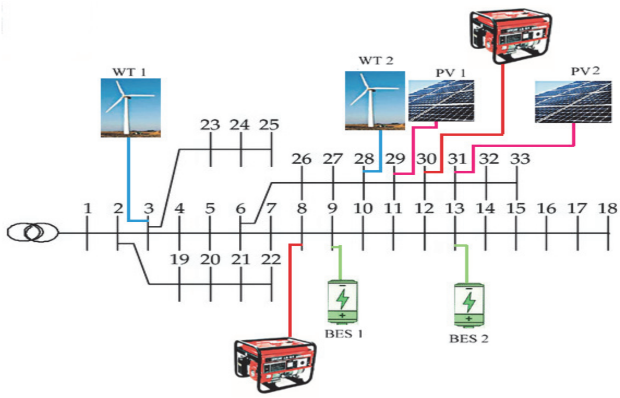

Figure 2 Single-line diagram of the IEEE 33-bus distribution system with DG

The network consists of 3.715 MW of actual power and 2.3 MVar. Wind power generation is connected in the buses 6 and 28, solar power generation is connected in the buses 3 and 29, MT is connected in the buses 13 and 5 and FC is connected in the buses 4 and 9. BESS, MT and FC are linked to busses 9 and 13, 4 and 5 and busses 30 and 8 respectively. This paper proves the feasibility of the suggested FFA approach by evaluating three major cases with and without batteries, initial costs and power system constraints. The specifications of the test systems are defined as follows. The test system is developed using the MATLAB R2016b Software. The proposed SM algorithm was examined under four test conditions as follows:

Case-A: Operating Cost without Battery.

Case-B: Minimizing Operating Cost with 6 MW Battery.

Case-C: Minimizing Operating Cost with 12 MW Battery.

Case-D: Minimizing Operating Cost with 18 MW Battery.

In these four cases, the feasible system parameters such as MG load profile, Electricity price and power from bulk network, battery storage power, Power loss, Operating cost, solar power and wind power are analyzed in a MG system under consideration, and the comparison also made between the proposed SM algorithm and FF approach. The detailed description of four cases is presented in this section.

Case-A: Operating Cost without Battery

In this case only the PV, WT and DG are connected in the MG system without BESS. The daily highest possible power generation in proposed MG system is presented in Fig. 3. The Electricity price taken from bulk network is shown in Fig. 4 also the Electricity taken from bulk network is shown in Fig. 5.

Wind power generation - P_{min} = 90 KW, P_{max} = 650 kW.

Solar power generation - P_{min} = 0, P_{max} = 800 KW.

Diesel generator power generation - P_{min} = 800 KW, P_{max} = 2000 KW.

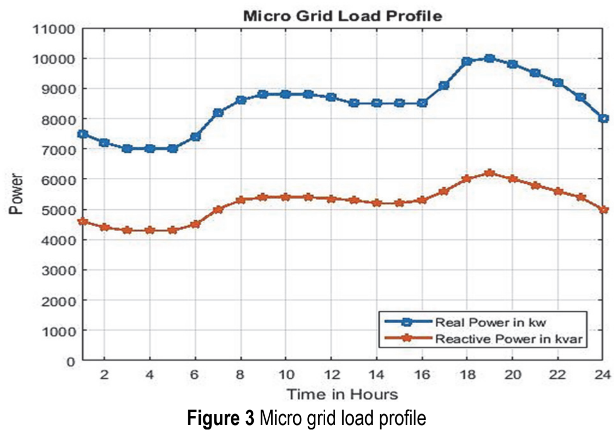

Figure 3 Micro grid load profile

The comparative data analysis of operating cost and using SM and FF algorithm is shown in Fig. 7. In Case A, the total micro grid operation cost and power loss of SM algorithm are found to be 24480.62 $ and 7687 kW. The FF algorithm operation cost and power loss are 24981.83 $ and 8096.98 kW. From the results, the total operation cost of SM algorithm and power losses is lesser in the proposed SM algorithm compared to FF algorithm.

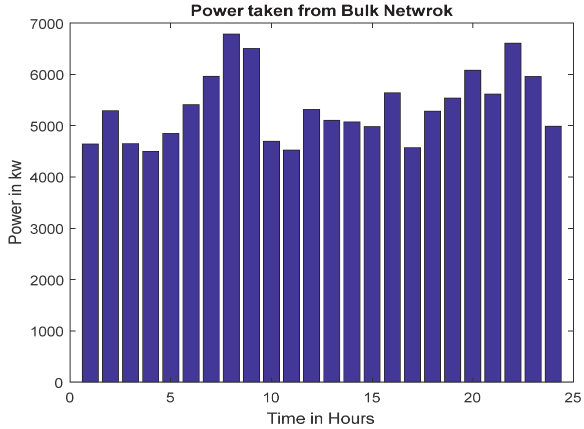

Figure 4 Power taken from bulk network

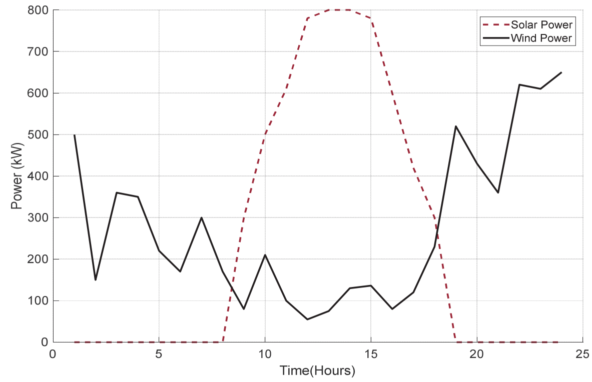

Figure 5 Tentative hourly PV power and wind power

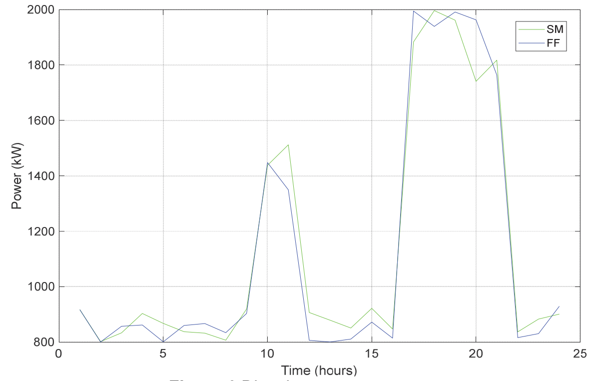

Figure 6 Diesel generator output power

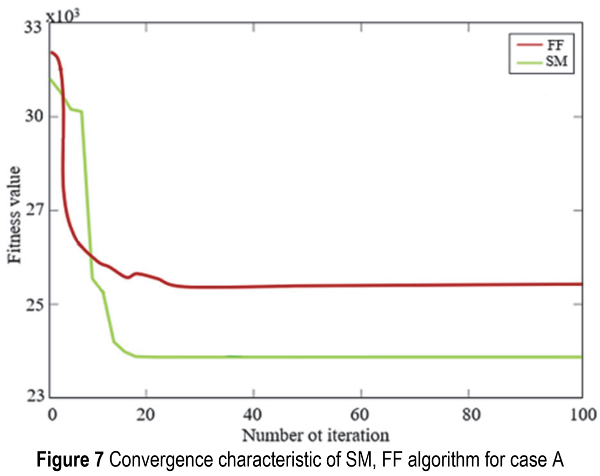

Figure 7 Convergence characteristic of SM, FF algorithm for case A

Case-B: Minimizing Operating Cost with 6 MW Battery

The variance of the parameters described above has been evaluated when the system is exposed to a state of 6 MW battery. In previous case battery is not installed in MG whereas in this case 6MW Li-ion battery has been installed. Wind power generation is connected in the buses 6 and 28, solar power generation is connected in the buses 3 and 29, DG is connected in the buses 13 and 5. Fig. 9 shows the diesel generator output power of proposed SM algorithm and existing FF algorithm. Fig. 10 demonstrates how the suggested SM algorithm properly computes and reduces power loss and operational costs. The proposed SM algorithm total micro grid operation cost and power loss are found to be 24981 $ and 7714 kW. The depth of discharge, or the amount of actual and reactive power that may be drawn from the BES, is another element that influences its longevity. Fig. 8 shows the battery storage power during the course of the project.

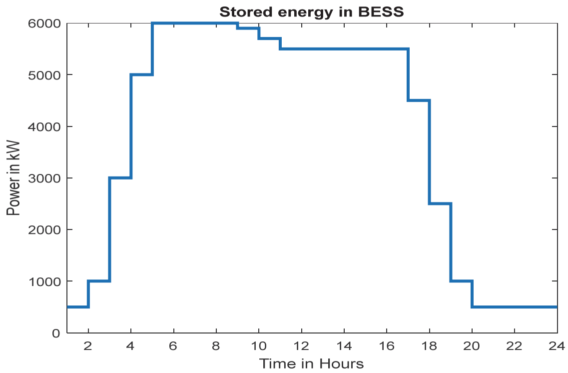

Figure 8 Storage power in battery

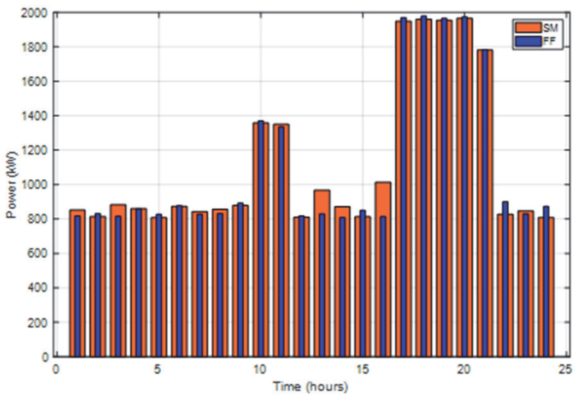

Figure 9 Diesel generator output power comparison

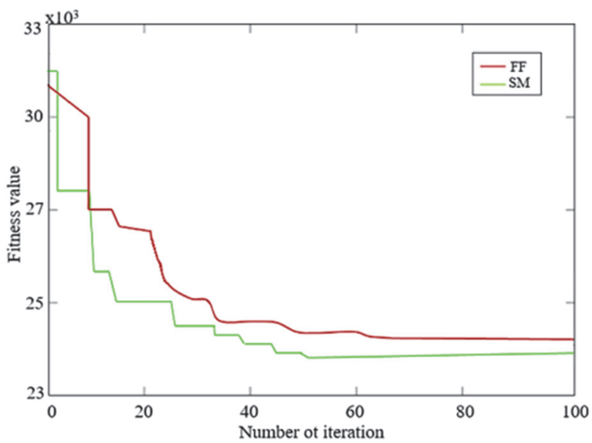

Figure 10 Convergence characteristic of SM, FF algorithm for case B

Case-C: Minimizing Operating Cost with 12 MW Battery

From the simulation, the optimal control parameters from the SM and FF optimization have been obtained when battery size is at 12 MW. As in the previous case the wind power generation, solar power generation and DG power generation are connected to the same number of buses. The reduced operating cost and power loss of BES was due to the self-organization characteristics of the SM algorithm compared to the FF algorithm. Fig. 11 shows the load demand by SM algorithm. Fig. 12 shows the storage power in battery by SM algorithm. Besides that, in terms of *SOC*, when battery capacity is increased from 6 MW to 12 MW, the operating cost is reduced by 6.20% by FF algorithm and when battery capacity is increased from 6 MW to 12 MW, the operating cost is reduced by 7.74% by SM algorithm. This reduction is due to the high efficiency and fast charge and discharge characteristics of Li-ion battery.

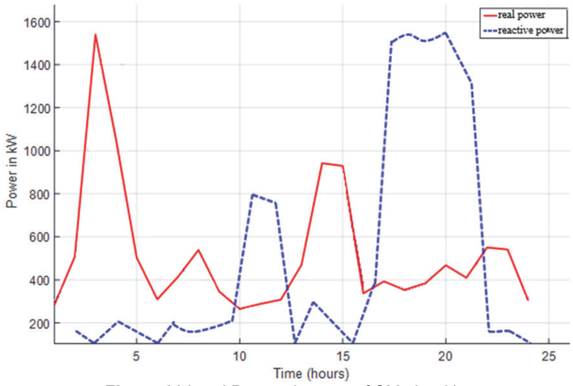

Figure 11 Load Demand power of SM algorithm

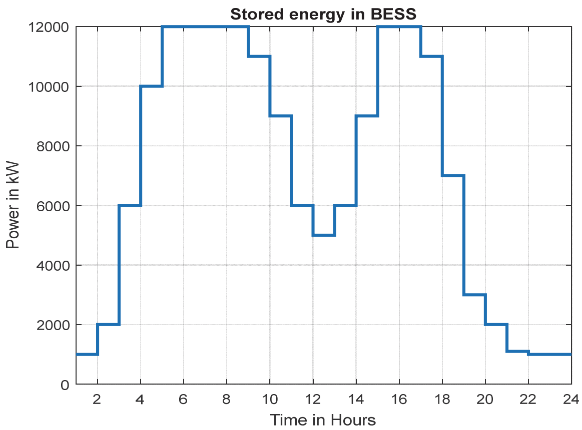

Figure 12 Storage power in battery SM algorithm

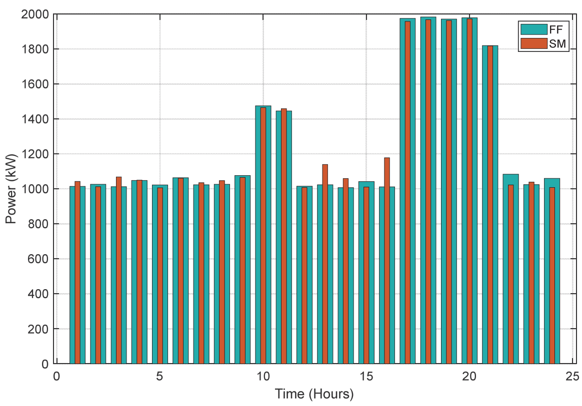

Figure 13 Diesel generator output power comparison

Fig. 13 shows the DG output power by proposed SM algorithm. The results of the convergence criteria using SM are as shown in Fig. 14, which shows that the optimal parameters have been obtained. The total operating cost of SM algorithm has 23049.48 $/KW. This indicates that the operating cost of SM algorithm is more convenient when compared to the FF algorithm.

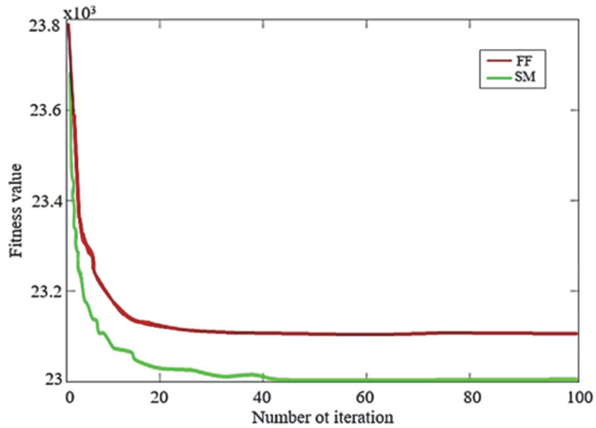

Figure 14 Convergence characteristic of SM, FF algorithm for case C

Case-D: Minimizing Operating Cost with 18 MW Battery

In this case, the illustrations describe the Micro Grid load, Electricity price taken from bulk network, PV Power and Wind power, diesel generator real Power of the system. Figs. 15 and 16 demonstrate the simulation effects of the SM algorithm with18 MW battery. As in the previous case the wind power generation, solar power generation and diesel generator power generations are connected to the same number of buses.

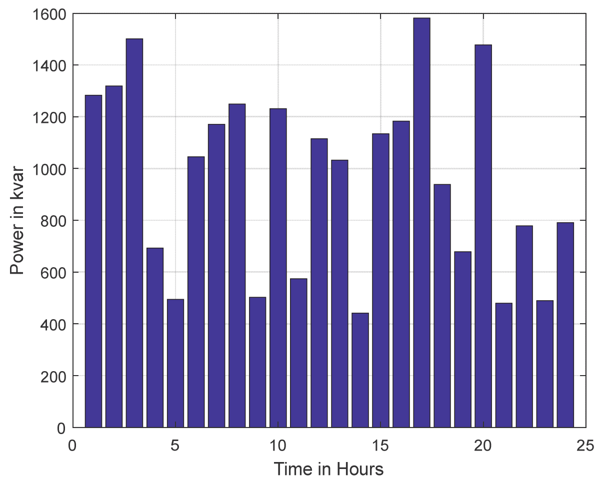

Figure 15 Diesel generator real power generation SM algorithm

From Fig. 17, the proposed SM algorithm minimises operating costs by optimizing battery system size more than FF algorithm. From the results of the iteration curve comparison of SM and FF for determining the minimum value of the objective function. According to Tab. 1, SM achieved a superior objective value during the 0-100 iterations to FF during maximum iterations. SM takes a shorter amount of time to conduct the optimization process when compared with FF when comparing the number of iterations and duration of the optimization process. Thus, when it comes to providing a minimum value for the objective function, both SM and FF are more appropriate in terms of their efficiency for providing minimal value for the objective function. In this work, SM is a better solution than FF for solving the problem.

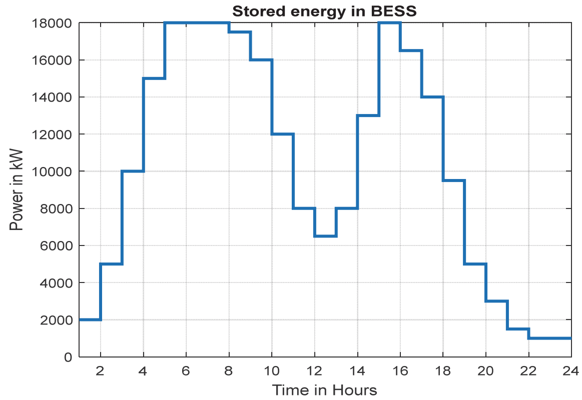

Figure 16 Storage power in battery SM algorithm

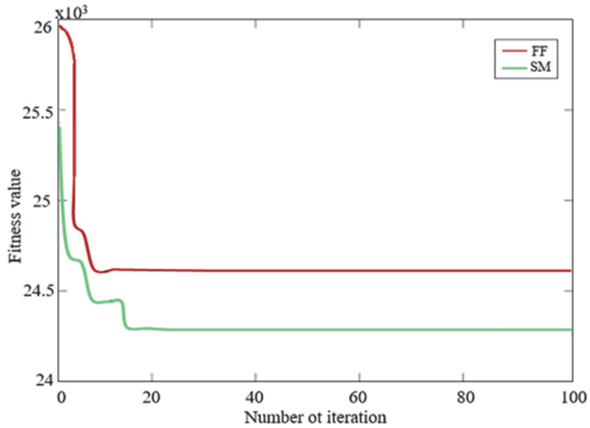

Figure 17 Convergence characteristic of SM, FF algorithm for case D

Table 1 Studied cases summary

Case	Battery Capacity	SM algorithm		FF algorithm	
		P_{loss} / KW	Operating cost / $/KW	P_{loss} / KW	Operating cost / $/KW
A	Without battery	7687.07	24853.18	8096.98	25847.40
B	6 MW	8147.83	24480.62	7714.64	24981.83
C	12 MW	12725.48	23049.48	12436.00	23185.28
D	18 MW	12844.67	24341.01	16474.58	24656.46
Case 3 is optimum results in both algorithms					

In order to reduce battery operational costs, SM is capable of regulating battery DOD to a low level. The operational cost with a battery size of 6 MW, 12 MW and 18 MW was compared to FF algorithm; from the results case 3 (12 MW) provides optimum results in both algorithms. Based on Tab. 1, SM has a lower cost per hour than FF and WOA algorithms, thereby minimizing both the cost of operating the microgrid and the power loss of the MG while satisfying the load demand. This method has the advantage of charging the battery when DOD values are high, preventing a battery depletion during critical hours.

6 CONCLUSION

This work proposes a detailed BES optimum sizing approach for multi-objective function in micro grid applications. To solve the multi-objective issues and battery sizing issues the Spider Monkey (SM) algorithm is proposed. In this research, four different cases have been considered and evaluated on the standard IEEE 33 bus network. According to the proposed algorithm, the optimal BES size (12 MW battery) and maximum depth of discharge can be determined that minimize the total operation costs and power loss of microgrids. Compared with existing Fire Fly (FF) algorithm, the proposed SM algorithm performs better in terms of minimization of total operation costs and power loss with faster convergence speed. The effect of changing load levels would be added in future development.

7 REFERENCES

[1] Jamshidi, M. & Askarzadeh, A. (2019). Techno-economic analysis and size optimization of an off-grid hybrid photovoltaic, fuel cell and diesel generator system. *Sustainable Cities and Society*, *44*, 310-320. https://doi.org/10.1016/j.scs.2018.10.021

[2] Kuang, H., Li, S., & Wu, Z. (2011). Discussion on advantages and disadvantages of distributed generation connected to the grid. *2011 International Conference on Electrical and Control Engineering*, 170-173.

[3] Mohammadi, M. (2013). GA-BASED optimal sizing of PV under pay as bid and uniform power market pricing considering uncertainty of solar radiation. *Tehnicki vjesnik/Technical Gazette*, *20*(3), 511-518.

[4] Robert, F. C., Sisodia, G. S., & Gopalan, S. (2018). A critical review on the utilization of storage and demand response for the implementation of renewable energy micro-grids. *Sustainable cities and society*, *40*, 735-745. https://doi.org/10.1016/j.scs.2018.04.008

[5] Kilic, R., Erkayman, B. (2021). A Simulation Approach for Transition to JIT Production System. *International Journal of Simulation Modelling*, *20*(3), 489-500. https://doi.org/10.2507/IJSIMM20-3-566

[6] Goldberg, D. E. & Holland, J. H. (1988). Machine Learning. *Special Issue on Genetic Algorithms*, *3*(2-3).

[7] Dorigo, M., Maniezzo, V., & Colorni, A. (1996). Ant system: optimization by a colony of cooperating agents. *IEEE Transactions on Systems, Man, and Cybernetics, Part B (Cybernetics)*, *26*(1), 29-41.

[8] Ali Khan, Z. & Abbasi, U. (2018). An Energy Efficient Architecture for IoT Based Automated Smart Micro-Grid. *Tehnicki vjesnik/Technical Gazette*, *25*(5), 1472-1477. https://doi.org/10.17559/TV-20160915124352

[9] Karaboga, D. (2005). *An idea based on honey bee swarm for numerical optimization*. Technical report-tr06, Erciyes University, Engineering Faculty, Computer Engineering Department.

[10] Rashedi, E., Nezamabadi-Pour, H., & Saryazdi, S. (2009). GSA: a gravitational search algorithm. *Information sciences*, *179*(13), 2232-2248. https://doi.org/10.1016/j.ins.2009.03.004

[11] Yang, X. S. (2010). *Nature-inspired metaheuristic algorithms*. Luniver press.

[12] Cui, Z., Fan, S., Zeng, J., & Shi, Z. (2013). Artificial plant optimisation algorithm with three-period photosynthesis. International Journal of Bio-Inspired Computation, 5(2), 133-139. https://doi.org/10.1504/IJBIC.2013.053507

[13] Yu, B., Cui, Z., & Zhang, G. (2013). Artificial plant optimization algorithm with correlation branches. *Journal of Bioinformatics and Intelligent Control*, *2*(2), 146-155. https://doi.org/10.1166/jbic.2013.1039

[14] Xie, L., Tan, Y., Zeng, J., & Cui, Z. (2010). Artificial physics optimisation: a brief survey. *International Journal of Bio-Inspired Computation*, *2*(5), 291-302. https://doi.org/10.1504/IJBIC.2010.036155

[15] Reddy, A. S. & Vaisakh, K. (2013). Environmental constrained economic dispatch by modified shuffled frog leaping algorithm. *Journal of Bioinformatics and Intelligent Control*, *2*(3), 216-222. https://doi.org/10.1166/jbic.2013.1047

[16] Jiang, K., Song, B., Shi, X., & Song, T. (2012). An overview of membrane computing. *Journal of Bioinformatics and Intelligent Control*, *1*(1), 17-26.

[17] Vrettos, E. I. & Papathanassiou, S. A. (2011). Operating policy and optimal sizing of a high penetration RES-BESS system for small isolated grids. *IEEE Transactions on Energy Conversion*, *26*(3), 744-756.

[18] Chen, W. Z., Li, Q. B., Shi, L., Luo, Y., Zhan, D. D., Shi, N., & Liu, K. (2012, May). Energy storage sizing for dispatch ability of wind farm. *2012 11th International Conference on Environment and Electrical Engineering*, 382-387.

[19] Topić, D., Knežević, G., Kosić, D., & Perko, J. (2018). Simplified model for optimal sizing of the off-grid PV system regarding value of loss of load probability. *Tehnicki vjesnik/Technical Gazette*, *25*(Supplement 2), 420-426. https://doi.org/10.17559/TV-20171203150754

[20] Khalid Mehmood, K., Khan, S. U., Lee, S. J., Haider, Z. M., Rafique, M. K., & Kim, C. H. (2017). Optimal sizing and allocation of battery energy storage systems with wind and solar power DGs in a distribution network for voltage regulation considering the lifespan of batteries. *IET Renewable Power Generation*, *11*(10), 1305-1315. https://doi.org/10.1049/iet-rpg.2016.0938

[21] Borhanazad, H., Mekhilef, S., Ganapathy, V. G., Modiri-Delshad, M., & Mirtaheri, A. (2014). Optimization of micro-grid system using MOPSO. *Renewable energy*, *71*, 295-306. https://doi.org/10.1016/j.renene.2014.05.006

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